Socioeconomic implications of global oil depletion for South Africa: vulnerabilities, impacts and transition to sustainability

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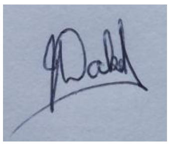

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Abstract

Oil is the quintessential resource in the modern industrial economy. It accounts for a third of world primary energy, fuels 95% of global transport systems, sustains a highly mechanised agribusiness and food distribution industry, and provides the feedstock for a staggering array of petrochemical products. Historically, global economic growth has been closely coupled with consumption of energy in general and oil in particular. Yet oil is a finite resource subject to depletion, which has profound implications for the long-term sustainability of industrial civilisation. This dissertation addresses a serious dearth of attention given to this vital subject within South African energy, economic and policy discourses. The overarching aims are to understand the implications of global oil depletion for socioeconomic welfare in South Africa and to propose viable strategies and policies for mitigating and adapting to potential negative impacts. A comparative evaluation of three fields of study found that neoclassical economics is limited by its monistic and reductionist approach and its failure to adequately incorporate energy into its key theoretical models, whereas ecological economics and the socioecological systems approach together provide an appropriate, holistic lens for analysing the role of energy in socioeconomic systems. In this view, energy is the master resource: it is a pre-requisite for economic activity and societal complexity. A review of the literature on global oil depletion finds that a peak and decline in world oil production appears imminent, while world oil exports most likely peaked in 2005. Moreover, the energy return on (energy) investment (EROI) for global oil production is on a declining trend. The world oil peak thus marks the end of the era of cheap and abundant oil. Increasing oil scarcity will likely be reflected in oil prices following a rising trend with heightened volatility. While there are many potential substitutes for oil, all have significant limitations, most have lower EROI than oil, and it may take decades to scale them up sufficiently. Many aspects of the South African socioeconomic system are either directly or indirectly dependent on petroleum fuels, while structural features of the economy and society render them vulnerable to external shocks. Historical evidence and empirical models suggest that oil price and supply shocks will have debilitating socioeconomic impacts. Under business-as-usual policies and behaviours, future oil scarcity will likely lead at best to a gradual contraction in the economy with rising unemployment and inflation, and at worst to systemic collapse of interconnected critical infrastructure systems. A comprehensive range of mitigation measures are proposed, including accelerated investments in renewable energy and electrified mass transport, agro-ecological farming, greening the economy, monetary system reform, and rationing schemes to protect the most vulnerable members of society. Together these measures can build resilience to shocks and gradually decouple economic activity from petroleum consumption. A successful societal transition from a fossil fuel based industrial regime to a sustainable socioeconomic regime requires purposive government intervention, the promotion of sustainability-oriented innovations in technology and institutions, and the political will to surmount obstacles such as powerful vested interests and socio-technical lock-in.

Opsomming

Olie is die kern-hulpmiddel in die moderne bedryfsgerigte ekonomie. Dit is verantwoordelik vir ’n derde van die wêreld se primêre energie, verskaf die aandrywing vir 95% van alle vervoerstelsels, onderhou ’n hoogs gemeganiseerde landboubedryf en voedselverspreidingsnywerheid, en voorsien die voerstof vir ’n verstommende reeks petrochemiese produkte. Histories beskou, is globale ekonomiese groei ten nouste gekoppel aan die verbruik van energie oor die algemeen en aan olie in die besonder. Tog is olie ’n beperkte hulpbron wat onderworpe is aan uitputting en lediging, en dit hou gevolglik onmeetlike implikasies vir die algemene langtermyn volhoubaarheid van nywerhede in. Dié verhandeling neem die ernstige gebrek aan aandag binne Suid-Afrikaanse diskoerse oor energie, ekonomie en beleidsrigtings wat betref hierdie lewensbelangrike onderwerp, in oënskou. Die oorkoepelende doelwitte is om die implikasies van globale olie-uitputting op sosio-ekonomiese welvaart in Suid-Afrika te begryp, en om lewensvatbare strategieë en beleidsrigtings voor te stel waarvolgens potensiële negatiewe invloede getemper en by aangepas kan word. ’n Vergelykende evaluering van drie studieterreine het bevind neoklassieke ekonomie is beperk weens sy monistiese en verlagingsbenadering en sy mislukking om energie doelmatig in te sluit by sy sleutel teoretiese modelle, terwyl die benaderings van die ekologiese ekonomie en die sosio-ekologiese stelsels saam ’n toepaslike holistiese lens bied vir die analisering van die rol van energie in sosio-ekonomiese stelsels. In dié opsig is energie die meester-hulpmiddel: dit is ’n voorvereiste vir ekonomiese bedrywigheid en gemeenskapsverbondenheid. ’n Oorsig van die literatuur oor globale olie-lediging toon dat ’n toppunt en daling in wêreldolieproduksie onvermydelik blyk te wees – globale olie-uitvoer het na alle waarskynlikheid sy toppunt in 2005 bereik. Voorts toon die energie-opbrengs op (energie) investering, ofte wel EROI, ten opsigte van wêreldolieproduksie ’n dalende tendens. Die wêreldolie-toppunt dui dus op die einde van die era van goedkoop en oorvloedige olie. Toenemende olieskaarste sal waarskynlik blyk uit oliepryse wat ’n stygende tendens volg gepaard met verskerpte veranderlikheid. Hoewel daar talle potensiële plaasvervangers vir olie bestaan, het almal beduidende beperkinge, die meeste se EROI is laer as olie s’n en dit kan dekades duur alvorens hulle genoegsaam opgegradeer sal kan word. Vele aspekte van die Suid-Afrikaanse sosio-ekonomiese stelsel is of direk of indirek afhanklik van petroleum-brandstowwe, terwyl strukturele kenmerke van die ekonomie en samelewing hulle kwesbaar vir eksterne skokke laat. Lesse uit die verlede en empiriese modelle dui daarop dat die olieprys en skokke rondom die voorsiening daarvan verlammende sosio-ekonomiese impakte en invloede tot gevolg sal hê. Onder ’n sake-soos-gewoonlik-beleid en optrede, sal toekomstige olieskaarste, optimisties beskou, waarskynlik aanleiding gee tot geleidelike inkrimping van die ekonomie met gepaardgaande stygende werkloosheid en inflasie – pessimisties beskou, kan dit die sistematiese ineenstorting van kritiesbelangrike en onderling verbonde infrastruktuurstelsels beteken. ’n Omvattende reeks verligtingsmaatreëls word voorgestel, insluitende versnelde investering in hernubare energie en geëlektrifiseerde massavervoer, agro-ekologiese landbou, vergroening van die ekonomie, monetêre stelselhervorming en rantsoeneringskemas om die mees kwesbare lede van die samelewing te beskerm. Saam kan dié maatreëls veerkragtigheid vestig teen skokke en ekonomiese bedrywigheid geleidelik van petroleumverbruik losmaak. ’n Geslaagde samelewingsoorgang van ’n fossielbrandstof-gebaseerde nywerheidsbestel na ’n volhoubare sosio-ekonomiese bestel vereis doelmatige regeringsintervensie, die bevordering van volhoubaar-georiënteerde innovasies in

tegnologie en instellings, en die politieke wilskrag om struikelblokke soos kragtige gevestigde belange en sosio-tegniese omsluiting te bowe te kom.

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Abbreviations and Acronyms

ANC	African National Congress
APPGOPO	All Party Parliamentary Group on Peak Oil
ARDL	Autoregressive distributed lag
AsgiSA	Accelerated and Shared Growth Initiative for South Africa
ASPO	Association for the Study of Peak Oil
BEV	Battery electric vehicle
BRT	Bus Rapid Transit
C&D	Cap and Dividend
C&S	Cap and Share
CAV	Compressed air vehicle
CCGT	Closed cycle gas turbine
CGE	Computable general equilibrium
CHP	Combined heat and power
CNG	Compressed natural gas
CPI	Consumer price index
CNG	Compressed natural gas
CRDP	Comprehensive Rural Development Programme
CSIR	Council for Scientific and Industrial Research
CSP	Concentrated solar power
CTL	Coal-to-liquid
CWP	Community Work Programme
DAFF	Department of Agriculture, Forestry and Fishing
DBSA	Development Bank of Southern Africa
DCoGTA	Department of Cooperative Governance and Traditional Affairs
DEA	Department of Environmental Affairs
DEAT	Department of Environmental Affairs and Tourism
DFI	Development Finance Institution
DME	Department of Minerals and Energy
DoE	Department of Energy
DoT	Department of Transport
DPLG	Department of Provincial and Local Government
DPW	Department of Public Works
DRDLF	Department of Rural Development and Land Reform
DST	Department of Science and Technology
DTI	Department of Trade and Industry
EDD	Economic Development Department
EE	Ecological economics
EIA	Energy Information Administration
EOR	Enhanced oil recovery
EPWP	Expanded Public Works Programme
EROI	Energy return on investment
EUR	Estimated ultimate recovery
EOR	Enhanced oil recovery
EWG	Energy Watch Group
FAO	Food and Agriculture Organisation
FSSA	Fertiliser Society of South Africa
GCIS	Government Communication and Information Systems
GCV	Grid-connected vehicle

GDE	Gross domestic expenditure
GDP	Gross domestic product
GHG	Greenhouse gas
GTL	Gas-to-liquid
GVA	Gross value added
GWP	Gross world product
HEV	Hybrid electric vehicle
ICE	Internal combustion engine
ICEV	Internal combustion engine vehicle
ICT	Information and communication technology
IDC	Industrial Development Corporation
IDP	Integrated Development Plan
IEA	International Energy Agency
IMF	International Monetary Fund
IOC	International oil company
IPAP	Industrial Policy Action Plan
IPCC	Intergovernmental Panel on Climate Change
IRP	Integrated Resource Plan
JODI	Joint Oil Data Initiative
LED	Local economic development
LNG	Liquefied natural gas
LPG	Liquid petroleum gas
LTMS	Long Term Mitigation Scenarios
MBT	Minibus taxi
MEFA	Material and energy flow accounting/analysis
MLP	Multi-level perspective
NAAMSA	National Association of Automobile Manufacturers of South Africa
NCCRWP	National Climate Change Response White Paper
NDA	National Department of Agriculture
NE	Neoclassical economics
NEF	New Economics Foundation
NEDLAC	National Economic Development and Labour Council
NFLED	National Framework for Local Economic Development
NFSD	National Framework for Sustainable Development
NGL	Natural gas liquids
NGP	New Growth Path
NMT	Non-motorised transport
NOC	National oil company
NPC	National Planning Commission
NRE	Natural resource economics
NSDP	National Spatial Development Perspective
NSSD	National Strategy for Sustainable Development
NTAP	National Transition Action Plan
NHTS	National Household Travel Survey
OCGT	Open cycle gas turbine
OECD	Organisation for Economic Cooperation and Development
OPEC	Organisation of Petroleum Exporting Countries
ORTIA	O.R. Tambo International Airport
PAP	Pollution authorisation permit
PHV	Plug-in hybrid vehicle
PPI	Producer price index

PRASA	Passenger Rail Authority of South Africa
PV	Photovoltaic
RE	Renewable energy
REM	Rare earth metal
RSA	Republic of South Africa
RTMC	Road Traffic Management Corporation
SA	South Africa
SACN	South African Cities Network
SAPIA	South African Petroleum Industry Association
SARB	South African Reserve Bank
SARCC	South African Rail Commuter Corporation
SAWEA	South African Wind Energy Association
SES	Socioecological systems
StatsSA	Statistics South Africa
TDM	Travel demand management
TEQ	Tradable energy quota
TIPS	Trade and Industrial Policy Strategies
TMR	Total material requirement
TFEC	Total final energy consumption
TPES	Total primary energy consumption
UA	Urban agriculture
UCG	Underground coal gasification
UK	United Kingdom
UKERC	United Kingdom Energy Research Centre
URR	Ultimately recoverable resources
US	United States
US-48	Lower 48 United States
USGS	United States Geological Survey
VAR	Vector auto-regression
VAT	Value Added Tax
WEO	World Energy Outlook
WNA	World Nuclear Association
WTO	World Trade Organisation

Units of Measurement

bbl	barrels
boe	barrels of oil equivalent
bpd	barrels per day
Btu	British thermal unit
Gb	gigabarrels (billion barrels)
Gt	gigatonnes (billion tonnes)
GW	gigawatts (billion watts)
GWh	gigawatt hours
kms	kilometres
km/h	kilometres per hour
kt	kilotonnes
kWh	kilowatt hours
mbpd	million barrels per day
mBtu	million British thermal units
MJ	megajoules (million joules)
mlpa	million litres per annum
Mt	megatonnes (million tonnes)
MW	megawatts (million watts)
MWh	megawatt hours
R	rands
tcf	trillion cubic feet

Introduction

This introduction begins with a brief background to the topic and the motivation for this research. It then specifies the research questions and discusses the conceptual nature of the topic. Thirdly, it describes the conceptual approach, including a brief statement of the ontological and epistemological positions and a discussion of transdisciplinarity. It then clarifies the scope and originality of the dissertation. The final part provides a chapter-by-chapter overview of the dissertation's structure.

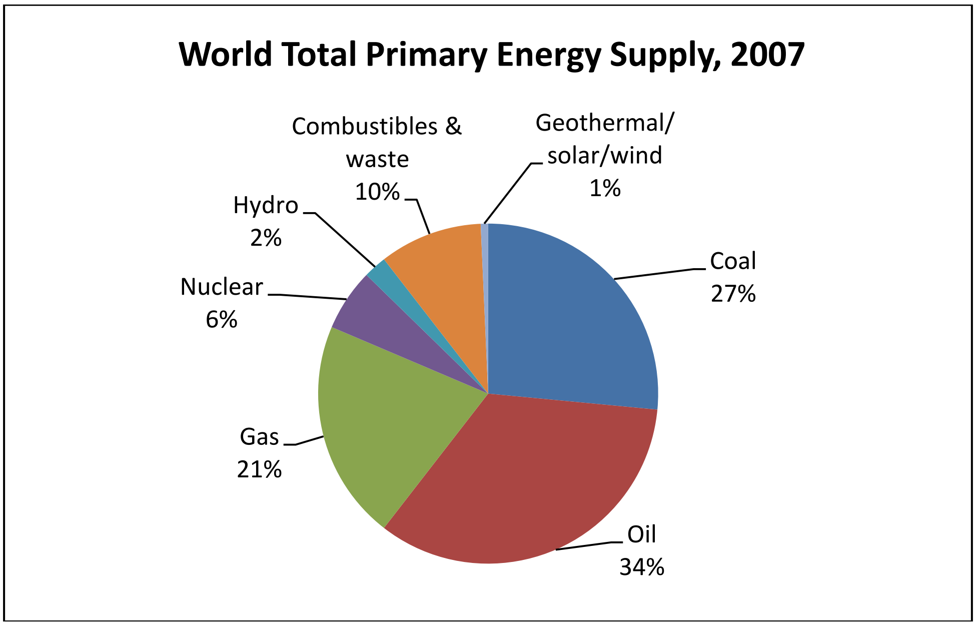
Background and motivation

Oil is arguably the quintessential commodity in the modern industrial economy. Although the industrial revolution was initially powered by coal, since the first commercial oil well was drilled in Pennsylvania in 1859 oil has gained increasing prominence as an energy source. In 2007, oil accounted for approximately 34 per cent (the largest share) of the world's primary energy supply (see Figure 0-1). Fossil fuels, which include oil, coal and natural gas, comprise over 80% of the world's primary energy. In contrast, all renewable sources together provide just 13% of primary energy.

Oil has two principal uses: as a form of energy, and as a feedstock for chemical processes and manufactured products (Hubbert, 1956). As an energy source oil is used for electricity generation, heating and – most importantly – as liquid fuels for transportation. The transport sector accounted for 62% of world petroleum product consumption in 2007, while industry consumed 9%, the residential sector 6%, commercial and public services 3%, and agriculture, forestry and fishing 3% (see Figure 0-2). Approximately 17% of oil products were used for non-energy purposes, mainly as feedstock for petrochemical products but also for lubrication of machinery.

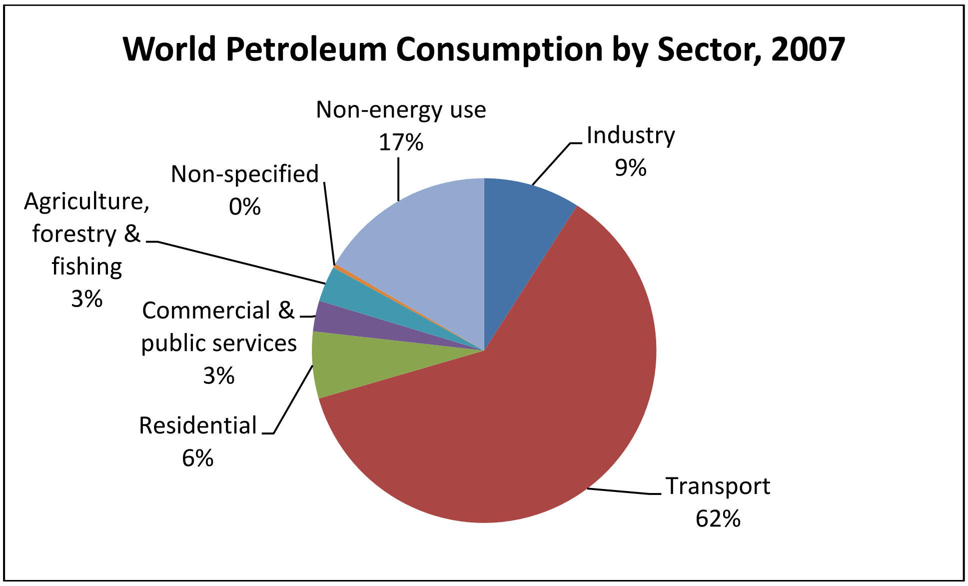
Dependence on oil pervades virtually all aspects of modern societies. Nowhere is this more evident than in transport; the world's transport systems (including ships, trains, airplanes and road vehicles) depend on oil for approximately 94 per cent of their energy (IEA, 2011a). Most sectors of the economy rely on the mobility of people and goods, and therefore depend indirectly on oil. Industrial agriculture in particular relies heavily on oil to power mechanised farming equipment and transport products to markets. Oil is also used for the production of herbicides and pesticides, while natural gas is the chief feedstock for synthetic nitrogen fertilizers. Mining and construction rely on oil-powered vehicles and machinery. The manufacturing sector uses oil both for energy and as a feedstock for a myriad of products from plastics to paints to pharmaceuticals. International trade and even local trade would be much less extensive without cheap transport. Many services depend directly on human mobility (e.g. tourism), or on equipment that was manufactured using oil (e.g. electronics such as computers). Thus almost all goods and most services involve the use of oil at some point in the production or distribution process.

Figure 0-1: Shares of world total primary energy supply, 2007



Source: IEA (2011a)

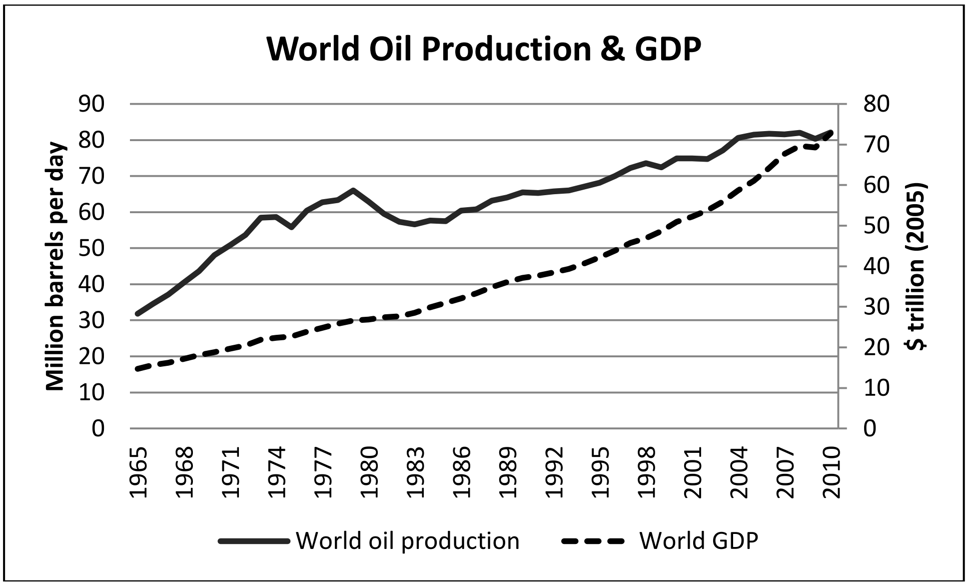
Figure 0-2: World petroleum consumption by sector, 2007



Source: IEA (2011a)

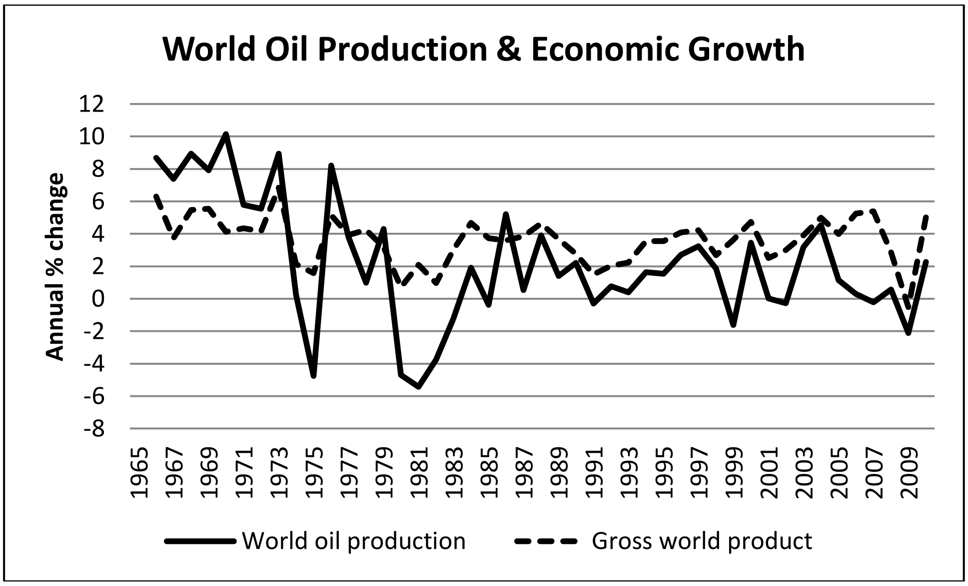
Rising production of oil has underpinned world economic growth for most of the past century, and particularly since 1950 (see Figure 0-3 and Figure 0-4). It has impressively boosted agricultural productivity and thus allowed a massive expansion of the world's human population (Brown, 2008). Cheap transport fuels derived from oil have enabled the globalisation of the world economy (Rubin, 2009).

Figure 0-3: World oil production and gross world product, 1965-2010



Source: IMF (2011a) and BP (2011)

Figure 0-4: Growth in world oil production and gross world product, 1965-2010



Source: Own calculations based on IMF (2011a) and BP (2011)

However, the historical trend of increasing supplies of the global economy's most critical energy resource cannot continue indefinitely. Most simply, this is because oil (like other fossil fuels) is a finite resource, having been formed in the geological past (Aleklett & Campbell, 2003). This finiteness necessarily implies that at some point, the annual production of oil at a global scale must reach an all-time maximum and begin an irreversible decline. This "peak oil" phenomenon, as it is commonly termed, has already been observed to occur in many individual regions and countries around the world (Sorrel et al., 2009). An increasing number of experts are warning that the global production of all types of oil is likely to peak before 2020, while some analysts, including the International Energy Agency, suggest that conventional oil production might have peaked around 2006 (IEA, 2010).

Given the long lead times required to develop alternative transport infrastructure that is less oil dependent (Hirsch, Bezdeck and Wendling, 2005), the ongoing depletion of global oil reserves and the prospect of an imminent decline in annual oil supplies raise vital questions about the potential impact on societies and their economies, including those of South Africa. Historically, episodes of temporary oil shortages and/or high oil prices, such as in 1973/4, 1979/80 and 2007/08, have been followed in short order by economic recessions in the major industrial countries and in the latter case for the world as a whole (Hamilton, 2009). In recent years the nature and implications of global oil depletion have received an increasing amount of attention internationally.[1] While opinions as to the potential severity of the consequences vary, there is a growing understanding that the issue demands extensive and urgent attention. Thus far the leaders, governments or government agencies of only a few countries have publicly acknowledged the threat posed by oil depletion, including Sweden, Ireland, France, the United Kingdom (UK) and the United States (US).[2] In addition, the issue of "peak oil" has been addressed explicitly by the US and German militaries,[3] as well as by various industry players.[4]

Yet despite an increasing global public awareness of the issue of oil depletion, it is receiving limited attention in the academic arena outside of a few mainly energy-specific journals. Most notably, the prospect of an imminent peak and decline in global oil production has largely been ignored within mainstream economics. In South Africa, there has been very limited attention given to global oil depletion in academic, public and policy discourses.[5] This dissertation aims to address this knowledge deficit in the South African context and to make a contribution to the international literature through a country case study.

[1] See, for example, Campbell & Laherrere (1998), Deffeyes (2001), Bentley (2002), Aleklett & Campbell (2003), Heinberg (2003), Green, Hopson & Li (2006), Strahan (2007), Sorrel et al. (2009). Chapter 2 provides a comprehensive review of the literature.

[2] See the Swedish Commission on Oil Independence (2006); Forfas (2006); Peak Oil News (2011); All Party Parliamentary Group On Peak Oil (APPGOPO, 2008); US Government Accountability Office (2007).

[3] See United States Joint Forces Command (USJFC, 2010) and Bundeswehr Transformation Centre (BTC, 2010).

[4] See, for example, National Petroleum Council (2007), UKITPOES (2008, 2010), Sankey et al. (2009) and Froggatt & Lahn (2010).

[5] The relevant South African literature is cited in Chapters 4 and 5.

Research questions

The central research question of the dissertation is as follows:

- What are the socioeconomic implications of global oil depletion for South Africa, in terms of its potential impacts and how these impacts could be mitigated in the pursuit of sustainable development?

This overarching research question is disaggregated into a number of subsidiary research questions:

- What is the role of energy in socioeconomic systems?
    - What is the perspective of neoclassical economics on this issue, and what are its advantages and limitations?
    - What is the perspective of ecological economics on this issue, and what are its advantages and limitations?
    - What is the perspective of the socioecological systems approach on this issue, and what are its advantages and limitations?
- What are the nature, meaning and implications of global oil depletion?
    - What is the likely profile of future global oil production?
    - What is the theory and evidence underlying the so-called 'Hubbert' curve?
    - When might the peak in world oil production be reached?
    - How rapid are the post-peak declines in aggregate oil production and world oil exports likely to be?
    - To what extent can alternative energy sources and energy conservation offset declining crude oil supplies at a global level?
    - What are the likely global consequences of peaking world oil production, especially for the world economy, transport, agriculture, trade and geopolitical conflict?
- What are the likely social and economic implications of global oil depletion for South Africa?
    - What are South Africa's particular strengths and vulnerabilities relative to global oil depletion and its likely global and local impacts?
    - To what extent does South Africa's energy security depend on imported oil?
    - What impact did international oil shocks have on South Africa in the past?
    - How vulnerable is our transport system to oil shortages and price spikes?
    - What is the likely impact of oil depletion on domestic agricultural production and food security?
    - What impact might the peak and decline in world oil production have on South Africa's macro-economy?
    - What are the likely social implications of the above impacts?
- How could the South African government mitigate the possible negative impacts of global oil depletion through appropriate policy interventions?
    - What appropriate policy measures can be implemented by national government to mitigate the effects of declining oil imports and rising oil prices?
    - What are the feasible alternative sources of energy to imported oil?
    - How can the transport system be adapted to use less oil?
    - How can domestic agriculture and food security be promoted and protected from the impact of higher oil prices?
    - How could macroeconomic policy be adjusted to mitigate global and domestic consequences of oil depletion?
    - How can social cohesion be maintained and enhanced in the face of these challenges?
- What are the implications of global oil depletion in terms of a societal transition to sustainability?

Nature of the topic

It is important to identify key characteristics of the dissertation topic as these will inform the appropriate conceptual framework for tackling the research question. These key characteristics may be summarised as: problem-centeredness; dealing with complex systems; involving issues of sustainability; and involving a case-study. These features are elaborated upon below.

The topic is problem-centred in that it deals with a practical problem involving the declining availability of a key material resource, which requires responses or solutions. The dissertation is therefore motivated both by a cognitive interest (explaining the nature of the problem) as well as by an action interest (how best to manage the problem) (Baumgärtner *et al.*, 2008: 7).

Global oil depletion is a complex issue. As described earlier, oil is ubiquitous in the modern, industrial socio-economy: it is used for many different purposes; many if not all economic sectors rely on it to a greater or lesser extent, including agriculture, mining, manufacturing, transport, trade and many services; it involves social, economic and environmental aspects; and it operates at global, regional, national and local scales.

The subject matter of the dissertation involves analysis of various systems, which Costanza (1996: 981) describes as "groups of interacting, interdependent parts linked together by exchanges of energy, matter, and information." A system "consists of complex, interacting elements, responds as a whole, with changes to individual elements being dependent on all the others. The behaviour of the whole cannot be characterised by summing the behaviour of individual parts because the interrelationships between system elements need to be considered" (Hector et al., 2009: 697, citing von Bertalanffy, 1950). The broadest system considered is the South African socioeconomic system. This system is itself comprised of several overlapping and interacting subsystems, some of which are examined in greater detail, namely: the energy system; the transport system; the agricultural system; the macroeconomic system; and aspects of the social system. According to Costanza (1996: 981, citing von Bertalanffy, 1968), complex systems "are characterised by: (1) strong (usually nonlinear) interactions among the parts; (2) complex feedback loops that make it difficult to distinguish cause from effect; (3) significant time and space lags; discontinuities, thresholds and limits; all resulting in (4) the inability to simply "add up" or aggregate small-scale behaviour to arrive at large-scale results."

Common and Stagl (2005:8) define sustainability as "maintaining the capacity of the joint economy-environment system to continue to satisfy the needs and desires of humans for a long time into the future". The topic of this dissertation intrinsically involves issues of sustainability and sustainable development, since it deals with the depletion of a finite resource (oil) upon which our complex society is critically dependent, and seeks alternatives to this dependence. A key question is therefore: how can (in particular South African) society sustain its complex socio-economy and development with declining inputs of oil? Definitions of sustainability will be explored further in Chapter 1.

This dissertation involves a case study of how the depletion of global oil supplies might impact on South Africa. According to Baumgärtner et al. (2008: 9; original italics), "[a] *case study* is the descriptive, explorative and prospective study of a concrete real-world situation, including its practical context and its determining factors, for the purpose of generating and testing hypotheses."

Conceptual approach

Ontological and epistemological positions

Following Hector et al. (2009: 696), this dissertation adopts an ontological position according to which a material reality exists independent of the human mind. Two schools of thought emerged from the Renaissance: (1) a mechanistic, reductionist conception of a reality made of components that could be analysed separately; and (2) a holistic view in which reality includes indivisible wholes that cannot be reduced to their component parts (Hector et al., 2009: 694). The latter approach is more appropriate to the current topic given its complex, systems character discussed above. Hector et al. (2009: 696) advocate an epistemology that "acknowledges the fundamental uncertainty and only partial knowability of many natural phenomena, in particular, of entities with emergent properties and relations." They term this "a moderate form of 'critical realism'" (Hector et al., 2009: 697).

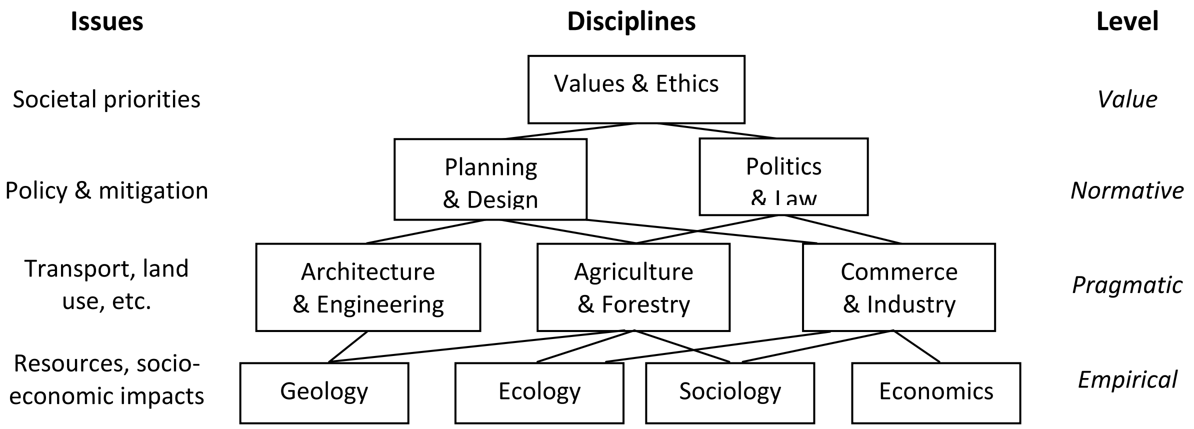
Transdisciplinary approach

Max-Neef (2005: 5) argues that "[i]f we go through a list of some of the main *problematiques* that are defining the new Century, such as water, forced migrations, poverty, environmental crises, violence, terrorism, neo-imperialism, destruction of social fabric, we must conclude that none of them can be adequately tackled from the sphere of specific individual disciplines. They clearly represent transdisciplinary challenges." Similarly, McGregor (2004: 1) asserts that "[i]t really is time to move beyond our penchant for specializations because society's problems are far too complex for one point of view." Dickens (2003: 95) makes the case even more strongly, urging that in the light of humanity's impact on the biosphere, "adopting a transdisciplinary perspective is a social and political, as well as a purely scientific, imperative." Rapport (1998:1-2) refers to "pressing global problems which require integrative science and knowledge" and argues that "[d]eveloping the capacity to think creatively and to integrate knowledge across disciplinary boundaries may well prove to be the key hope for averting planetary failure and making the transition to a viable future." At a national level, Winberg (2006: 160) states that "[t]raditional, discipline based academic knowledge is increasingly perceived as unable to address issues of importance to South African Society," and calls for the use of transdisciplinary methods of knowledge production.

Max-Neef (2005) provides a definition and overview of the concept of transdisciplinarity, distinguishing between weak and strong forms. Weak transdisciplinarity is explained as a practical concept by contrasting it with other methodological approaches, arranged in increasing order of complexity. According to Max-Neef (2005: 6), "*disciplinarity* is about mono-discipline, which represents specialisation in isolation." *Multidisciplinary* research involves the perspectives and methods of a variety of disciplines, but constitutes an amalgam of distinct analyses "without any integrating synthesis" (p. 6). "*Pluridisciplinarity* implies cooperation between disciplines, without coordination," while *interdisciplinarity* involves a coordination of two or more disciplines from a higher level concept (Max-Neef, 2005: 6-7). Max-Neef (2005: 6-7) describes a pyramidal organisation of disciplines in which the successively higher levels are classified as *empirical*, *pragmatic*, *normative* and *value*. "*Transdisciplinarity* is the result of a coordination between all [these] hierarchical levels" (Max-Neef, 2005: 7).

Max-Neef's (2005) list of problematiques (cited above) can be augmented by another: 'global oil depletion'. Because oil is so fundamental to the way modern societies and economies function, its supply and price have wide-ranging consequences for many aspects of life and most – if not all – sectors of the economy. Affected areas include energy, transport, trade, tourism, agriculture, manufacturing, public services, settlement patterns, and social stability and security. As a result, a comprehensive assessment of the impacts and mitigation of oil depletion needs to draw on a diverse range of physical and human (empirical) sciences, including geology, ecology, economics and sociology, as well as pragmatic disciplines such as engineering (e.g. dealing with energy technologies) and agriculture. Mitigation (for instance, provision of alternative modes of transport) also clearly involves planning and design, which operates at the normative level. This in turn necessitates some discussion of values to inform our approach to planning and our priorities. Therefore, following Max-Neef's (2005) schema, a transdisciplinary methodology is most appropriate for studying the effects of global oil depletion on South Africa. The hierarchical relationships among the disciplines mentioned above, classified according to the four 'levels', are represented in Figure 0-5.

Figure 0-5: Transdisciplinary analysis of global oil depletion



Source: Adapted from Max-Neef (2005: 9, Graph 3)

Strong transdisciplinarity, according to Max-Neef (2005: 10, citing Nicolescu, 1998) rests on three pillars, namely: (1) levels of reality, (2) the axiom of the included middle, and (3) complexity. Max-Neef (2005: 11) defines a "level of reality" as "a set of systems that are invariant with respect to the action of certain laws"; thus movement between levels involves a discontinuity in established laws or concepts. For example, the realm of objects and physical states can be separated from that of consciousness and subjective experience. The "logic of the included middle" implies that an apparent dichotomy (e.g. light as a wave or a particle) may not appear as such when viewed from a different level of reality. Complexity theory, including chaos theory and non-linear dynamics, goes beyond linear logic and can afford greater levels of understanding of complex problems or processes.

Furthermore, according to Max-Neef (2005: 10), transdisciplinarity includes both rational and relational modes of thought, the latter incorporating intuition. Relational thought helps to understand linkages and complexities. In Max-Neef's (2005: 15) words, transdisciplinarity is "a different manner of seeing the world, more systemic and more holistic." In assessing the potential impacts and mitigation of oil depletion, complexities, linkages and interactions between the various economic and social sectors will be identified. Such systemic, integrated analysis will lay a much more solid platform for appropriate policy prescriptions than would be afforded by a single, discipline-specific approach as it utilises both the rational and the relational modes of thought that are intrinsic to transdisciplinarity. Intuition will play an important role in the attempt to understand

and predict the implications of oil depletion because this event – namely, declining supplies of the predominant source of energy – is completely new to the modern world as a whole.[6]

Other characteristics of the transdisciplinary approach also make it suitable for the topic at hand. One is its problem-driven rather than discipline-specific nature (Costanza et al., 1991: 3, in Hirsch Hadorn et al., 2006: 120). As the foregoing statement of research questions make clear, this dissertation will be problem-driven and practical. A second characteristic is that the dissertation topic falls within the general field of sustainability, as argued earlier. Hirsch Hadorn et al. (2006: 120) argue that "[t]o be effective in coping with the challenges of sustainable development, changes in practices and institutions have to be based on reliable knowledge, which entails transgressing disciplinary boundaries." Further motivations for the adoption of a transdisciplinary approach for this dissertation will be discussed in the course of the review of theoretical approaches to the energy-economy relationship in Chapter 1.

Research methods

Because it utilises a transdisciplinary approach, the dissertation employs an eclectic mix of research methods, including: critical literature surveys; deductive and inductive reasoning; historical-descriptive methods; policy analysis; and scenario sketching. Research methods are explored more fully in Chapter 1 where the analytical techniques of three main fields (neoclassical economics, ecological economics and socio-ecological systems) are discussed.

Data

The dissertation makes use of secondary data drawn from several international and South African databases, which are listed below in Table 0-1.

Table 0-1: Data sources

Source	Description
International Energy Agency (2011)	International Energy Statistics Key World Energy Statistics
US Energy Information Administration (2011)	International Energy Statistics
International Monetary Fund (2011)	International Financial Statistics World Economic Outlook
BP (2011)	Statistical Review of World Energy
South African Reserve Bank (2011)	Quarterly Bulletin
Statistics South Africa (2008, 2009a, 2009b, 2011)	Income and expenditure survey 2005/2006 Mid-year population estimates 2009 Labour Force Survey 2009Q2 Consumer Price Index
Department of Energy (2011)	Fuel prices
Department of Transport (2005)	National Household Travel Survey 2003
Department of Trade and Industry (2011)	Trade Statistics
Department of Agriculture (2011)	Abstract of Agricultural Statistics
South African Petroleum Industry Association (2011)	Petroleum product sales
Council for Scientific and Industrial Research (various)	Freight volumes and distances
eNatis (2011)	Live vehicle population

[6] Many earlier civilisations have encountered this phenomenon at a smaller scale, for example when they depleted their forest resources. The result was usually a collapse of the society to a lower level of complexity (see Diamond, 2006; Tainter, 1988).

Problem structuring

Hector et al. (2009) draw on decision sciences and behavioural theory to develop an approach to structuring problems in the context of complex societal decisions. They argue that their approach is especially applicable to problems involving sustainability, because of "their irreducibility; their emergent, dynamic, systems nature; their fundamental complexity, uncertainty and unknowability; and the inherent limitations of human cognition in dealing with these matters" (Hector et al., 2009: 698). The problem-structuring approach of Hector et al. (2009) provides a useful orienting schema for this dissertation, given that its subject constitutes a complex societal problem. Certain aspects of their multi-step approach are adopted and adapted, as follows.

- First, the *system boundaries* are defined, which in this case constitute the country of South Africa – its human population, economy, and geographic boundaries.
- Second, several *subsystems* are identified (as described and motivated in the section on scope below): energy; transport; agriculture; macro-economy; and society. These subsystems form the organising structure of the analysis of vulnerabilities (Chapter 3), impacts (Chapter 4) and mitigation policies (Chapter 5).
- The third step is to characterise the '*As-Is system*'. This is done in Chapter 3 in terms of an empirical and descriptive overview of major subsystems and their strengths and weaknesses in relation to global oil depletion and its likely impacts.
- The fourth step is to introduce a *disturbance* to the system. Chapter 4 explores the impact of oil shocks, in terms of both a rise in the price of oil as well as reduced availability of oil imports.
- The fifth step assesses the *likely impact* in terms of a "likely future" scenario: the response of the As-Is system, assuming no fundamental change to the system. This is performed in Chapter 4, which discusses the likely unmitigated impacts of oil depletion in a quantitative and qualitative manner. In addition, a "desirable future" scenario is sketched in Chapter 6, which discusses a vision for a post-oil socioeconomic system.
- The final step described by Hector et al. (2009: 703) is to develop a *narrative* "identifying major issues and barriers which would prevent achievement of the ''Desirable Future"." This step is included in Chapter 6, which analyses the constraints and risks associated with the proposed mitigation policies and transition strategy.

Analysis and argumentation

As detailed above, the dissertation addresses four key questions, which can be distilled as follows:

- What is the role of oil (energy) in the socioeconomic system?
- What is the nature and meaning of global oil depletion?
- What are the likely impacts?
- How can these impacts be mitigated?

In tackling these questions, the dissertation employs two strategies of explanation in a matrix structure (see Dunleavy, 2003). The first strategy is analytical: tackling a practical problem and working out its implications according to various subsystems (important areas of the socio-economy) as identified above, i.e. energy, transport, agriculture, macro-economy, and society. The second explanatory strategy is argumentative: comparing the perspectives of different disciplines or fields of study. In particular, the mainstream (neoclassical) economic approach is contrasted to those of ecological economics and socioecological systems. As will be shown, the former generally does not regard oil depletion as an issue of particular importance, while the latter two fields hold it to be of critical importance. This dialectical debate runs through each of the four questions listed above, and a subsidiary aim of the dissertation is to arrive at a synthesis position.

To summarise, the choice of conceptual approach is based on the following considerations:

- global oil depletion is a complex, multi-dimensional problem;
- it involves and impacts on dynamic systems (economic, social and ecological);
- it inherently entails issues of sustainability and sustainable development; and
- consequently, a transdisciplinary, holistic approach is required for its analysis and understanding.

This argument is further substantiated in Chapter 1 (conceptual issues) and Chapter 2 (nature of global oil depletion).

Scope

While the scope of the research is broad by conventional standards for a doctoral dissertation, as argued above it permits a more realistic and useful analysis of the problem at hand. However, in order for the research to be tractable, certain limitations must be imposed. First, the analysis will be conducted mainly at a macro level, aiming at a strategic overview of the implications of oil depletion (in terms of impacts and mitigation policies at the national government level), rather than at a detailed micro level that focuses on individual entities such as firms or households, or the details of specific investment projects.

Second, certain areas or sectors of the economy and society will receive more attention than others by virtue of being especially vulnerable to disruptions of oil supplies or high oil prices, or because they are of particular strategic importance to societal welfare. These priority areas include energy, transport, and agriculture.[7] The transport sector has the highest proportionate oil dependency, followed by agriculture (Chapter 3 provides the data). Transport is a necessary requirement for much economic activity, including most production chains, trade in physical goods, and many services. Food is obviously one of the most fundamental human needs and the current industrial agriculture and food system relies directly on oil inputs for both production and distribution. In addition, the analysis will include two broader categories. The first is the "macro-economy", where the focus is on variables such as government spending, inflation and interest rates, the rate of economic growth, the unemployment rate, etc. The macro-economy by definition affects most people in the society (except possibly some that are completely marginalised). The last category is named "society", and includes a range of quantitative and qualitative social issues such as poverty and inequality, household food security, human settlement patterns and social cohesion.

In general, an explicit treatment of environmental implications of global oil depletion for South Africa is considered beyond the scope of this dissertation, which focuses on social and economic impacts. There are two relatively minor exceptions, both relating to feedbacks between the environment and the socioeconomic system. First, there might be ways in which decreasing oil consumption in South Africa could have positive environmental benefits, which in turn contribute positively to long-term sustainability including the social and economic welfare of future generations. Second, certain policy responses that might make sense on purely economic or social grounds might be detrimental to the environment in ways that harm future (or event current)

[7] Geels (2011: 25) regards these three sectors or systems as "empirical domains where sustainability transitions are most needed".

generations. A prime example is the contribution of carbon dioxide emissions (e.g. from burning coal) to global warming and climate change.

This delineation of scope explicitly recognises that more detailed research will be required (beyond this dissertation) in other areas and at the micro level; some specific suggestions are included in the concluding chapter. However, the holistic approach suggests that such research would be best informed by an initial exploration at the macro-systemic level.

Originality

The originality of this dissertation has three major dimensions. The first is the type of approach taken, namely an integrative, transdisciplinary perspective. The advantage of this approach is that the multidimensionality of the problématique can be tackled, in contrast to any one discipline-centred methodology that might omit important aspects or lack certain appropriate analytical tools. In particular, the conceptual approach draws on recent developments in the fields of ecological economics and socioecological systems as well as more traditional economic analysis. Further, the socio-economy is conceptualised as a complex system which is itself composed of interacting subsystems. This allows a tractable analysis of potential impacts and mitigation policies in several major areas of society, while maintaining the breadth of view necessary to understand the dynamic interactions and feedback effects between them. This in turn lays a more solid platform for integrated policy proposals that carry a lower risk of negative unforeseen or unintended consequences than policies derived from a narrower perspective.

The second dimension of originality is related to content: the forthcoming peak and decline in world oil production is an unprecedented global phenomenon with extensive implications for South Africa. The topic involves a search for practical responses to a new, significant societal challenge. To date there has been a marked paucity of research on this critical issue in South Africa, with limited treatments found in Feasta (2005), Hallowes and Munnik (2007), Hendler et al. (2007) and Wakeford (2007a; 2007b). This dissertation aims to provide an original contribution to knowledge by filling this void, i.e. by investigating the potential impacts of global oil depletion on the South African economy and society, and how these impacts can be mitigated. In the latter respect, it adds an important critique of existing government policies, which largely ignore the oil depletion issue.

Thirdly, this case study of the implications of global oil depletion for a developing country may serve a useful purpose beyond the nation itself, in at least two ways. First, a developing country perspective may challenge dominant Northern preconceptions about the potential impacts as well as prescriptions for policy responses. Second, in many ways South Africa represents a microcosm of the world: it has a high reliance on fossil fuels (including oil); the economy is fairly well diversified across primary, secondary and tertiary sectors; and perhaps most importantly, its society is characterised by a mix of a relatively affluent consumer class who enjoy the benefits of infrastructure that in some instances (e.g. financial services) approach “first world” levels, while roughly half of the population subsists on the margins of the formal economy, many relying on government grants. This means that the issues faced by South Africa in relation to oil depletion could serve as a useful proxy for similar issues at a global scale (as well as for certain other developing nations). Finally, the dissertation contributes to the international and national literatures on energy, economic and societal transitions, and in doing so it addresses a gap that exists between the separate literatures on ‘peak oil’ and ‘societal transitions’.

Structure

The first two chapters review the relevant international literatures on the role of energy in general, and global oil depletion in particular. The subsequent four chapters focus on the South African case study, while the final chapter contains the conclusions.

Chapter 1 examines various theoretical approaches to the energy-economy relationship and therefore operates at the broadest conceptual level. Three fields of study are considered, namely: (1) neoclassical economics, and especially the subfield of natural resource economics; (2) ecological economics; and (3) social-ecological systems. In each case, the discussion begins with philosophical foundations, moves to how the energy-economy relationship is conceptualised, and then provides an evaluation of the merits and limitations of the approach. The concluding section compares and contrasts the three approaches and identifies the concepts and analytical tools that are deemed most appropriate to the central and subsidiary research questions.

Chapter 2 reviews the international literature on global oil depletion. More specifically, it discusses the nature of oil depletion, potential substitutes for oil, and possible implications of depletion for the global economy and society. This review substantiates the initial characterisation of the topic (in this introduction) as complex and broad-ranging, which in turn provides the philosophical justification (on ontological, epistemological and methodological grounds) for the criteria used to select an appropriate theoretical approach (or set of approaches). Chapter 2 includes a dialectical debate between two opposing conceptual approaches, one of which is closely aligned to the neoclassical economic approach while the other is rooted in the natural sciences, and provides a synthesis perspective based on ecological economics.

Chapter 3 details empirically the status quo of the major subsystems, namely energy, transport, agriculture, macro-economy, and society. In particular, it provides historical data on how oil flows through the South African socio-economy, and highlights the key parameters of the other systems insofar as they relate to oil dependency and vulnerability to oil shocks.

Chapter 4 draws on historical and empirical evidence to sketch the likely impacts of global oil depletion on South Africa, assuming that government authorities do not plan proactively to mitigate oil shocks. It sketches alternative scenarios for a gradual decline in economic activity and for a rapid, systemic collapse of socioeconomic structures. Finally, the chapter considers various possible national response scenarios, ranging from denial to predatory militarism to totalitarian retrenchment.

Chapter 5 addresses the issues of mitigation and adaptation by describing and evaluating a broad range of policy responses. The policy options are organised according to the subsystems, and are additionally delineated between demand side and supply side interventions, as appropriate. Further distinctions are made between short- to medium-term, and long-term, policies and measures. The discussion focuses mainly on the national level, although local scales are also considered where especially relevant.

Chapter 6 places the policy recommendations within a broader conceptual framework informed by a review of the literature on societal transitions. It then presents a vision of a post-oil, sustainable future, along with a transition action plan as a guide to its attainment. The chapter also discusses the obstacles and risks facing implementation of the action plan.

Finally, Chapter 7 summarises and draws together the main conclusions from each of the foregoing chapters and discusses some broader implications for South African society and for economic theory. It ends by considering some avenues for further research that were beyond the scope of this dissertation.

CHAPTER ONE

1. The Role of Energy in Socioeconomic Systems

"Energy is the ultimate resource."

Alvin Weinberg

This chapter addresses the following question: what is or are the most appropriate theoretical framework(s), concepts and analytical tools for understanding the socioeconomic implications of global oil depletion? The specific aims of the chapter are threefold. First, it reviews several theoretical approaches that deal explicitly with the role of energy in socioeconomic systems. Second, it evaluates their usefulness with respect to the central research question of the dissertation. Third, it seeks to develop a synthesized conceptual language for understanding the relationship between energy and the socio-economy. This language will then be applied in subsequent chapters.

To begin with, it is necessary to understand the meaning of 'energy'. The definition of energy in physics is "the capacity for doing work, where work is the action of a force acting over some distance" (Ornes et al., 2010). Energy, according to the First Law of Thermodynamics, is not consumed in physical or economic processes, but rather changes to successively less useful forms. The appropriate term for 'available energy', 'useful energy' or 'potential work' is 'exergy', and this quantity is dissipated (used up) in physical processes. To be consistent with the majority of the literature, however, the term 'energy' is used in this dissertation to refer to "the capacity to perform useful work", although 'exergy' is more precisely correct. Energy exists in many different forms, including thermal, chemical, electromagnetic, gravitational, nuclear, mechanical, acoustical, and elastic energy (Common & Stagl, 2005; Ornes et al., 2010). These forms of energy can be either potential (stored) or kinetic (active). Energy is measured in several ways, often depending on its form. Under the *Système International d'Unités,* the unit of measurement is the joule, which is "equal to the work done by a force of one newton acting over a distance of one meter" (Ornes et al., 2010). In some instances, energy is measured by volume (e.g. litres or barrels of liquid fuels; cubic metres of gas), mass (e.g. tonnes of coal), or capacity for heating (e.g. British thermal units, or Btus). The energy content of food is usually measured in kilocalories. Electrical and thermal power capacity is measured in Watts and use of electric energy by Watt-hours.

In economic terms, energy is considered as a resource, i.e. something that has use value for humans. *Primary energy sources* include non-renewable resources (e.g. coal, peat, oil, natural gas, uranium) and renewable resources (e.g. biomass, solar, wind, hydro, geothermal, ocean current, wave, and tidal energy). Some of these primary energy resources are used as they are, while others are transformed into *energy carriers* that can be readily used for final consumption in the form of solids (e.g. wood, coal), liquids (e.g. petrol, diesel, jet fuel, paraffin, heating oil, bio-ethanol, biodiesel), gases (e.g. natural gas, liquefied petroleum gas, biogas, hydrogen), and electricity. *Energy systems* refer to the infrastructure for extracting/capturing primary energy sources, processing them into energy carriers, and distributing them to final consumers. For example, the electricity system converts primary resources such as coal, gas and wind energy into electricity and distributes it via power lines to consumers. The petroleum system begins with oil drilling and extraction, converts the oil into useful forms in refineries, and distributes these products to consumers via various modes of transport (pipelines, trucks and ships). An *energy service* is the useful outcome provided by an energy carrier, such as lighting, heating, cooling, kilometres travelled, telecommunications, etc. (Kendall, 2008: 153).

Three conceptual approaches (or theoretical frameworks) that deal with the energy-economy relationship are reviewed in this chapter, namely: neoclassical economics (and in particular, the sub-field of natural resource economics); ecological economics (incorporating a biophysical approach to economics); and socio-ecological systems analysis (a relatively new field of inquiry). For reasons of tractability, scope and focus, other fields are not included in the review. For example, other heterodox approaches to economics such as institutional economics, evolutionary economics, and socioeconomics, as well as economic history, do not give primary importance to the role of energy, but tend rather to focus on social institutions, knowledge/technology, and other components of human culture (see e.g. Ropke, 2004: 304). In addition, the relatively new field of industrial ecology overlaps substantially with the socio-ecological systems approach in terms of key concepts (e.g. industrial metabolism) as well as analytical methods (e.g. material and energy flow analysis) (see Fischer-Kowalski, 1998). Industrial ecology also draws to some extent on the same roots as ecological economics (Ropke, 2004: 301) and studies similar issues (e.g. the economy-ecology interaction, sustainability, etc.). Energy is not a central concern in the field of economic sociology, which "can be defined as the application of the sociological tradition to economic phenomena" (Swedberg, 2003: xi). Rather, the focus in this latter field is on the role played by social relations and institutions in the economy.

Several criteria are used to evaluate the suitability of the three conceptual frameworks for understanding the socioeconomic implications of global oil depletion. First, on a methodological level the approach should be able to deal with the nature of the global oil depletion issue as described in the introduction, i.e. its problem-centredness, its complexity, and its implications for sustainability. As argued earlier, this requires a systems perspective and a transdisciplinary approach. The framework should also include appropriate analytical tools such as quantitative modelling, qualitative investigation and case study analysis. Second, on a conceptual level the approach must provide concepts and insights that afford a realistic and useful treatment of the role of energy in socioeconomic systems. Third, the framework should provide an explicit treatment of normative ethics and values. Fourth, it should be able to motivate and inform relevant policy options.

The chapter is structured according to the three selected approaches, i.e. neoclassical economics, ecological economics and socioecological systems. In each section, the field or approach is first characterised in terms of its intellectual history, subject matter, aims, ontology, epistemology and methodology. Next, the perspective of the field on the function of energy in socioeconomic systems is considered in detail, including key concepts, analytical tools, normative stance and policy orientations. Thirdly, each approach is evaluated according to the criteria outlined above. The final section of the chapter provides a comparative evaluation and synthesis of the three theoretical frameworks.

1.1 Neoclassical Economics

1.1.1 Characterisation of neoclassical economics

The intellectual roots of contemporary mainstream economics reach at least as far back as classical economic writers such as Adam Smith, David Ricardo and John Stuart Mill. However, the "marginalist revolution" of the 1870s marked a turning point in that many classical ideas were shunned, and mathematical formalism (using differential calculus) was adopted as the key vehicle for theory development. This in turn provided the foundations for neoclassical economics, which was systematised by Alfred Marshall in the late nineteenth and early twentieth centuries. From the 1930s onwards, the mainly microeconomic theories of neoclassical economics were melded with

Keynesian macroeconomics to form the "neoclassical synthesis". Neoclassical economic theory remains at the core of mainstream economics, despite many advances in various directions (Colander, 2000).

There has been considerable debate in the history of economics literature over what is considered to be the appropriate terminology to describe current orthodox economics. Most heterodox critiques (including ecological economics) apply the label "neoclassical economics" to mainstream economics. Colander (2000) argues that mainstream economics is now much more eclectic than neoclassical economics, and deserves a new label such as "new millennium economics." While acknowledging these debates, for simplicity this dissertation adopts the label neoclassical economics (NE) to refer to the core orthodox approach to economics.

Alfred Marshall (1920), regarded as the father of neoclassical economics, defined economics as "the study of mankind in the ordinary business of life". However, the most common definition of (neoclassical) economics, originally advanced by Robbins (1932: 16), is that it is "the science which studies human behaviour as a relationship between ends and scarce means which have alternative uses." Thus the allocation of scarce resources to satisfy unlimited human wants is the core focus of neoclassical economics. Alternatively, economics concerns the production, distribution and consumption of goods and services. Neoclassical economics aims to explain – and sometimes predict – economic processes and phenomena at a micro scale (with an emphasis on the decision-making of individuals, households and firms) and a macro scale (the functioning and performance of national economies).

Surprisingly, given the above definitions, the relationship between the economy and the natural environment (ecology) is not accorded primary importance within neoclassical economics, but has rather been relegated to two sub-disciplines. The first is environmental economics, which is concerned principally with how waste outputs from the economy affect the environment. The second sub-discipline is natural resource economics (NRE), which primarily focuses on the extraction of raw materials from the environment (Common & Stagl, 2005: 4). Both fields are relatively recent; natural resources was only classified as a field in the *Journal of Economic Literature* and *Economic Abstracts* in 1969 (Cleveland, 1987: 64). However, the two fields expanded rapidly from the 1970s, and were institutionalised through the launch of the *Journal of Environmental Economics and Management* in 1974, followed in 1979 by the establishment of the Association of Environmental and Resource Economists (Ropke, 2004: 302). Nonetheless, environmental and resource economics have not had a major impact on the core of orthodox economics (Ehrlich, 1989: 9). Within neoclassical economics, NRE is the field most pertinent to the subject matter of this dissertation. However, certain other concepts, theories and analytical tools from NE are also relevant, especially in terms of evaluating the potential impacts of oil depletion and the policies that could mitigate them.

Mainstream or neoclassical economics is located firmly within the modernist tradition, which informs the discipline's ontological, epistemological and methodological foundations (Klamer, 2001: 77). The ontological point of departure is scientific realism: an objective reality is assumed to exist, (mostly) independent of the human mind (Dow, 2001).[8] It is in the nature of this reality that there are unifying forces and regularities. Consequently, it is believed that there are 'laws of economics' that can be discovered through scientific enquiry (Norgaard, 1989: 47). The epistemology is absolutist in the sense that economic thought is believed to undergo a process of continual progress (via the accumulation of facts) towards an objective, ultimate and unchanging truth that describes reality. Furthermore, orthodox economics is monist in its approach to knowledge acquisition: there is believed to be one correct way of conducting economic research (Dow, 1997). In its

[8] Maki (2008), however, notes that social objects such as institutions are mind-dependent.

methodological approach, therefore, neoclassical economics is strongly disciplinary, in that it sets itself apart from other disciplines and does not in general advocate inter- or transdisciplinary research. It has even been accused of 'imperialism', in the sense of imposing its methods on other disciplines (Fullbrook, 2004). The dominant methodology is logical positivism, which involves a rationalist and reductionist (as opposed to holistic) approach to scientific enquiry (Norgaard, 1989: 45). However, McCloskey (1983) argues that the positivist rhetoric of NE is not borne out in practice; theories based on deductive reasoning (which is strongly preferred over inductive reasoning) are seldom adequately tested against empirical evidence. Although neoclassical economics nominally adopted Popper's (1959) position that all scientific theories should be falsifiable, this has been impossible to achieve in practice, partly because facts are often theory-laden (Dow, 1997: 76). The analytical approach of NE is founded on methodological individualism, in which "[s]ocial wholes are built up from the actions of individual agents without feedback from the system or its subsystems to the individual" (Christensen, 1989: 26). Thus, for example, macro-economic models are given micro foundations. NE is further characterised by its formalistic methods of inquiry, i.e. the use of mathematical and statistical models (Backhouse, 2000; Dow, 2000). The excessive formalism of NE has been criticised as restricting both the scope and the progress of the discipline (Dow, 2000: 160).

Neoclassical economics holds that a distinction can and should be drawn between positive (value free) science and normative science. All policy recommendations involve normative judgements (e.g. economic growth is good for human welfare). The normative position of NE is consequentionalist (Sen, 2008), i.e. "moral correctness is to be judged in terms of the consequences that follow from an action" (Common & Stagl, 2005: 7). Furthermore, NE is based on a utilitarian philosophy which holds that actions that maximise pleasure and minimise pain or displeasure are morally correct, and societal utility or social welfare is the ultimate value to be optimised (Riley, 2008). The NE perspective is anthropocentric, i.e. it considers the pleasure and pain of humans only, and not of any other non-human animals, whether 'sentient' or not (Common & Stagl, 2005: 9). Neoclassical economics also adheres to the doctrine of 'consumer sovereignty", whereby each individual is considered the best judge of their own utility or welfare according to their own preferences, which are taken as given and exogenous to the economy (Common & Stagl, 2005: 9-10). As far as specific societal goals are concerned, the main focus of NE has traditionally been on allocative efficiency, while normative issues of distribution and equity are accorded secondary importance (Daly & Farley, 2004). The generally accepted criterion for allocative efficiency is Pareto optimality, according to which it is impossible to increase the welfare of any one individual without decreasing the welfare of at least one other individual in the society.

These philosophical underpinnings inform the neoclassical economic approach to the function of energy in economic systems, which is considered next.

1.1.2 Neoclassical economic approach to the role of energy

Within neoclassical economics, energy is treated chiefly as a resource; that is, an input into economic production activities that deliver utility to humans (see Heal, 2008). In addition, neoclassical economics includes energy systems as a major sector of the economy. Energy development "can be interpreted broadly to mean increased availability and use of energy services" (Toman & Jemelkova, 2003: 93). Neoclassical economics in general does not however accord a central place in its core theory to energy, although energy is an important issue for the sub-field of natural resource economics (Kneese & Sweeny, 1993).[9] The following subsections consider how

[9] There is no entry specifically on "energy" in T*he New Palgrave Dictionary of Economics, 2nd edition* (edited by Durlauf and Blume, 2008); there is, however, an article on "Oil and the macroeconomy" (Hamilton, 2008), which explores the impact of oil price shocks.

energy is treated (or neglected) in both NE and NRE, at the levels of theories and concepts, research methods, normative stance and policies.

Key concepts

The point of departure for the neoclassical economic perspective on the role of energy is the theory of production. Classical economists identified three factors of production, namely land (i.e. natural resources, including energy), labour and capital (i.e. human-made machinery and infrastructure). Departing from their classical roots, however, neoclassical economists effectively dropped raw materials and energy from their theory of production. Instead they advanced a theory of the distribution of output that assumed "variable proportions" of independent inputs could be applied in the short run, and generalised this to a theory of substitutability between inputs (Dasgupta, 2008; Christensen, 1989: 22-26). To the extent that it is considered, energy is generally treated as an intermediate input (as opposed to a primary input), whose demand is derived from the demand for labour and capital (Dasgupta, 2008). Consequently, the amount of energy available to the economy is assumed to be endogenous (Stern and Cleveland, 2004). The marginalisation of energy in neoclassical theory is seemingly supported by the empirical observation that energy consumption (measured in monetary terms) accounts for a very small share of GDP in most countries (Stern, 2011). However, as will be discussed in Section 1.2, this interpretation is misleading.

Following from the theory of production, mainstream models of economic growth typically do not incorporate natural resources or energy (Jorgenson & Wilcoxen, 1993). In Solow (1956)'s renowned neoclassical growth model, aggregate economic activity is assumed to be a function of capital and labour inputs and technological progress. At a constant savings rate, the economy tends towards an equilibrium or stationary state as a result of diminishing returns to capital. Continued growth is made possible by technological change, which is assumed to be exogenously determined. In empirical studies based on Cobb-Douglass production functions (with capital and labour as factors), technical progress has become known as the 'Solow residual', and in empirical estimates usually accounts for the bulk of measured productivity gains in the long run.

More recent growth models have attempted to explain technical change endogenously. Three principle endogenous growth mechanisms have been proposed (Aghion and Howitt, 1998). First, in learning-by-doing models (e.g. Arrow, 1962), technological progress is related to cumulative production: accumulating knowledge raises productivity. Second, in increasing returns to scale models (e.g. Romer, 1987) capital is seen to be comprised of both manufactured capital and technological knowledge. The latter (e.g. derived from research and development) does not deplete with use and also creates positive externalities, so there are increasing returns to scale in production, which allow continuous growth. Third, Schumpeterian growth models focus on the incentives for innovation, such as temporary monopoly profits. Energy does not feature prominently (or at all) in any of these endogenous growth models, which basically focus on investments in physical capital and/or technological knowledge (Ayres & van den Bergh, 2005: 98).

In summary, many mainstream models of production and growth assume that economic growth is a result of capital and labour accumulation and technical progress (either exogenously or endogenously determined) and gives rise to increasing consumption of natural resources and energy (Jorgenson & Wilcoxen, 1993; Ayres & Warr, 2005: 183). In other words, the causality runs from economic growth to energy consumption. Other neoclassical economists have adopted the 'neutrality hypothesis': energy consumption is assumed to be neutral with respect to aggregate economic activity (or growth), i.e. there is no expectation of a causal relationship between the two variables (Stern & Cleveland, 2004). Mainstream macroeconomics further assumes that the economy can continue growing indefinitely. This rests on an implicit conception of the environment as being a subset of the economy. As will be seen in Section 1.2, this view is diametrically opposed to the perspective of ecological economics. Nevertheless, the exhaustibility of certain natural resources and its possible implications for economic growth has been addressed within the neoclassical economics literature, mainly within the sub-field of natural resource economics.

The pioneering treatment of resource economics was contributed by Hotelling (1931), who developed a theoretical model of the dynamic workings of markets for exhaustible resources (Halvorsen & Smith, 1991). The central issue in theories of exhaustible resources is the trade-off between present and future consumption (Heal, 2008: 106). This inter-temporal choice is dependent on the discount rate. In the Hotelling model, as long as the discount rate is positive, consumption should be positive in the present period and decline over time; if the discount rate were zero, consumption should be zero (effectively postponed indefinitely). To achieve allocative efficiency, the marginal utility of consumption must equate to the resource's shadow price (i.e. the opportunity cost to society). According to the so-called 'Hotelling rule', the shadow price of a resource must rise at the discount rate (assuming perfect competition). Assuming a constant cost of extraction, the 'rent' accruing to the producer rises as the price diverges from the marginal cost (Heal, 2008: 109), reflecting the growing scarcity of the resource. In a more realistic case, the marginal costs of extraction depend on cumulative extraction: they tend to rise over time as higher quality sources of the resource are consumed earlier on.

However, rising marginal costs of production due to depletion could in theory be counteracted by technological development and factor substitution. Another seminal contribution to the neoclassical economic view on natural resources was made by Barnett and Morse (1963), who provided empirical evidence that the costs of resource extraction had mostly declined since the late 1800s. Barnett and Morse came to the conclusion that the depletion of any one natural resource acts via the price mechanism to stimulate discoveries of further deposits of the resource as well as substitute resources. Hence they foresaw no problems associated with fossil fuel depletion.

In the 1970s, however, the debate sparked by the publication of "The Limits to Growth" report of the Club of Rome (Meadows, Meadows & Randers, 1972),[10] together with the oil price shocks of 1973 and 1979, stimulated further research by neoclassical economists on the exhaustibility of natural resources and the implications for economic growth. Two of the key questions addressed in this literature were: (1) "how fast should a resource stock be depleted?" and (2) "will market-determined depletion rates be acceptable?" (Heal, 1974: 1).[11]

In respect of the first question, Dasgupta & Heal (1974: 4) identify a key issue to be "the elasticity of substitution between reproducible inputs and exhaustible resources". These authors also point out that whether or not a resource is essential for the production of goods has major implications for the optimal depletion policy, although the nature of 'essentiality' is not clear (Dasgupta & Heal, 1974: 25). In Stiglitz's (1974a) model, sustained growth in per capita consumption is possible in the face of limited, exhaustible and essential natural resources. However, the optimal depletion question is clouded by uncertainty arising *inter alia* from the impossibility of generating accurate forecasts of technological change over long time horizons as well as the irreversibility of decisions regarding the depletion of resources (Stiglitz, 1974a; Dasgupta & Heal, 1974). The optimal rate of depletion also depends on the identified social objectives. For example, rather than relying on the traditional utilitarian framework with an infinite time horizon as do Dasgupta and Heal (1974), Solow (1974) explicitly incorporates the issue of intergenerational equity. Solow's (1974) model shows that per capita income could be sustained at a constant level despite growing scarcity of resources as long as

[10] The Limits to Growth report elicited vociferous counter-arguments by the likes of Cole et al. (1973) and Beckerman (1974).
[11] Several other publications sought to challenge the "limits to growth" thesis in general terms (see e.g. Smith, 1979; Simon, 1980).

capital could be substituted for natural resources, and thus gave further impetus to the view expressed by Barnett and Morse (Cleveland, 1987: 65-66).

With regard to the second question, i.e. whether or not markets can produce an optimal outcome, Zeckhauser and Weinstein (1974) demonstrated that the market could perform efficiently under certain assumptions. However, Stiglitz's (1974b) model of growth in a competitive economy showed that market efficiency is not guaranteed. Market failure in the form of missing futures and risk markets results in instability that is more severe than that found in ordinary capital markets (because the entire return for holding natural resource stocks is speculative gain). In addition, imperfect foresight might result in a rate of depletion that is too rapid or too slow.

The models developed by Hotelling (1931), Dasgupta and Heal (1974), Solow (1974) and Stiglitz (1974a; 1974b) provided the logical foundation for the neoclassical conception of sustainability (Bromley, 2008: 114). The assumption of input substitutability plays a key role in this neoclassical approach to sustainability. So-called "weak sustainability" (Greenwood & Holt, 2008) can be achieved through the substitution of manufactured or human capital for non-renewable or renewable natural resources. Bromley (2008: 114) terms this "sustainability as replacement." This notion of sustainability will be contrasted with "strong sustainability" in Section 1.2.

The literatures on scarcity and growth, and the economics of exhaustible resources, address the question of whether the depletion of resources (including non-renewable energy sources) imposes constraints on economic growth. Another body of research addresses the relationship between energy and economic activity from a different (positive) perspective: what role does energy play in promoting economic (and social) development? Toman and Jemelkova (2003) find that the (mainstream) literature on the relationship between energy and development is relatively sparse, and tends to concentrate mainly on how economic development drives demand for energy.[12] Exploring at a theoretical level the question of whether improved energy services can disproportionately stimulate development, they identify various potential sources of increasing returns to the production and utilisation of energy services. These include: economies of scale in large energy infrastructure developments; raising the productivity of other factors of production; positive interactions with other types of infrastructure such as transport and telecommunications networks; and health and education benefits for households. In the empirical literature, Toman and Jemelkova (2003) find some support for a strong role for energy in stimulating development through various channels, although usually in combination with other drivers. For example, improvements in energy provision (e.g. electrification) have been shown to be an important contributor to development in the household sector, especially in poorer countries. At an economy-wide level, the IMF (2011b) notes that in developing countries the income elasticity of energy consumption is approximately unity. Toman and Jemelkova (2003) conclude that although it seems clear that there are strong linkages between energy and development, the direction of causality remains an open question that is difficult to determine from macroeconomic models and data.

Another body of literature, which emerged in the wake of the 1970s oil crises, analyses the impact of oil price shocks on the macro-economy, and especially on GDP growth (see Hamilton, 2008, for a review). In a seminal contribution, Hamilton (1983) demonstrated that oil price hikes played a significant role in every post-World War II recession in the United States except the 1960 recession. In particular, the oil shocks of 1973/4 and 1979/80 resulted in rising inflation together with severe recessions and higher unemployment (i.e. stagflation) in many of the industrialised economies. More recently, Hamilton (2009) found that the oil price spike of 2007-8 was most likely a primary factor contributing to the collapse of the US housing market and the subsequent debt crunch and

[12] Toman and Jemelkova (2003) effectively ignore the biophysical and ecological economic literatures on energy and economic development, which are discussed in Section 1.2.

economic crisis. Hamilton (2003) demonstrates that oil price shocks have nonlinear effects on GDP; in particular, price increases affect GDP but decreases do not. This literature therefore confirms that oil price shocks, which are generally seen as exogenously determined, have historically been associated with adverse economic impacts (see also Brown & Yucel, 2002; Toman & Jemelkova, 2003). This conclusion is at odds with mainstream production and growth theory.

Research methods

As discussed above, in practice neoclassical economists in general do not include energy variables in their models; but this does not mean energy cannot be included. The research methods commonly employed by neoclassical economists at a micro level include rational choice theory and game theory (for modelling individual choices), static and dynamic optimisation, general equilibrium theory, linear programming and benefit-cost analysis. The latter technique is particularly useful for choosing among potential investment projects. The chief analytical tool used in resource economics to determine optimal rates of extraction is dynamic optimisation (involving the calculus of variations and optimal control theory). Macro level methods include general equilibrium models, growth models, growth accounting, macro-econometric modelling and input-output analysis. Macro-econometric models are able to assess the impact of energy price shocks but do not deal well with physical measures of energy. A common feature of these analytical methods is that in the few instances in which practitioners do include energy, it is almost always measured in monetary rather than physical units. This imposes certain limitations, which are discussed in Section 1.2.

Normative stance

In neoclassical economics, allocative efficiency is accorded priority status amongst societal objectives at a micro level. At a macro level, the primary goal for society is seen to be economic growth, as measured by the rate of change of gross domestic (or national) product. These overarching goals are reflected in the sub-discipline of natural resource economics, whose broad aim is to "determine the adequacy of those resources in meeting human needs" (Ward, 2005: 12). At a micro level, the main objective for an individual producer (firm) is to maximise the net present value of profits. At a macro level, the goal is to achieve intertemporal efficiency of resource allocation (Heal, 2008: 106). For exhaustible resources, this requires finding an optimal rate of resource depletion, which maximises social welfare over a certain time horizon. As discussed earlier, sustainability is interpreted as non-declining consumption; weak sustainability can be achieved through the substitution of human-made capital for natural resources.

Distributional equity is also a concern within neoclassical resource economics, but this is accorded a lower status relative to efficiency (Daly, 2004: 249). Intergenerational equity is sometimes considered explicitly with respect to exhaustible resources (e.g. Solow, 1974), and again is influenced by the degree of capital/resource substitutability. However, the common practice of assuming a (significantly) positive discount rate inherently disadvantages future generations relative to the current generation. At a more philosophical level, neoclassical economic theory holds that economic values are (and should be) formulated on the basis of individual preferences.

Policies

When it comes to policy, neoclassical economics in general advocates minimal government intervention in the economy, since the system of market prices is regarded as better able to achieve an efficient allocation of resources than government planning. However, even a (free) market system requires a foundation of well-defined property rights and enforcement of the rule of law, which are seen as the chief responsibilities of government in mainstream economics. In some instances, institutions and markets might be missing and need to be created. For example, endogenous growth theories have led to the view that policies that promote learning, innovation and technological progress – such as institutional or incentive support for research and development – can help to promote economic growth (Aghion & Howitt, 1998).

In the specific case of energy resources, neoclassical RE advocates the assignment of (usually private) property rights for exploiting mineral deposits as well as intellectual property rights associated with the development of new technologies, while the determination of energy prices is largely left to markets. The price system is assumed to stimulate the development of substitutes and new technologies so that specific policies are not in general required.[13] Nevertheless, the existence of several market failures provides a rationale for energy policy (Ward, 2006: 359). Market failures include natural monopolies (e.g. electricity networks), public good characteristics of energy (e.g. low private returns but high social returns to innovation), information asymmetries (e.g. between energy suppliers and consumers) and environmental externalities (e.g. pollution). To the extent that policy instruments are required, neoclassical economists generally prefer market-based incentives over direct regulations, as the former are considered more efficient, while 'moral suasion' techniques aimed at influencing economic actors' behaviour or changing their preferences are viewed as relatively ineffectual (Common & Stagl, 2005: 406). A further rationale for energy policy is the desire for energy security (Toman, 1993; Ward, 2006: 359).

1.1.3 Evaluation of neoclassical economics

The strongly modernist philosophical foundations of neoclassical economics render this field somewhat limited in terms of its applicability to understanding the nature and implications of global oil depletion. First, the reductionist and mechanistic ontological approach is less useful than a holistic conception of reality for understanding complex societal problems and systems (Hector et al., 2009).[14] Second, the disciplinary monism advocated by neoclassical economics is overly restrictive, especially for exploring sustainability issues, which, as argued earlier, intrinsically require a transdisciplinary approach.[15] Third, the methodological predilection for formalistic models and quantitative evidence, while ensuring a high degree of internal logical consistency, can result in inadequate treatment of certain unquantifiable, qualitative issues (such as social dimensions).

The treatment of energy within neoclassical economics is also lacking. In the orthodox economic theory of production and growth, energy (and materials more generally) is for the most part ignored; at best it is considered as an intermediate input in production that can be substituted for by other inputs or technology. The majority of empirical work on economic growth and development reflects this theoretical stance. Hence "economic analysis as currently practiced is divorced from, and even does not recognise, its biophysical foundations" (Proops, 1989: 64).[16]

Nevertheless, the neoclassical approach does have a number of analytical strengths. These include its analysis of economic costs and benefits; the rigorous treatment of allocative efficiency (at least in the short term); the role of prices and market mechanisms; and the effect of economic incentives on

[13] In the words of Tilton (1996: 96), "[t]echnological change, resource substitution, recycling, new discoveries, and other activities induced by the price system are all likely to help maintain sustainable development even with the growing exploitation of exhaustible resources."

[14] "The difficulties historically encountered in construing literally *all* problems (in particular, complex problems) atomistically or mechanistically... give reason to reject the view that entities and systems of entities are only ever complex in a merely aggregative sense" (Hector et al., 2009: 694).

[15] Greenwood and Holt (2008: 450) argue that "the neoclassical approach to growth and development cannot deal adequately with sustainability or quality of life issues (Greenwood and Holt 2007) because of its underlying assumptions and methodology."

[16] According to Stern and Cleveland (2004: 11), the neoclassical literature is often misinterpreted as *implying* that economic growth can be divorced from energy/resource consumption; rather, neoclassical economists *assume a priori* that substitution is technically possible and focus their attention on possible institutional constraints to growth.

individual behaviour. These techniques are applied to energy within the sub-field of natural resource economics. However, the analytical tools such as dynamic optimisation that are typically employed by neoclassical resource economists are not geared towards understanding the role of energy within complex systems with holistic qualities.

Neoclassical economics concerns itself primarily with 'positive' issues and in general downplays the importance of normative value judgements. From the vantage point of sustainable development, the neoclassical approach is too narrowly focused on maximising allocative efficiency and economic growth, to the exclusion of other goals such as social equity and ecological sustainability. For example, Ehrlich (1989:9) states that "[i]t has long been clear to ecologists that the extreme growth orientation of neoclassical economics is a major component in the failure of politicians, businessmen, and others advised by economists, as well as the public at large, to recognize the increasingly serious predicament of *Homo sapiens*." Furthermore, the prime place given to current human preferences as a basis for societal values, "leaves us with the dictates of the market and the subjective judgements of the present generation as to the values which should be placed on resources and natural environments" (Christensen, 1989: 27), while the wishes of future generations cannot be determined in the present.

Energy has generally been accorded a relatively low status in neoclassical economic policy prescriptions (e.g. for growth and development), for at least two reasons. The first is the insignificant status of energy in economic theory and models, where energy consumption is considered as a derived demand, which misses the complementarity between energy use and production of goods and services. The second is the strong belief in the power of free market forces and technology to overcome problems of scarcity. Typically, mainstream economists have tended to be concerned about energy supply only in times of high energy prices, and usually it is assumed that market forces obviate a role for government policy, except possibly in addressing political aspects of energy security. Many of the limitations of neoclassical economics are explicitly addressed by the relatively new field of ecological economics, which is considered next.

1.2 Ecological Economics

The second conceptual approach to the role of energy in socioeconomic systems is ecological economics (EE). The following three sub-sections characterise this field in general terms, elucidate its main theoretical concepts and empirical evidence in respect of the role of energy, and evaluate its strengths and weaknesses vis-à-vis the research problem.

1.2.1 Characterisation of ecological economics

Ecological economics has intellectual roots reaching back at least a century but its development was given a major boost in the 1960s and 1970s by the emerging discourses on issues such as pollution, energy, resources and population (Ropke, 2004; Martinez-Alier, 1987). However, EE crystallized as a distinct field of study comparatively recently, with the launch of the International Society for Ecological Economics (ISEE) in 1988 and its dedicated academic journal, *Ecological Economics*, in 1989 (Costanza, 1989; Ropke, 2004). The modern formulation of EE draws on perspectives and concepts from a wide range of disciplines, including "systems ecology, different strands of economics (heterodox biophysical economics, environmental and resource economics, agricultural economics, socioeconomics), energy studies mainly based on physics and engineering, and general systems theory" (Ropke, 2004: 310).

Although the field has grown in popularity since its institutionalisation, from the vantage point of mainstream (neoclassical) economics EE remains one of several heterodox schools of thought existing on the fringes of the orthodoxy (Backhouse, 2000). Adherents to the EE approach, on the other hand, see their field as the intersection of the disciplines of ecology and economics and as overlapping with mainstream economics but not a subset thereof (Common & Stagl, 2005: 1-2; Daly & Farley, 2004). As will be discussed later, some proponents of EE argue that it operates within a fundamentally different paradigm to that of neoclassical economics and the latter's subsets, environmental economics and natural resource economics (e.g. Daly, 2004; Daly & Farley, 2004).[17] The differences relate both to 'pre-analytic vision' as well as to subject matter and analytical techniques.

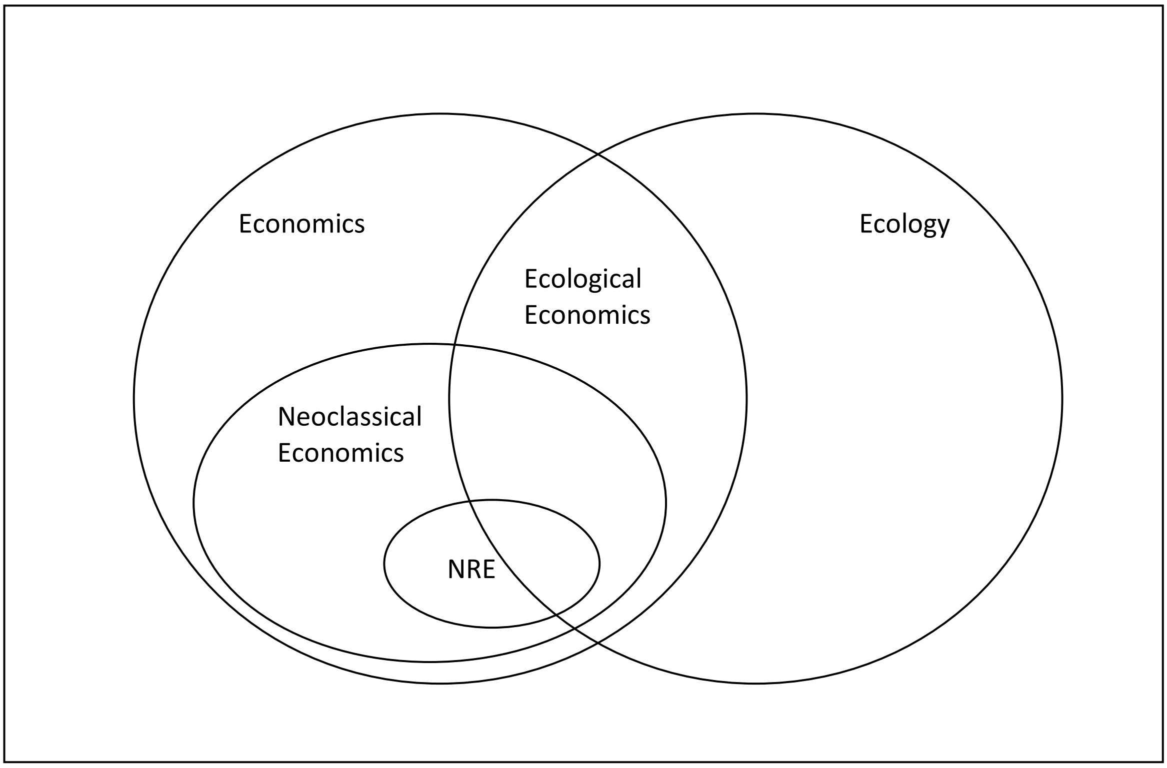
Another field closely allied to ecological economics is biophysical economics, which focuses on the physical foundations of economic activity, such as energy and natural resources. The origins of biophysical economics can be traced back as far as the French Physiocrats in the 1760s, who argued that nature (especially agriculture) was the source of all real value in the economy (Cleveland, 1987: 50). The physical laws of thermodynamics, formulated in the nineteenth century, became the foundation of the biophysical approach to economics and society. Cleveland (1987) outlines how many of the pioneering contributors to biophysical economics in the nineteenth and twentieth centuries were not economists but rather natural scientists (e.g. Lotka (1924), a biologist; Soddy (1922), a chemist; Cottrell (1955), a sociologist; Hubbert (1949), a geophysicist; Odum (1971), an ecologist; Cook (1976), a geologist; and Ayres (1978), a physicist), although key contributions were also made relatively recently by two 'unconventional' economists, Georgescu-Roegen (1971) and Daly (1977). Biophysical economics has long been critical of the neoclassical approach to production and resources and is not a sub-discipline of mainstream economics (Cleveland, 1987); however it is not generally recognised as an independent school of thought. Because of its strong focus on energy, the biophysical perspective is of particular relevance to this dissertation, while some issues covered by EE (e.g. environmental impact of human activities, valuation of ecosystem services, etc.) are not. The biophysical perspective on energy economics has largely been adopted by EE (see Ropke, 2004: 303), and for the remainder of this dissertation it is treated as a subset of EE. Figure 1-1 illustrates the relationships between neoclassical economics (and its subsets, environmental and resource economics), ecology, ecological economics and biophysical economics.

Various definitions of EE have been proposed, most of which focus on the discipline's subject matter, the core of which is the economy-ecology relationship. EE studies the "relationship between ecosystems and economic systems in the broadest sense" Costanza (1989: 1), or following the Greek roots of the words economics and ecology, "the relationships between human housekeeping and nature's housekeeping" (Common & Stagl, 2005: 1).[18] Common and Stagl (2005: 4) state that "[w]hereas neoclassical economics treats the study of economy-environment interdependence as an optional extra, for ecological economics it is foundational." More specifically, EE centres on three chief concerns, namely the allocation of resources, the distribution of income, and the scale of the economy relative to that of the ecosystem (Daly, 2004: 247). According to Daly (2004: 248), the "issue of 'scale', by which is meant the *physical* size of the economy relative to the containing ecosystem, is not recognized in standard economics, and has therefore become the differentiating focus of ecological economics." Additionally, EE has been described as "the science and management of sustainability" (Costanza, 1991). Sustainability and sustainable development are key concerns of EE, and will be elaborated upon in the following subsection.

[17] Proops (1989: 60) sees environmental economics as "a rather limited subset of ecological economics."

[18] Similar definitions are offered by Proops (1989: 60) and Baumgärtner et al. (2008: 2).

Figure 1-1: Relationships between economics, ecological economics and ecology



Source: Adapted from Common & Stagl (2005: Figure 1.1)

Note: Ecological economics is the intersection between economics and ecology, and overlaps with neoclassical economics (NE) and its subset, natural resource economics (NRE). Biophysical economics (not shown) is a subset of ecological economics that also overlaps with NE and NRE. NE does not occupy all the space within Economics as there are other non-mainstream schools of thought in addition to EE, such as institutional economics, Marxist economics, Austrian economics, etc.

EE has two principle aims, already alluded to in the above definitions. The first is to understand the interrelationships between economic and ecological systems. The second is to use this understanding to promote the sustainable management of the ecological-economic system (Baumgärtner et al., 2008: 2). According to Baumgärtner et al. (2008: 7), the former aim represents a "cognitive interest, i.e. an interest to understand and explain the world as it is," while the latter objective represents an "action interest, i.e. an interest to manage the world based on an idea of how it ought to be." Similarly, Proops (1989: 60) distinguishes between "scientific aims and problems" on the one hand, and "political and ethical issues" on the other. The former include "[e]stablishing an historical perspective on social-natural interactions" and "[f]inding a common language and set of concepts for the analysis of economies and ecosystems" (Proops, 1989: 60-61). The political and ethical concerns involve creating a "forum and structuring for policy analysis", providing a "framework for the ethical analysis of intertemporal and interspecies choice," and "influencing of decision makers" (Proops, 1989: 62-63).

In pursuit of these aims, the ontological position adopted by EE is realist, i.e. an objective reality is assumed to exist independent of human minds. In addition, the conception of reality is holistic rather than reductionist, i.e. wholes are not reducible to constituent parts. The epistemological stance of EE, which might be termed 'mildly' relativist, represents a compromise between an absolutist position (objective truth exists and can be discovered by scientific enquiry) and a strong relativist position (all knowledge is context-specific and socially constructed). A second epistemological compromise for EE is advocated by Baumgärtner et al. (2008: 5), namely between *radical empiricism* (the belief that "all human knowledge exclusively stems from experience, from the observation of a given real world") and *pure rationalism* (according to which "all correct human knowledge stems from the human mind"). In sum, "[k]nowledge... is the result of the interplay between human intellect and empirical experience" and may arise in different forms that are historically and socially contingent (Baumgärtner *et al*, 2008: 5).

Ecological economics is an explicitly inter- and transdisciplinary field. This follows necessarily from its subject matter and aims (Baumgärtner et al., 2008:1). EE is by nature a transdisciplinary field since "there are phenomena and problems that cross, or are beyond, the disciplinary boundaries" of economics and ecology and require "a common perspective that 'transcends' those that are standard in the two disciplines" (Common & Stagl, 2005: 5). Additionally, the fact that the relations between the economy and the ecosystem are complex means that the perspectives of a range of scientific disciplines are required (Baumgärtner *et al*, 2008: 2). Furthermore, the second major aim of EE, namely the management of sustainability, "requires the interconnection between EE as a science and society", which in turn necessitates a transdisciplinary approach (Baumgärtner *et al*, 2008: 4). Ropke (2005: 267) states that a core belief of EE is that "[t]ransdisciplinary work is essential to meet the challenge of understanding environmental problems and suggesting ways to overcome these problems." In general, EE "takes a holistic "systems" approach that goes beyond the normal boundaries of the academic disciplines" (Costanza, 1996: 980). It also explicitly treats the economy and ecosystem as complex, dynamic systems characterised by uncertainty.

In keeping with this transdisciplinary approach, ecological economics favours methodological pluralism over a unitary methodological approach. This has been criticised on the basis that "the knowledge structure of the field as such is obviously not well structured and systematically organized" and because the "core beliefs provide a framework for research, but... give little specific guidance" (Ropke, 2005: 285). However, Baumgärtner et al. (2008: 15) argue conversely that "the apparent heterogeneity of approaches, methods and contributions is not per se problematic but rather necessary to ecological economics." Similarly, Norgaard (1989: 37, 38) makes the case that "all the aspects of complex systems can only be understood through multiple methodologies" and argues for "retaining the full range of methodologies available in both disciplines [i.e. ecology and economics] rather than merely the approaches they hold in common." Further, Norgaard (1989: 49) contends that "the greater methodological diversity of ecology has helped it be more scientific than economics." Thus EE borrows (and to an extent merges) research methods from a range of disciplines including, but not limited to, economics and ecology.

The normative position of EE**,** as in the case of neoclassical economics**,** is consequentialist, utilitarian and anthropocentric (Common & Stagl, 2005: 9).[19] In contrast to NE, however, EE places explicit emphasis on the importance of value judgements. Baumgärtner et al. (2008: 4) suggest that the focus of EE on sustainable development requires factual knowledge as a basis for problem analysis and solutions, as well as treatment of values and normative judgements (descriptive and normative ethics). Adherents to the EE perspective generally advocate intra- and inter-generational equity and adequate 'space under the sun' for biodiversity (Daly & Farley, 2004). Furthermore, EE assumes that "there can be an ethical basis for comparing, evaluating and seeking to change tastes" of individuals so as to further the goals of individual and social wellbeing (Common & Stagl, 2005: 9-10). In contrast to NE, therefore, EE does not ascribe to the notion of 'consumer sovereignty'. In addition, EE considers that nature has intrinsic value (Ropke, 2005: 267).

[19] Costanza (1996: 980) states that in addition to being anthropocentric, ecological economics "is at the same time biocentric in the sense that it is concerned about the survival and well-being of all other life as well." On balance, however, more attention is given to how human needs are met.

1.2.2 Ecological economic approach to the role of energy

In ecological economics, energy is defined according to the physical science definition as the capacity to perform work, although it is also commonly regarded as a resource. This section provides an overview of the key concepts, analytical tools, normative goals and policy recommendations of ecological economics as it pertains to the role of energy in socioeconomic systems.

Key concepts

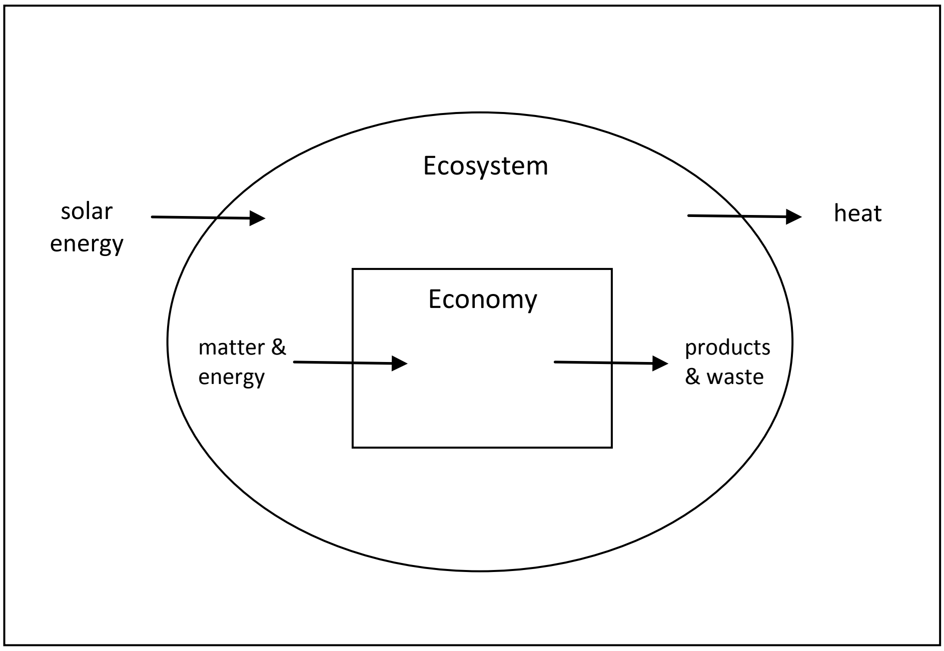
The conceptual point of departure for ecological economics is to view the human economy as embedded within nature or the 'geo-biosphere' (Common & Stagl, 2005: xxvii; Ropke, 2005: 267; see Figure 1-2).[20] According to Daly and Farley (2004: 24), this "change in vision from seeing the economy as the whole to seeing it as part of the relevant Whole – the ecosystem – constitutes a major paradigm shift in economics." A related aspect of this paradigm shift is that the environment is considered as a critical life-support system for human society, rather than simply a fund of resources to be exploited as is the case with neoclassical economics (Ropke, 2005: 266). The notion of embeddedness follows naturally from a conception of economic and ecological systems and their interactions in terms of flows of energy and matter (Ropke, 2005: 266). The economy relies on its surrounding ecosystem both for sources of energy and materials (e.g. mineral ores, aquifers, fisheries and arable land) and also for sinks (e.g. the atmosphere, oceans and landfills) to absorb its waste products (Daly & Farley, 2004: 29). The linear flow of materials and energy through the economy is termed "throughput", and results in degradation of both the ecosystem's sources (i.e. depletion) and sinks (i.e. pollution) (Daly, 2004: 248).

The throughput of energy and materials, measured in physical units, is governed by the laws of thermodynamics (Daly & Farley, 2004: 29).[21] The First Law of Thermodynamics, or the Law of Conservation of Energy, states that energy cannot be created or destroyed. It implies that "all human production must ultimately be based on resources provided by nature" (Daly & Farley, 2004: 69). The Second Law of Thermodynamics**,** or the Entropy Law, holds that "[t]he entropy of an isolated system tends to a maximum" (Binswanger, 1993: 211). Entropy in turn refers to the "irreversible dissipation of free (available) energy, which can be used to perform work, into bound (unavailable) energy, which cannot be used to perform work any more" (Binswanger, 1993: 212, citing Georgescu-Roegen, 1976: 8). In other words, "energy and matter in the universe move inexorably toward a less ordered (less useful) state" (Daly & Farley, 2004: 29). In summary, in the ecological economics perspective "[t]he economy is thus an ordered system for transforming low-entropy raw materials and energy into high-entropy waste and unavailable energy, providing humans with a "psychic flux" of satisfaction in the process" (Daly & Farley, 2004: 70).

[20] The economic system is also seen as being embedded within in a broader socio-cultural system (Ropke, 2005: 267).

[21] These laws have been a key building block of biophysical economics since their discovery in the 19th Century (Cleveland, 1987),and have subsequently been adopted by ecological economists.

Figure 1-2: The economy as a subset of the ecosystem



Source: Adapted from Daly & Farley (2004: Figure 2.1)

Ecological economics argues that the laws of thermodynamics, together with the notion that the (global) economy is embedded in a (global) ecosystem that is "finite, non-growing, and materially closed (though open with respect to solar energy)" (Daly, 2004: 248), implies that there are constraints on the physical growth of the economy (Ropke, 2005: 267). More specifically, EE assumes that there are two types of limits: (1) the exhaustion of (some) finite resources; and (2) the degradation of sinks and of ecosystem services (such as climate stability), both of which are a consequence of entropy. There is thus an opportunity cost to the growth in scale of the economy. According to Daly (2004: 248), the scale of the economy has two alternative measures: "(1) the throughput flow of physical resources that constitute the material component of the annual flow of goods and bads, and (2) the accumulated stock of goods in the form of wealth, and of bads in the form of 'illth'." The scale of the economy is seen as 'sustainable' if throughput is maintained "within the natural capacity of the ecosystem to absorb wastes and regenerate depleted resources" (Daly, 2004: 249). Daly (2004: 249) defines optimal scale as "the particular sustainable scale that maximizes the difference between wealth and illth (i.e., equates marginal goods produced with marginal bads)". Beyond the optimal scale, growth will become 'uneconomic'.[22]

The exhaustibility of natural resources, including fossil fuels, has been and remains a key issue of contention between neoclassical economists on the one hand, and biophysical and ecological

[22] Ecological economists generally consider the current scale of the human economy to be very large in relation to its encompassing ecosystem, such that further growth in throughput would indeed be uneconomic (Daly & Farley, 2004:121). For instance, Ehrlich (1989:10) contends that "[t]here already are abundant signs that the scale of the human economy is already larger than can be supported over the long term." This is a result of meta-resource depletion, or "the reduction of the total number of Earth's exploitable resources through the extermination of populations and species of other organisms, the destruction of forests, the poisoning of aquifers, the erosion of soils, the using up of high-grade ores, and so on" (Ehrlich, 1989:13). Ehrlich (1989:12) further argues that "some resources might be irreplaceable in terms of the functions they can serve in the human economy." Daly and Farley (2004: 118) argue that "[f]or virtually every renewable stock of significance, the rate of extraction is limited by resource scarcity, not by a lack of adequate infrastructure."

economists on the other.[23] As discussed in the previous section, most neoclassical economists do not believe that the depletion of any one resource (including energy sources such as fossil fuels) presents a problem because technology can always be relied upon to develop a substitute (Daly & Farley, 2004: xviii). In contrast, ecological economists – following the biophysical perspective – argue that energy (on the one hand) and capital and labour inputs (on the other hand) are *complements* in production. This is because both capital and labour require low-entropy energy and materials to be created and maintained, but cannot create these resources themselves (Cleveland, 1987: 48-49). Consequently, as the physical size of the economy expands relative to the ecosystem (i.e. in the move from an "empty world" to a "full world"), natural resources rather than manufactured capital will progressively become the limiting factor of production (Daly, 2004; Ayres & van den Bergh, 2005: 97). Thus Ayres (1993: 200) argues that "it is not safe to assume that technological improvements will continue forever to compensate for natural resource scarcity on a finite earth."[24]

The complementarity of energy (resources) and capital/labour in production, together with the laws of thermodynamics, leads to a view in EE that energy is a fundamental requirement for economic growth. In the words of Ayres and Warr (2009: xx), "[w]ithout exergy inputs, there can be no production." Fossil fuels in particular have been seen by many developers of biophysical economics as a critical basis for the Industrial Revolution and subsequent rapid growth of economies, human population and even technology (Cleveland, 1987; Ayres and Warr, 2005; Ayres & Warr, 2009).[25] Ayres (1993: 200) regards petroleum as "the most economically important single natural resource in the world today." Odum (1977) and Costanza (1981) have gone as far as to develop energy theories of value, whereby all economic value is ultimately derived from energy inputs or embodied energy. Similarly, in contrast to the view in NE that energy and resources are merely intermediate inputs, Ayres & Warr (2005: 185) argue that "the economic system should be understood as a sequential materials processing system, converting raw materials (and fuels) by stages into final products and services."

Whereas neoclassical economics assumes that economic growth causes energy consumption, ecological economics argues that energy consumption enables growth. Ayres and van den Bergh (2005) propose a theory of economic growth that explicitly incorporates energy and material resources. They identify three self-reinforcing feedback mechanisms, or what they term "growth engines". The first is based on resources – principally fossil fuels – whose prices decline over time. The energy-growth feedback loop consists of: technological progress – cheaper fossil fuels – substitution of fossil fuels and machines for labour – better metals – better machines – cheaper mining of fossil fuels. Thus falling resource prices are seen as a cause and not simply a consequence of growth, as in neoclassical economics (Ayres & Warr, 2005: 190). Ayres and van den Bergh (2005: 100) note that "this growth mechanism must falter and eventually fail since fossil fuels and other extractive resources will eventually become scarce and the costs of finished materials and useful work (energy services) derived from them will start rising." The second growth mechanism is termed "scale-cum-learning" and involves investment in physical scale and capacity, division of labour and

[23] Following from the laws of thermodynamics, exhaustion of resources is viewed by biophysical economists not in terms of the disappearance of the substance, but rather in terms of its transformation from a useful to a less useful form (Ayres, 1993: 199).

[24] Ayres (1993: 195) states that "[t]here are many, including myself, who believe that given a reasonably free market, technology can generally be depended upon to find a substitute for almost any scarce material resource input (except energy itself). However, there are no plausible technological substitutes for climatic stability, stratospheric ozone, air, water, topsoil, vegetation – especially forests - or species diversity. Degradation of most of these is irreversible. In every case, total loss would be catastrophic to the human race, and probably lethal."

[25] See Cleveland (1987) for a review of the contributions of Soddy (1922); Cottrell (1955, 1972); Hubbert (1949; 1974); and Cook (1976, 1979).

learning-by-doing. This will also be constrained at some point by resource depletion and pollution. The third engine is dematerialisation through the substitution of knowledge for resources, and is considered as “essential to permit sustainable future economic growth” (Ayres & van den Bergh, 2005: 101). Dematerialisation means to “add value to, and extend the useful life of, durable products while simultaneously reducing use of fossil fuels and other dissipative intermediates” and “includes reuse, renovation, remanufacturing, and recycling on various levels” (Ayres & van den Bergh, 2005: 101).

Empirical testing of the direction of causality in the energy-GDP relationship by way of time series models that do not specify a structural relation between these variables yield variable and sometimes conflicting results, depending on the selected country, time period and model specification (Stern & Cleveland, 2004: 26). Stern and Cleveland (2004: 28) argue in favour of a multivariate approach that includes other inputs (e.g. labour and capital) as well as energy prices, and adjusts for energy quality. Based on a review of the literature, Stern (2011: 27) finds that “energy and gross domestic product (GDP) cointegrate and energy use Granger causes GDP when capital and other production inputs are included in the vector autoregression model.”

Theoretical and empirical research by ecological and biophysical economists has highlighted several other important concepts that are neglected in the neoclassical approach to the energy-economy relationship. These concepts challenge the two fundamental assumptions of neoclassical resource economics, namely that technological change and factor substitution can always be relied upon to overcome resource scarcity (Cleveland, 1987).

First, it is not just the *quantity* of energy that counts, but also its *quality*: the amount of physical work obtained from a certain heating value (Ropke, 2004: 303; Cleveland et al., 1984). Energy quality depends on factors such as “energy density, cleanliness, amenability to storage, safety, flexibility of use, [and] cost of conversion”, and can vary over time (Stern & Cleveland, 2004: 23). According to Stern and Cleveland (2004: 23), “it is generally believed that electricity is the highest quality type of energy followed by natural gas, oil, coal, and wood and biofuels in descending order of quality.” Considerable economic advantage is conferred on societies that have access to high-quality energy sources (Cleveland, 2008; Odum, 1977).

Second, another crucial variable that partly determines energy quality is the energy surplus or net energy yielded by a process. Net energy is the difference between the energy inputs required to produce energy that is useful for economic activity, and the resulting energy outputs. For example, the production of oil requires investments in exploration and drilling equipment (which embody energy), labour and energy inputs (usually in the form of diesel and electricity). A related variable is energy return on investment (EROI),[26] which is defined as “the ratio of how much energy is gained from an energy production process compared to how much of that energy (or its equivalent from some other source) is required to extract, grow, etc., a new unit of the energy in question” (Murphy & Hall, 2010: 102). Over time, the EROI of fossil energy sources tends to decline as progressively more marginal sources (e.g. smaller and/or more remote oil and gas fields) and sources of lower quality are exploited (Cleveland, 2008). This in turn raises the costs of fossil energy over time (Gupta & Hall, 2011; Heun & de Wit, 2011).

Third, Hall et al. (1986) and Cleveland et al. (1984) demonstrated that increases in labour productivity and even technological change itself have been partially reliant on growing fossil energy use per worker. Ayres & Warr (2005) find that the neoclassical ‘Solow residual’ of technical progress mostly disappears for the US economy between 1900 and 1975 when a variable representing ‘useful

[26] Some authors use the equivalent term “energy return on energy invested” (EROEI), but the term EROI will be used henceforth following Murphy and Hall’s (2010) recommendation.

work' (or what they term 'exergy services') is included in the production function alongside capital and labour. In other words, the most important contribution to technical progress for most of the 20th Century appears to have come from enhanced efficiency in the conversion of exergy (potential work) to useful work. More specifically, Ayres & Warr (2005: 187) conclude that "[e]lectrification has been perhaps the single most important source of useful work for production of goods and services, and... the most important single driver of economic growth during the twentieth century."[27]

Fourth, increases in energy efficiency may result in a "rebound effect", whereby unanticipated behavioural responses by consumers results in increased consumption of energy services, either partially or even to greater extent than the initial efficiency-induced saving (Sorrell, 2010). The rebound may be a *direct* demand response to lower marginal costs of energy, or *indirect* responses on an economy-wide basis, for instance as faster economic growth or shifts in expenditures to more energy-intensive goods and services. Empirical studies of economy-wide rebound effects suggest that they are typically higher than 30% and sometimes greater than 100% (Sorrell, 2010: 3). The rebound effect therefore limits the potential for economic growth to be decoupled from energy consumption.

In summary, Stern and Cleveland (2004) and Stern (2011) argue that the relationship between energy and economic growth may be influenced by four factors, namely: (1) the degree of substitutability between energy and other factors of production; (2) technological innovations that improve energy efficiency; (3) changes in the mix of energy inputs towards higher quality fuels; and (4) the structure of production or output mix. The weight of evidence, according to Stern and Cleveland (2004), suggests that both substitution and technological change are subject to thermodynamic constraints, while changes in the composition (quality) of energy inputs are more important than shifts in production structure for explaining instances of declining energy intensity.

The predominant view in EE that there are biophysical limits to the growth in size of the economy and that modern civilisation is heavily dependent on finite fossil fuels leads to a strong emphasis on the issue of sustainability (Common & Stagl, 2005:8). Sustainability is a much-debated concept and there is no single definition accepted by all disciplines or paradigms. A representative EE perspective on sustainability, which is considerably broader than that of neoclassical economics, is provided by Goodland and Daly (1996: 1002-3), who differentiate among three types of sustainability. *Economic sustainability* is defined (as in mainstream economics) as the maintenance of human-made (and financial) capital. *Social sustainability* is the maintenance of social (or moral) capital and human capital (which includes health, education and nutrition). *Environmental sustainability* is defined as the maintenance of natural capital (which includes resources, environmental sinks and ecosystem services). It has three requirements, namely: (1) renewable resources must be harvested at a rate below their regenerative capacity; (2) non-renewable resources must not be depleted faster than renewable substitutes can be found; and (3) wastes and emissions must be kept within the absorptive capacity of the environment. This latter definition recognises the scarcity of natural capital.

A distinction can also be drawn between various degrees of sustainability, essentially depending on the degree of substitutability between the various types of capital listed above, especially natural and manmade capital (Goodland & Daly, 1996: 1006). 'Weak sustainability' requires that the total capital stock is maintained, irrespective of how it is composed in terms of the four different types of capital. This definition assumes a high degree of capital substitutability, and prevails in the neoclassical paradigm. 'Strong sustainability' requires keeping each type of capital intact separately,

[27] Since the 1970s, other factors – possibly investments in energy conservation and efficiency precipitated by the oil price shocks, and/or information and communications technology – have also made a significant contribution to value creation (Ayres & Warr, 2005).

and assumes that manufactured capital and natural capital are mostly complementary in economic production. This is the notion of sustainability generally advocated by ecological economists.[28]

Research methods

As noted in Section 1.2.1 above, ecological economics employs research methods from both economics and ecology. Ecological-economic modelling combines techniques from both disciplines, usually within a systems framework (see Costanza, 1996). Techniques drawn from ecology include systems modelling, ecological footprint analysis, and life-cycle assessment. The latter two tools are usually used for environmental impact analysis rather than to model energy/resource use and impacts. Biophysical economists who have studied the function of energy in the economy have in some cases used fairly standard macroeconomic models such as growth models (e.g. Ayres & van den Bergh, 2005; Ayres & Warr, 2005) and time series econometric techniques (e.g. Stern, 2000; Stern, 1993), but have explicitly included energy in these models. Other EE modelling methods include evolutionary models, thermodynamic models, neo-Austrian models, multi-criteria evaluation, agent-based models and input-output models (Proops & Safonov, 2004). The latter have been applied in particular to energy analysis.

Normative stance

In line with the foregoing definition of sustainability, ecological economics identifies three key social goals, namely: (1) an economically efficient allocation of resources (i.e. one that improves material living standards and quality of life); (2) a just distribution of wealth, both inter- and intra-generationally; and (3) an optimal scale of the economy relative to the ecological system (see, for example, Common & Stagl, 2005: 8; Daly & Farley, 2004; Daly, 2004). These three goals correspond to the three pillars of 'sustainable development', another term characterised by a long and on-going history of controversy and debate. The most frequently cited definition of sustainable development comes from the so-called Brundtland Report, which defined it as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). This definition, although politically acceptable, has been criticised as being too vague (Carvalho, 2001). Goodland and Daly (1996: 1002) see sustainable development as "development without growth in throughput of matter and energy beyond regenerative and absorptive capacities." The latter definition draws a key distinction between quantitative *growth* (in consumption of physical resources and production of wastes) and *development*, which is regarded as qualitative improvements in human life that do not necessarily require increased material consumption (see also Daly, 1996). Daly and Farley (2004: 64) contend that "[e]cological economics does not call for an end to economic development, merely to physical growth, while mainstream economists' definitions of economic progress confusingly conflate the two." Daly (1977: 17) has argued that the ultimate goal for society should be a 'steady state economy', i.e. "an economy with constant stocks of people and artefacts, maintained at some desired, sufficient levels by low rates of maintenance 'throughput"' that conform to ecological sustainability criteria. As regards energy specifically, the goals identified by ecological economics include energy conservation (Ayres & Warr, 2005: 199), raising energy efficiency and developing renewable energy to substitute for non-renewable fossil fuels.

Policies

Ecological economics assumes that there is a need for government policies to support the attainment of the foregoing goals. Markets are insufficient to guarantee sustainable development, for three reasons (Common & Stagl, 2005: 361; Daly & Farley, 2004: 426). First, markets do not always achieve allocative efficiency as a result of various types of failures (e.g. missing markets and

[28] Goodland and Daly (1996: 1006) also define "intermediate sustainability", which requires definitions of critical levels of each form of capital that are difficult to determine practically, and "absurdly strong sustainability," in which no resources would be depleted at all.

imperfect or asymmetric information). Second, efficiency does not necessarily imply inter- or intra-generational equity. Third, allocatively efficient prices do not ensure that the scale of the economy will be sustainable. That is, market forces do not have a good record when it comes to preserving environmental resources and limiting pollution (see Christensen, 1989: 33). Ecological economics therefore sees a need for policies that address market failures, redistribute income and wealth so as to reduce poverty and achieve greater equity, and enhance ecological sustainability (Daly & Farley, 2004: 427; Greenwood & Holt, 2008). In addition, ecological economics recognises pervasive uncertainty in both science (nature) and economics and therefore advocates the use of the precautionary principle, which states that "where the environmental consequences of regulatory inaction are (1) in some way uncertain/ambiguous but (2) non-negligible, regulatory inaction is unjustified" (Common & Stagl, 2005: 389).

Policy instruments advocated by ecological economists can be grouped into three categories (Common & Stagl, 2005). The first group are market-based interventions that alter the economic incentives facing individuals and firms. These include taxes (e.g. on carbon or other emissions), subsidies (e.g. for 'clean' technologies or renewable energy) and tradable permits. The second category comprises non-market regulations, otherwise known as 'command-and-control' instruments, which prescribe and proscribe certain behaviours or activities. Examples are legal quantitative restrictions (e.g. quotas for harvesting natural resources or for emissions and wastes), technical standards (e.g. for vehicle efficiency or emissions), and restrictions on the location of polluting activities. The third category of policy instruments is termed 'moral suasion', which involves the provision of relevant information and appeals to individuals' sense of what is right so that they make appropriate personal choices. Examples include public awareness campaigns and educational programmes conducted through various media and schools, eco-labelling (product labels that alert consumers to environmental impacts), and support for research and development. Ecological economists recognise that uncertainty (e.g. in terms of changing circumstances or outcomes) clouds the choice of appropriate policy instrument for achieving a given objective (Common & Stagl, 2005: 435). Moreover, there are often trade-offs among the various criteria used to select policy instruments.

1.2.3 Evaluation of ecological economics

From the point of view of understanding the implications of global oil depletion, ecological economics has many advantages relative to neoclassical economics. At the methodological level, EE is explicitly transdisciplinary in its approach as it combines economic and ecological concepts and analytical techniques. It is also equipped to deal with complex systems and sustainability is a central concern. Sneddon et al. (2006: 254) argue that EE, through its pluralistic and transdisciplinary approach, could help to take the world closer to achieving sustainability. Although EE has been criticised for possible vagueness in its methodological pluralism, this approach is arguably appropriate for tackling the broad nature of this dissertation's central research question. Similarly, EE includes a varied toolkit of research methods and analytical tools, including systems-oriented models that can explicitly incorporate energy.

At the conceptual level, a major advantage of ecological economics (and especially its subset, biophysical economics) is that it treats energy as absolutely fundamental to socioeconomic systems. As it is founded on physical principles and laws, EE provides a realistic assessment of the role played by energy. Furthermore, EE highlights important concepts such as energy quality, energy surplus, the "rebound effect", and the relationship between energy on the one hand and other factors of production (capital and labour) as well as technology on the other hand. However, one possible criticism of EE is that it gives insufficient attention to the role of knowledge and institutions in economic development (Greenwood & Holt, 2008), and may be too pessimistic regarding technology (Costanza, 1989).

A further strength of EE is that it generally makes value judgements and normative goals explicit, rather than assuming they are irrelevant or leaving them implicit. Moreover, the goals identified by EE are sufficiently broad, recognising economic, social and environmental aspects and highlighting the central importance of sustainability. Possible conflicts or tradeoffs between the various goals are however acknowledged. The role advocated for government policies in ecological economics is consistent with its analysis of how socioeconomic systems function and the limitations of markets. The policy framework provided by EE incorporates a wide range of measures that take into account the various goals mentioned above.

All in all, the perspectives, concepts and techniques of ecological economics are highly relevant to the topic of this dissertation. However, EE does not provide a complete understanding of the role of fossil fuels on its own, which is why an additional approach is considered below.

1.3 Socioecological Systems

The third conceptual approach to the energy-economy relationship considered in this dissertation may be termed the analysis of "socioecological systems" (Fischer-Kowalski & Haberl, 2007b), abbreviated here as SES.[29] Section 1.3.1 characterises the approach in terms of its intellectual history, disciplinary foundations, subject matter, aims, ontology and normative position. Section 1.3.2 examines the SES approach to the role played by energy. Section 1.3.3 highlights the advantages and limitations of the SES framework relative to the central research question.

1.3.1 Characterisation of socioecological systems analysis

The analysis of socioecological systems is a relatively new research approach although it draws on various intellectual traditions and theories dating back at least as far as 1860 (Fischer-Kowalski, 1998). Since the early 1990s this approach has been developed and applied principally by European researchers and especially by a group of scholars based at the Institute for Social Ecology at Klagenfurt University in Vienna, Austria (Fisher-Kowalski & Haberl, 2007b; Fischer-Kowalski & Huttler, 1999). It has been gaining in popularity quite rapidly since the turn of the millennium. The disciplinary foundations of the SES approach are not restricted to any one field. Scholars working in this area have backgrounds *inter alia* in economics, ecology, sociology and industrial ecology, and have tended to publish articles in journals such as *Ecological Economics* and the *Journal of Industrial Ecology*. It is not yet clear whether SES analysis represents a paradigm in its own right; the approach is possibly too young, and its practitioners too few, to be considered as such at this stage.

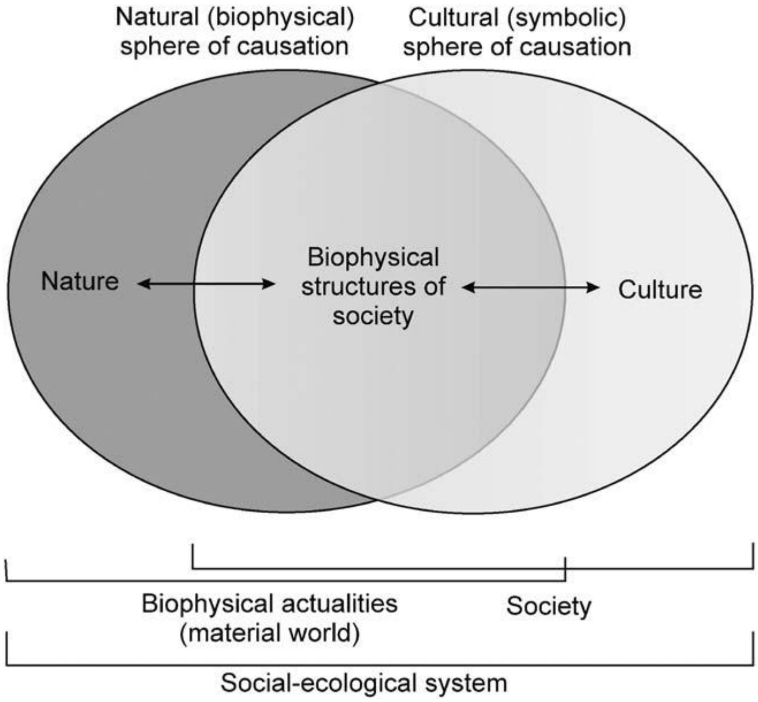
In terms of subject matter, at its broadest level the SES approach studies the interactions between human societies and nature.[30] In the words of Fischer-Kowalski and Amann (2001: 12), "we are interested in examining socioeconomic systems (such as national economies) as systems that reproduce themselves not only socially and culturally but also physically through a continuous exchange of energy and matter with their natural environments and with each other." Social-ecological systems have been defined as "comprising a ''natural'' or ''biophysical'' sphere of

[29] An equivalent label, apparently used in earlier writings, is "social-ecological systems" (Haberl, Fischer-Kowalski, Krausmann, Weisz & Winiwarter, 2004). Henceforth, the two terms will be treated synonymously.

[30] In addition to its subject matter, the SES approach is perhaps best characterised by its dominant research method, namely material and energy flow analysis (MEFA), which is discussed more fully in the next section once the relevant terminology and concepts have been defined.

causation governed by natural laws, and a ''cultural'' or ''symbolic'' sphere of causation reproduced by symbolic communication" (Haberl et al., 2004: 201). This is represented schematically in Figure 1-3. Alternatively, a "social-ecological system emerges through the interaction of a society with its natural environment" (Haberl et al., 2004: 201).

Figure 1-3: Social-ecological systems as the union of natural and cultural spheres of causation



Source: Haberl et al. (2004: Figure 1).

Society is further defined as "a social unit functioning to reproduce a human population within a territory, guided by a specific culture" (Fisher-Kowalski & Haberl, 2007b: 9). Society "comprises both a cultural system, as a system of recurrent self-referential communication, and material components; a certain human population; and... a physical infrastructure (buildings, machines, artefacts in use and animal livestock)" (Fisher-Kowalski & Haberl, 2007b: 11). The whole collection of human and physical infrastructure is termed ''biophysical structures of society'' (Haberl et al., 2004: 201) or "bio-physical compartments of socioeconomic systems" (Fischer-Kowalski & Amann, 2001: 13). Culture interacts with nature through these biophysical compartments or structures. According to this perspective, societies possess emergent properties and cannot be viewed as subsets of ecosystems (Fisher-Kowalski & Haberl, 2007b: 12), as is the case in ecological economics. Society-nature relations are viewed as being co-evolutionary: society changes nature and these changes stimulate changes in society (Fisher-Kowalski & Haberl, 2007b: 13-14). Society reproduces its population "by interacting with natural systems, by organizing energetic and material flows from and to its environments, by means of particular technologies and by transforming natural systems through labour and technology" (Fisher-Kowalski & Haberl, 2007b: 14).

Broadly speaking, then, the main aim of the SES approach is to understand how societies and nature interact. More specifically, it seeks to understand how energy and materials flow between nature and human society. Research in this tradition often has an agenda of promoting sustainable development (Fischer-Kowalski and Huttler, 1999: 123).

The ontological position adopted by researchers using the SES approach appears to be realist, i.e. an objective reality is assumed to exist independent of the human mind. The conception of reality is holistic rather than reductionist, as evidenced by the interacting systems approach. The epistemological stance has not been explicitly elucidated, but appears to be consistent with that of ecological economics, i.e. mildly relativist. The methodology employed by the SES approach is explicitly interdisciplinary and transdisciplinary, since it draws on concepts and methods of both natural and social sciences, including (but not limited to) ecology, economics, sociology, anthropology and history.

In the SES approach, society-nature interactions are generally viewed from the vantage point of (1) how human societies use nature to meet their needs and (2) what impact humans have on nature. Thus the implicit normative position weighs more heavily on an anthropocentric rather than a biocentric perspective. As mentioned previously, sustainability is often regarded by scholars working in the SES tradition as an important social goal. Thus far, much of the literature in this area does not take a strong stand on issues such as social equity, redistribution of wealth, and so on. The concern lies more with describing the nature and functioning of socio-ecological systems.

1.3.2 Socioecological systems approach to the role of energy

In the social-ecological systems literature, energy is conceived of chiefly as a particular category of physical resource, which is generally measured in tonnes (of fossil fuels and biomass) or in energy units (joules). This section explores the key concepts, analytical tools, normative prescriptions and policy recommendations of the SES approach in respect of the role of energy in socioeconomic systems.

Key concepts

The socioecological systems approach employs several key concepts, including: societal metabolism; socioecological regimes and modes of subsistence; and transitions between regimes or modes. The flows of energy and materials utilized by societies are absolutely fundamental to the SES approach. These flows also provide the basis for its conception of sustainability, which raises issues such as "decoupling" of energy/material use from economic growth and "dematerialisation" of economic processes. All of these concepts are defined and elaborated upon in this section.

One of the fundamental notions of the SES approach is that any society (or, equivalently, socioeconomic system) has a 'metabolism'.[31] The notion of metabolism originated within biology in the 1860s and was soon applied within various social sciences (Fischer-Kowalski, 1998: 62-63). In biology and ecology, the concept of metabolism has been conventionally applied from the level of cells up to individual organisms, but application of the concept further up the scale hierarchy – to communities of organisms – has been debated, primarily between 'holistic' and 'reductionist' camps, with the former being in favour of the generalisation and the latter against it (Fischer-Kowalski, 1998: 63).

Fischer-Kowalski (1998) reviews the development of research on societal metabolism from the 1860s to 1970, tracing the origins of metabolism in the social sciences from pioneering thinkers such as Marx and Engels, Herbert Spencer and Sir Patrick Geddes, to more recent ecological anthropology and social geography. A cultural revolution in late 1960s permitted a critical stance on economic growth as well as consideration of the environment, with some new studies focusing on flows of materials and energy between society and nature. One early example was Boulding's (1966) contrast

[31] The terms "socioeconomic metabolism," "society's metabolism" and "societal metabolism" are treated as equivalent and interchangeable (Fischer-Kowalski and Huttler, 1999:108).

between a “cowboy economy” versus “spaceship Earth” and his argument that the quantity and quality of the total (physical and human) capital stock was more important than production and consumption. According to Fischer-Kowalski (1998: 73), a seminal contribution to the development of material flow analysis (MFA) was provided by Ayres and Kneese’s (1969) model of the socioeconomic metabolism of the United States, which “not only set up an appropriate conceptual framework, but also arrived at reasonable empirical results”. Nevertheless, it was another two decades before “this paradigm and methodology became widely recognized as a useful tool” (Fischer-Kowalski, 1998: 73).

When applied to human society, the term metabolism has to bridge a gulf between the natural sciences and the social sciences or humanities. For human societies, “the concept of metabolism needs to be expanded to encompass material and energetic flows and transformations associated with “living things” but extending beyond the anabolism and catabolism of cells” to include, for example, buildings, infrastructure, etc. (Fischer-Kowalski, 1998: 63). Put simply, socioeconomic metabolism “refers to the sum total of the material and energetic flows into, within, and out of a socioeconomic system” (Fischer-Kowalski & Amann, 2001: 12). The function of socioeconomic metabolism is twofold: it “serves (a) to produce and reproduce the biophysical structures of the socioeconomic system in exchange with the natural environment, and (b) eventually to produce or consume deliverables from other socioeconomic systems” (Fischer-Kowalski & Amann, 2001: 12-13).

In the literature the concept of socioeconomic metabolism has most commonly been applied to industrial societies. According to Fischer-Kowalski (1998: 62), research into industrial metabolism has blossomed since the pioneering studies were undertaken in the 1960s, although the term itself was introduced relatively recently in Ayres and Simonis (1994). Industrial metabolism highlights the flows of energy and materials in modern industrial societies “through the chain of extraction, production, consumption, and disposal” (Fischer-Kowalski, 1998: 62). Expressed in biological nomenclature, “industrial systems are characterized by uptake, transformation, storage, recycling, and excretion of materials” (Bringezu et al., 2003: 44). The industrial metabolism is, according to Schiller (2009: 1677), an example of a dissipative structure that relies on and irreversibly degrades flows of materials and energy, and as such can be described as “emergent, complex, irreversible and hierarchical.” Fischer-Kowalski and Huttler (1999: 119-120) identify several problems with the industrial metabolism, including the exhaustion of resources such as fossil fuels, minerals and metals, as well as pollution, entropy, the scale of metabolic throughput, and the need for closing open cycles (or recycling). In the long term, a sustainable metabolism must rely mostly on renewable resources (Bringezu et al., 2003: 60).

Industrial metabolism is just one possible type of societal metabolism that forms part of a specific form of social organisation and resource use. Two closely related, broader concepts are modes of subsistence and socioecological regimes. Fisher-Kowalski & Haberl, 2007b: 8; 14) define a *socioecological regime* as “a specific fundamental pattern of interaction between (human) society and natural systems” that persists “in a more or less dynamic equilibrium over long periods of time.” Haberl et al. (2004: 201) define *modes of subsistence* as “ideal types of qualitatively different societal organization with respect to resource use, population growth, economic institutions, etc.”, while social-ecological regimes are understood as “the basic features of social-ecological systems typically related to a specific mode of subsistence.” The latter distinction lacks clarity, and in fact the two terms appear to be used almost interchangeably by the leading scholars in this field in their various publications. Drawing on literature in economic history, sociology and anthropology, Haberl et al. (2004: 201) identify three historical modes of subsistence, namely hunter-gatherer, agrarian and industrial societies. The identical labels are used by Fisher-Kowalski and Haberl (2007b: 14-16) to distinguish three historical socioecological regimes. A brief description of the characteristic features of each mode of subsistence (or socioecological regime) provides a useful overview of the key differences in socioeconomic metabolism – i.e. differences in the patterns of use of materials and energy – which in turn can provide an indication of which resources are central in each case (Haberl et al, 2004: 202).

The hunter-gatherer mode relies on passive solar energy, which is captured via photosynthesis in plant biomass, without intentional intervention by humans in the energy conversion process (Sieferle, 2003 in Fisher-Kowalski & Haberl, 2007b: 15). These societies are therefore limited in their population size and their ability to accumulate possessions (and to pollute their surroundings) by the available resource density. The form of social organisation thus consists mainly in nomadic bands and small tribes possessing very few artefacts and having very little division of labour.

Agrarian societies are based on 'active solar energy utilisation', which involves deliberate intervention by humans in the process by which solar energy is transformed, using biotechnologies and mechanical devices (Fisher-Kowalski & Haberl, 2007b: 15, citing Sieferle, 2003). Land-based ecosystems and the organisms they contain are transformed or exploited in such as way as to yield the maximum utility for humans. Agriculture and forestry are the major sources of the primary energy needed to meet humans' needs and must generate a positive net energy balance (or, equivalently, an energy return on investment ratio greater than unity) (Fischer-Kowalski, Haberl & Krausmann, 2007).

Fischer-Kowalski et al. (2007) describe several other characteristic features of the agrarian socioecological regime. First, although there is greater division of labour than in hunter-gatherer societies, it is limited by the need for the bulk of the population (typically 80-90 per cent) to be engaged in agriculture and forestry to produce a surplus to sustain the non-agricultural population. This need also ties most of the population to the land and thus constrains the size of urban settlements. Second, the location of settlements (and non-agricultural production) is influenced by topography and transport options. In general, the costs of transport are high and long-distance transport of heavy or large materials can only be accomplished by water-based transport. Third, these constraints on energy and transport imply that usage of materials is much lower and more localised than in industrial societies – although higher and more widely spread than in hunter-gatherer societies. Consequently, local agrarian socioecological systems are "largely self-contained and self-sufficient" (Fischer-Kowalski et al., 2007: 229). Fourth, agrarian systems are dynamic, not static. Typically, innovations in agricultural techniques raise the productivity per unit of land, but at the same time drive population growth so that agricultural productivity per capita may not rise appreciably (Fischer-Kowalski et al., 2007: 241). This was a central issue for classical economists such as Malthus, Ricardo and J.S. Mill, who saw economic growth as a transient phase ending in a 'steady state' (see Schandl & Krausmann, 2007: 102).

In terms of long-term sustainability, agrarian societies have "always struggled, with varying degrees of success, to maintain the delicate balance between population growth, agricultural technology, labour force needed to maintain the productivity of agro-ecosystems, and the maintenance of soil fertility" (Fisher-Kowalski & Haberl, 2007b: 15). This struggle for balance implies perpetual risk for individual agrarian societies, but nevertheless the regime has endured from about 10,000 years ago till the present.

The industrial socioecological regime, which began less than 300 years ago, is based energetically on the exploitation of fossil fuels (Fisher-Kowalski & Haberl, 2007b: 16). Fossil fuels have several special qualities: they are energy dense and were relatively abundant on a global scale, and they can be readily stored and transported. These characteristics "allowed the development of new transport systems with far-reaching consequences for the spatial organization of societies." (Krausmann & Haberl, 2007: 53) The utilization of fossil fuels broke the shackles on growth inherent in the active solar agrarian regime and permitted a huge increase in both population size and the rates of material and energy consumption per person (Schandl & Krausmann, 2007: 108). Fossil fuels considerably boosted agricultural productivity, and together with new transport technologies this resulted in a rapid and extensive process of urbanisation as well as unprecedented division of labour (Fischer-Kowalski et al., 2007: 245). However, the finiteness of fossil fuels, together with their polluting properties, implies that the industrial socioecological regime is unstable and unsustainable in the long term (Schandl & Krausmann, 2007: 112; Haberl et al., 2004: 203; Krausmann & Haberl, 2007: 54). This raises the question of what comes next. Fisher-Kowalski & Haberl (2007b) suggest the possibility of a future 'sustainable' regime to follow the industrial regime, but they do not describe what this might entail.

Fisher-Kowalski & Haberl (2007b: 8) define a socioecological transition simply as "a transition from one socioecological regime to another." In their conception, a transition "lies between two qualitatively distinct states, and that no linear, incremental path leads from one state to the other but rather a dynamic, possibly chaotic process of change." (Fisher-Kowalski & Haberl, 2007b: 3). The notion of growth or modernization – much favoured by neoclassical economics – implies gradual change within the same "basic setting", while transition implies discontinuities and a change in the basic setting. Transitions are sometimes subdivided into take-off, acceleration and stabilisation phases and can occur on timeframes from decades to centuries (Fisher-Kowalski & Haberl, 2007b: 8).

Transitions between regimes or modes "may be driven by a host of socioeconomic and natural factors such as climate change, extinction of key species, resource availability, cultural change, demography, etc." (Haberl et al, 2004: 201). According to the developmental stages conception, "transitions occur according to an endogenous process and the built-in dynamics of the system itself", while Darwinian evolutionary models assume "the future to be contingent upon the past, yet principally unpredictable" (Fisher-Kowalski & Haberl, 2007b: 5-6). Two socioecological transitions have occurred thus far in human history: the so-called Neolithic Revolution from hunter-gatherer to agrarian; and the Industrial Revolution (Fisher-Kowalski & Haberl, 2007b: 14).[32] An analysis by Fischer-Kowalski et al. (2007) of the nature of agrarian-industrial transitions, based on the various case studies documented in their edited volume, provides important insights into the role of fossil fuels.

As already mentioned, the exploitation of fossil fuels, which represent a very large store of accumulated solar energy, overcame the temporal limits of the solar energy based regime, which according to Fischer-Kowalski et al. (2007: 235) "could never have been overcome by technological innovations based on human ingenuity alone." The fossil energy system of industrial societies boosted consumption of materials and energy per person by factors of 3-5, while consumption per area unit increased much more – by factors of 15-25 – since rapid population growth accompanied the transition (Fischer-Kowalski et al., 2007: 232). The transition process initially involved the "formation of a 'growth engine' based on the technology complex of coal, iron and railroads plus abundantly available human labour", while later on an "advanced growth engine based on oil, electricity and related technologies and infrastructures such as the internal combustion engine, electrical engines, cars, electrical appliances and an extensive road system" emerged (Fischer-Kowalski et al., 2007: 233).

Two notable lessons can be drawn from historical transition experiences (Fischer-Kowalski et al., 2007: 239). First, late-comers may benefit from technology and their transition process can be faster and easier than it was for the pioneer. Second, the proportion of the population involved in agriculture correlates quite closely with the share of fossil fuels in total energy use. The transition

[32] Fisher-Kowalski & Haberl, (2007b) consider the important question of why these transitions took place to be beyond scope of their book.

from an agrarian to an industrial regime is still under way – at different stages for different countries - for at least two thirds of the global population (Fischer-Kowalski et al., 2007: 223). Some regions (e.g. South America) are following a resource-intensive path, while others (e.g. East Asia) are pursuing a labour-intensive development trajectory (Eisenmenger, Martin and Schandl, 2007). However, Eisenmenger et al. (2007) stress the role of the international context in shaping the transition path followed by individual countries, especially in recent years. In the future, the availability of cheap energy and minerals is no longer assured or even likely (Fischer-Kowalski et al., 244), so that countries in the early stages of transition to the industrial regime might experience constraints or even be unable to complete this transition (see Heun & De Wit, 2011).

For countries that have already industrialised, the question is whether and how they will make another transition – perhaps to a 'sustainable' socioecological regime. Because of the apparent unsustainability of the industrial mode, Fisher-Kowalski and Haberl (2007b: 8) argue that such a transition "appears as the only plausible alternative to chaotic and possibly catastrophic developments of history."[33] Furthermore, it would not be assumed to occur automatically, but rather would require "deliberative human agency". They suggest further that "sustainability may involve guiding this transition within a corridor of acceptable quality of life, for present and future human generations" (Fisher-Kowalski & Haberl, 2007b: 16).

The conception of sustainability, which is clearly a key concern in the SES literature, requires some elaboration.[34] In general, sustainability in the SES view requires reducing flows of nonrenewable resources, stabilising flows of renewable resources and reducing outflows of wastes (Haberl et al., 2004). According to Bringezu et al. (2004: 98), for a socioeconomic metabolism to become more sustainable will require "detoxification (pollution abatement and chemicals control), dematerialization (through increased resource efficiency) and a shift to renewable resources (through increased consistency of man-made and natural flows and stocks)." It is also recognised that the "accumulation of socioeconomic stocks results in future flows needed to maintain or use these stocks (Huttler et al., 2001) and, thus, may also compromise a society's options to reduce its future resource consumption" (Haberl et al., 2004: 206). In the case of oil, for example, if more and more internal combustion vehicles are produced, it locks society into further dependence on oil. Furthermore, Haberl et al. (2004: 206) point out that "once a society derives a large proportion of vital inputs from colonized systems, it becomes dependent on its own ability to properly manage these systems and to counteract any unforeseen and unintended effects."[35] An example is industrial agriculture, which requires ever-increasing use of fossil fuel based fertilisers and pesticides, and degrades the land at the same time, potentially setting the stage for a rapid decline in productivity when fossil fuels become scarcer and more expensive.

In terms of the three historical socioecological regimes, it would appear that – at least in terms of resource and energy use and environmental impact – sustainability has been declining with successive transitions. A transition from the industrial socioecological regime to a sustainable regime

[33] Fischer-Kowalski et al. (2007) do not draw too many lessons about the next ('sustainability') transition, nor do they provide any data about how much fossil fuels might be left, but they make strong claims about the transience of the industrial regime because of such scarcity. The issue of how much fossil fuels remain is the main focus of Chapter 2 of this dissertation, while a key question addressed in later chapters is what role the depletion of oil reserves might play in forcing another socioecological transition – if not regression.

[34] Haberl et al. (2004: 203) claim that "[w]hile a conclusive, comprehensive definition of sustainability is not possible at the moment, we have established that observing progress towards (or further departure from) sustainability requires the analysis of social-ecological systems."

[35] Colonisation "refers to society's deliberate interventions into natural systems in order to create and maintain a state of the natural system that renders it more useful socially" (Fisher-Kowalski & Haberl, 2007b:18, citing Fischer-Kowalski and Weisz, 1999).

could involve, according to the SES literature, three types of "decoupling" or "delinking" (Haberl et al., 2004: 208). First, economic growth must be decoupled from material and energy throughput. This is known as "dematerialisation". Second, material and energy throughput could be decoupled from social well-being. This is termed "sufficiency". The third type of decoupling is between social well-being and economic growth, and involves improving "equity".

The most commonly discussed type of decoupling is dematerialisation, which involves both a reduction of material and energy throughput below carrying capacity as well as a reduction of the environmental impact (Schiller, 2009: 1678; Bartelmus, 2003: 68). One way to achieve dematerialisation is through technological improvements that reduce the material intensity of production, or equivalently, raise material productivity (Fischer-Kowalski & Amann, 2001: 17). As Bartelmus (2003: 69) points out, "[t]he critical question is *how much* dematerialization do we need to attain ecological sustainability of economic activity?" This question has yet to be answered. Moreover, an important distinction needs to be drawn between absolute and relative dematerialisation (or decoupling). According to Behrens et al. (2007: 445), "Absolute dematerialisation, also referred to as strong dematerialisation, occurs when total material input to an economy decreases in absolute terms. Relative dematerialisation, or weak dematerialisation, refers to a decrease in the intensity of use, requiring the ratio between material input and GDP to fall over time."

Relative dematerialisation does not necessarily imply absolute dematerialisation (Bartelmus, 2003: 73). For example, there is some empirical support for relative but not absolute dematerialisation for the US, UK, Germany, Japan, Netherlands and Austria, due mainly to structural changes in these economies, but also to some degree from deliberate policies aimed at reducing material intensity (Fischer-Kowalski & Amann, 2001: 18-20). Apart from one isolated instance, "no absolute decline of direct material input of industrial economies took place" in the sample considered by Bringezu et al. (2004: 99). An important caveat is that some countries that have experienced relative dematerialisation have done so via "burden shifting", whereby the intensive use of energy and materials, as well as environmental impact, is shifted to foreign regions (Bringezu et al, 2004: 121).

The SES literature makes it clear that relationship between material and (fossil) energy use and affluence is not straightforward. For example, Bringezu et al. (2004: 117) find for a large sample of countries that the "share of fossil energy supply in TMR [total material requirement] did not correlate with GDP... The metabolic performance of the energy supply can obviously vary significantly, and there is neither a unique pattern nor fixed relation with regard to economic growth." Thus "a high resource requirement is no prerequisite of economic wealth and prosperity is possible also at relatively low resource requirements" (Bringezu et al, 2004: 121). Similarly, according to Fischer-Kowalski & Amann (2001: 37), per capita affluence (in monetary terms, usually GDP) is not always directly linked to material comfort (e.g. basic needs being met).

Another important set of concepts that have been developed within the socioecological systems approach are the notions of resilience, adaptability and transformability.[36] Resilience has been defined as "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" (Walker, Holling, Carpenter & Kinzig, 2004: 5). Adaptability in a SES is "the collective capacity of the human actors in the system to manage resilience" (Walker et al., 2004: 5). Resilience is not necessarily desirable; in certain circumstances and at certain scales, managed change is preferable. This leads to the concept of transformability, which is defined as "[t]he capacity to create a fundamentally new system when

[36] The term 'resilience' was introduced in the context of ecological systems by Holling (1973), and has subsequently been applied in the study of linked social-ecological systems as well as within ecological economics.

ecological, economic, or social (including political) conditions make the existing system untenable" (Walker et al., 2004: 5). Examples of transformative changes in the history of human civilisation include the agrarian and industrial revolutions. These three concepts are highly relevant to understanding the impact and mitigation of energy shocks: how can societies and communities increase their resilience (i.e., adapt) to more expensive and scarcer oil, and how can they transform their socioeconomic systems to be less dependent on this energy source?[37] These questions are explored in detail in Chapter 6.

Research methods

The SES literature employs two main research methods or analytical tools, one broad and one quite specific. The broader method is the analysis of social and environmental history, which draws upon and overlaps with the techniques of various social science disciplines including history, sociology, anthropology and economic history. This method underpins the conception of different socioecological regimes, and transitions from one regime to another. The second, more specific method is materials and energy flow analysis (MEFA).[38] In fact, this technique is a defining feature of much of the research falling within the SES conception. According to Haberl et al. (2004: 200), "[t]he MEFA framework analyses important aspects of society–nature interaction by tracing socio-economic materials and energy flows and by assessing changes in relevant patterns and processes in ecosystems related to these flows". Alternatively, MEFA "can be regarded as a set of methods for describing and analyzing socioeconomic metabolism" (Fischer-Kowalski & Amann, 2001: 12). Fischer-Kowalski and Huttler (1999: 111) provide a system for classifying MEFA studies. First, MEFA can operate at various *levels*, namely global (the anthroposphere and geo-biosphere), national, regional and functional (e.g. firm, household, or sector). In each case the units are social systems, i.e. they are "integrated by social and economic organization." Second, MFA can focus on *flows* of matter, energy, or substances, and on input materials, output materials, or both. Third, the *time horizon* could be a contemporary point in time, a time series or a long-range historical perspective (e.g. comparing industrial, agrarian, hunter-gatherer metabolisms). MEFA quantifies in unweighted mass units both resource use (inputs) and emissions (outputs) (Fischer-Kowalski & Amann, 2001: 13). A major drawback is that it does not differentiate the quality of different materials or energy sources; for example, a ton of oil contains more usable energy than a ton of coal and is more versatile. As will be discussed in Chapter 2, a range of quality characteristics of alternative energy sources are vital to the significance and implications of oil depletion.

Normative stance

Applications of the SES and MEFA approach have for the most part focused on objective analyses of material and energy flows and the nature of socioecological systems and transitions. Normative discussion of social goals has been rather limited, perhaps partly because the approach is still regarded as being in its infancy. Nevertheless, as mentioned previously, sustainability is a key concern in this field. In particular, an important goal for industrial societies is seen to be a successful transition to a 'sustainable' socioecological regime. As already noted, this would require reductions in both material/energy consumption and environmental impact, possibly via improved resource productivity. Fischer-Kowalski et al. (2007: 249) round off their seminal volume with their conviction

[37] The terms mitigation and adaptation as applied to oil depletion are explicated in the introduction to Chapter 5.

[38] The use of terminology in this literature is somewhat confusing. MEFA sometimes refers to "materials and energy flow *accounting*" (e.g. Haberl et al., 2004: 200) and other times to "materials and energy flow *analysis*", although these terms appear to refer to the same set of techniques. Furthermore, there are subsets of the MEFA approach, namely materials flow analysis (MFA) and energy flow analysis (EFA). However, some studies using the term MFA include both material and energy flows (e.g. Bringezu et al., 2003; Behrens et al., 2007). The following discussion refers to MEFA in general, unless specifically stated otherwise.

that "finding a path towards more sustainable solutions requires a vision and determined political efforts". This raises the issue of the means or policies required to achieve greater sustainability.

Policies

As in the case of the normative goals, discussion of specific policy recommendations is sparse in the SES literature thus far. The main policy avenues suggested by Fischer-Kowalski et al. (2007) are global climate policy, restricting material consumption in the industrial core, the creation of new infrastructure requiring less energy and materials, and the protection of pristine wilderness areas. Similarly, Bringezu et al. (2004: 122) argue that "future dematerialization of economies may not be expected from business as usual under current conditions, but will require synergistic changes in policy and industry". Several policies aimed at altering economic incentives and imposing certain regulations are proposed in some studies. These include "economic measures such as ecological fiscal reforms (e.g. material input and energy taxes), reforms of the subsidy systems (e.g. temporary support for development of new eco-efficient technologies and materials), certificates trading systems, and eco-efficient public procurement" (Behrens et al, 2007: 450). Behrens et al. (2007: 450) further recommend that "[f]ocussing on key sectors that are either directly (e.g. mining, agriculture, fisheries) or indirectly responsible for large amounts of natural resource extraction (e.g. energy, transport, and industry) will benefit the efficiency of the selected mix of instruments."

1.3.3 Evaluation of socioecological systems approach

The SES approach has both advantages and limitations in terms of its methodology, conceptual content, normative goals and policy recommendations. At the methodological level, one of the greatest strengths of SES analysis is its holistic and transdisciplinary treatment of complex social, economic and ecological systems. Another advantage of SES is that it has an explicit focus on understanding the role of energy flows in sustaining socioeconomic systems and it deals explicitly with sustainability issues. It also provides a number of very useful concepts that are not found in other fields. For example, concepts such as socioeconomic metabolism and socioecological regimes and transitions provide a long-run perspective on the energy-economy relationship. They make it clear that the depletion of oil (and other fossil fuels) implies that another transition beyond the industrial regime is inevitable. Also, given what is known about other non-fossil energy sources, it is possible to develop at least a preliminary idea of what a post-oil, renewable energy-based socioeconomic system might look like. Despite the focus on sustainability issues, a significant limitation of the SES approach is that normative issues, goals and policy recommendations receive relatively little explicit treatment in the literature to date.

The analytical tools employed by the SES approach are another useful contribution. First, historical analysis provides a long-run context for the role of energy in socioeconomic systems. Second, MEFA includes an explicit and quantitatively rigorous treatment of energy flows through socioecological systems. Although MEFA is broader than is required for the purposes of this dissertation in that it can potentially include all major materials and energy sources, it is possible to limit the focus of the framework to one type of energy (e.g. oil). However, applications of MEFA to date appear to be focused mainly on environmental impacts rather than on the impacts of energy/material resource depletion on socioecological systems. Other limitations include insufficient attention given to the role of prices, insufficient treatment of qualitative aspects of energy and net energy, and a high level of aggregation.

In summary, the SES approach is not sufficient in itself to adequately understand the implications of global oil depletion, but it nonetheless provides a valuable long-term historical context as well as several useful concepts and analytical techniques.

1.4 Conclusions

The aim of this chapter was to review and evaluate several fields of study or conceptual frameworks that may be appropriate for addressing the central research question of the dissertation, namely: what are the socioeconomic implications of global oil depletion for South Africa? Three theoretical approaches to understanding the role of energy in socioeconomic systems were selected: neoclassical economics; ecological economics; and the analysis of socioecological systems. This concluding section provides a comparative evaluation of the three approaches, a synthesis of methods and concepts, and an indication of how this synthesis will be applied in subsequent chapters. Several criteria were selected for the evaluation. On a methodological level, the approach should involve a holistic, systems-oriented and transdisciplinary perspective in order to meaningfully understand the complex societal problem of oil depletion and the challenge this poses for sustainability. On a conceptual level, the approach must provide a realistic assessment of the energy-economy relationship and be able to inform relevant policies on the basis of explicit normative judgements.

To begin with there are substantial differences, as well as some similarities, in the philosophical and methodological orientations of the three approaches (these are summarised in Table 1-1). All three approaches depart from an ontological assumption that an objective reality exists (in contrast for instance to the extreme post-modern position, which denies the existence of an objective reality). However, NE has a reductionist conceptualisation of that reality, believing it can be understood in terms of its disaggregated components, while EE and SES share a holistic notion of reality, recognising that it is comprised of complex systems with emergent properties that cannot be reduced to individual parts. EE and SES are explicitly concerned with the functioning of interacting, complex socioeconomic and ecological systems. Further, NE adheres to a monistic epistemology (there is one correct way of gathering knowledge) and is strongly disciplinary. By contrast, EE and SES both favour methodological pluralism and a transdisciplinary approach to knowledge acquisition. In terms of the foregoing evaluative criteria, therefore, EE and SES are methodologically more suitable than NE, which is restricted by its modernist and monist approach. This dissertation therefore follows EE and SES in adopting a transdisciplinary and pluralistic methodology and conceives of the socio-economy holistically as a complex system.

When it comes to normative issues, all three frameworks adhere to a consequentialist, utilitarian and anthropocentric position, although this is arguably stronger in neoclassical economics than in the other two fields. A key difference is that NE upholds the notion of consumer sovereignty, while EE espouses both individual and social wellbeing. NE prefers to separate 'positive', value-free science from normative issues. EE, on the other hand, more readily acknowledges the importance and inevitability of subjective valuations and ethical concerns, especially as a basis for policy prescriptions. Much of the SES literature focuses on positive rather than normative issues. Of the three fields, EE gives most explicit attention to normative concerns.

The role ascribed to energy in the socioeconomic system, and the implications derived from this, differ markedly between NE on the one hand, and EE and SES on the other (see the summary in Table 1-2). To a significant extent, this divergence stems from fundamental differences in the way in which neoclassical and ecological economists conceive the relationship between the economy and the environment. NE views the environment (resources) as a subset of the economy, while EE regards human society and the economy as part of the environment. This difference in perspective has been termed a "paradigm shift", a "change in preanalytic vision" (Daly & Farley, 2004: 23), and a "scientific revolution" (Baumgartner, 2004: 105). In the SES view, society is not a subset of the environment, since it possesses emergent properties; the environment and society are seen as two interlocking and interdependent systems.

The contrasting preanalytic visions lead to very different degrees of theoretical emphasis on energy. Neoclassical economics accords a very minor status to energy (and resources more generally) in its theories of production and growth, in which capital, labour and technology are viewed as the key ingredients. To the extent that energy is considered within neoclassical economics, it is usually assumed that the causality runs from economic growth to energy consumption. In contrast, in the EE and SES perspectives the environment, resources and energy are all seen as absolutely fundamental elements of socioeconomic or socioecological systems. EE is grounded on the biophysical laws of thermodynamics and regards the throughput of low-entropy energy and materials to high-entropy wastes as the essence of economic processes. Similarly, in SES the types of energy and material flows societies typically process are referred to as their “metabolism”. Three historical ‘modes of subsistence’ or ‘socioecological regimes’ have been identified, namely hunter-gatherer, agrarian and industrial. Fossil fuels are regarded as critical to sustain the metabolism of industrial societies.

Another major point of contention between neoclassical and ecological economists is the question of whether the finiteness of the Earth’s resources (especially exhaustible ones like fossil fuels) implies that there are limits to economic growth. Within neoclassical economics, the exhaustibility of resources is treated within the subfield of natural resource economics. According to this field, resource exhaustibility does not necessarily impose any limits on economic growth because it is assumed that manufactured and human capital (or alternatively, technology and knowledge) can be substituted for natural resources (e.g. see Barnett & Morse, 1963; Goeller & Weinberg, 1976; Smith, 1979; Simon, 1980). Thus economic growth can be decoupled from resource use and there is no limiting factor of production. In contrast, EE views resources and manmade and human capital as essentially complements; knowledge is mostly embodied in technology, which is seen to be constrained by the laws of thermodynamics. Consequently, the finiteness of natural capital will ultimately impose a physical limit on the scale of the economy, in terms of rates of energy and material throughput (e.g. Meadows et al., 1972; Daly, 2004). Furthermore, ecological economists highlight several factors that limit the possibilities for decoupling economic growth from energy use. These include the quality of energy sources and net energy availability, the rebound effect (whereby increasing energy efficiency can result in higher energy consumption), and the (partial) dependence of technology and labour productivity on energy inputs. The SES approach falls somewhere between these two extremes. SES analysts advocate dematerialisation through enhanced eco-efficiency and resource productivity, but recognise that in practice absolute decoupling has proved extremely difficult for industrial economies to achieve.

The difference in perspective between neoclassical and ecological economists on technology and substitutability has been characterised as a debate between “technological optimists” and “technological pessimists” (Costanza, 1989; see also Ekins, 1993; Tilton, 1996). Costanza (1996: 342) acknowledges the uncertainty surrounding the capacity of technology to overcome resource scarcity and invokes the precautionary principle to argue that it is safer to assume that biophysical limits do exist because the negative consequences of assuming they do not are potentially enormous.

As a result of their contrasting perspectives on capital substitutability and technology, NE and EE have different interpretations of sustainability. Neoclassical economics adheres to the notion of ‘weak sustainability,’ which maintains that human-made capital can substitute for natural resources, and thus does not regard restrictions on consumption or major changes in the economic system as necessary (Schiller, 2009: 1680). In contrast, EE advocates ‘strong sustainability,’ which requires the separate maintenance of stocks of each type of capital, since the possibilities for substitution are limited. What is more, non-renewable resources must over time be replaced by renewable resources (whose stocks must not be consumed faster than they can regenerate), and the waste-absorption capacity of the environment must not be exceeded. Similarly, in the SES view sustainability requires reducing flows of non-renewable resources, stabilising flows of renewable resources and reducing outflows of wastes. The depletion of fossil fuels (and the need to reduce their negative impact on the environment) suggests the need for industrial societies to undergo a transition to a 'sustainable' socioeconomic regime. Sustainability is therefore of prime importance in EE and SES, but not in NE.

The research methods employed by the three fields reflect both their philosophical underpinnings as well as their conception of the role of energy. Neoclassical economics emphasizes mathematical models and quantitative analysis, especially dynamic optimisation (at the micro level), and growth and macroeconometric models (at the macro level). A common feature of these modelling techniques is a strong focus on prices: variables are almost always measured in monetary values. The toolkit of ecological economics includes ecological-economic models as well as quantitative and qualitative analysis of case studies. EE focuses both on prices (market valuation) and on biophysical indicators such as energy and resource throughput and emissions. The SES approach involves the use of historical analysis as well as the materials and energy flow accounting (MEFA) framework. MEFA typically emphasizes physical rather than monetary indicators, although it can incorporate socioeconomic statistics. This dissertation employs a mix of quantitative and qualitative analysis, historical investigation and some basic energy flow analysis. It also gives attention both to price and physical aspects of energy dynamics.

In addition to conceptual and analytical differences, the three approaches also vary in their normative stance, such as the principal social goals they highlight. NE primarily emphasizes allocative efficiency on a micro scale and economic growth on a macro scale. EE, by contrast, emphasizes the prior importance to allocative efficiency of a just distribution of income and wealth (both intra- and inter-generationally) and an optimal (sustainable) scale of the macro-economy (Daly, 2004: 249). These three main objectives (just distribution, sustainable scale and allocative efficiency) are seen in EE as the pillars of sustainable development. The main goals identified by SES are sustainable development and successful transitions between successive socioeconomic regimes. Together, EE and SES provide a broadly balanced set of socioeconomic goals, incorporating the narrower goals of NE.

Finally, the three fields place different emphasis on the need for, and types of, policy interventions. Neoclassical economics assumes that markets will by and large result in allocatively efficient outcomes and that the primary role of government is to ensure a system of property rights is upheld by the rule of law. NE does not see a need for interventionist policies to preserve exhaustible resources, promote sustainable development, or limit population growth (Tilton, 1996). In contrast, ecological economics has less faith in the capacity of markets and technology to meet economic, social and environmental goals (e.g. sustainable development) than does NE (Common & Stagl, 2005: 11). Ecological economists recognise the pervasiveness of market failures in relation to resources and the environment and thus advocate regulations and moral suasion in addition to market-based incentives. SES is perhaps less policy-driven than EE, but also advocates incentives and regulations for industrial economies in the pursuit of sustainability. Ecological economics thus provides the most encompassing approach to policy formulation.

In summary, there is a marked divide in the treatment of energy within neoclassical economics on the one hand, and ecological economics and socioecological systems analysis on the other. Being largely divorced from biophysical principles of the natural world, NE fails to deal adequately with energy and therefore its analysis of and prescriptions for oil depletion are likely to be lacking. There is a great deal of overlap between EE and SES, in terms of aims, methodology, subject matter and concepts, and the two approaches are highly complementary. Both fields are firmly rooted on biophysical foundations, which show that energy and material flows are fundamental to the functioning of socioeconomic systems. EE contains many important concepts relating to energy that are neglected in NE. SES further provides a long-run, historical context for understanding the role of fossil fuels. EE provides a sound normative basis for policy formulation, and an inclusive treatment of various policy instruments.

The contrasting perspectives on energy held by neoclassical and ecological economists are very evident in the debate over the nature and implications of global oil depletion, which is reviewed in the next chapter through the lens of the conceptual synthesis developed above. The holistic approach to energy also lays the foundation for the subsequent empirical case study analysis of South Africa in Chapter 3 (which details the status quo dependency on oil) and Chapter 4 (which provides a qualitative and empirical analysis of likely impacts). Chapter 5 draws on the foregoing discussion of normative goals and policies to formulate strategies and policies to mitigate the impact of oil depletion on South Africa, while Chapter 6 elaborates on the concept of a transition to a sustainable socioeconomic regime. In the concluding chapter, the conceptual circle is closed by considering the implications of global oil depletion for economic theory.

Table 1-1: Summary characteristics of the three conceptual approaches

	Neoclassical Economics	**Ecological Economics**	**Socioecological Systems**
Definition and subject matter	Allocation of scarce resources amongst competing human wants Production, distribution and consumption of goods & services	Relationship between economic and ecological systems Science and management of sustainability	Interdependent biophysical & cultural spheres of causation
Aims	Explain the functioning of the economy	Produce knowledge for sustainable management of ecological-economic systems	Explain the functioning of socioecological systems
Ontology	Realist Reductionist	Realist Holistic	Realist Holistic
Epistemology	Absolutist Monistic	Relativist (moderate) Pluralistic	Relativist (moderate) Pluralistic
Methodology	Logical positivist Disciplinary Methodological individualism Deductive reasoning	Logical positivist Transdisciplinary Methodological pluralism Inductive & deductive reasoning	Logical positivist Transdisciplinary Methodological pluralism Inductive & deductive reasoning
Normative positions	Consequentialist Utilitarian Anthropocentric Consumer sovereignty *Homo economicus*	Consequentialist Utilitarian Anthropocentric Individual & social wellbeing	Consequentialist Anthropocentric

Table 1-2: Summary of theoretical approaches to the role of energy

Framework	**Neoclassical Economics**	**Ecological Economics**	**Socioecological Systems**
Key concepts	Environment is a subset of economy Key factors of production: labour & capital Laws of supply & demand Optimal rates of resource extraction Hotelling's rule Growth economy Energy is an intermediate input Economic growth causes energy consumption Substitutability of energy and (human & physical) capital Substitutability of technology and resources Weak sustainability	Economy is a subset of environment Key environmental services: sources & sinks Laws of thermodynamics Optimal scale of economy Sustainable throughput Steady state economy Energy enables economic activity Energy quality Energy surplus Rebound effect Complementarity of energy and physical capital Complementarity of technology and resources Strong sustainability	Socioeconomic & ecological systems overlap and interact Resource inputs & waste outputs Societal metabolism Modes of subsistence Socioecological regimes & transitions Energy as fundamental basis of socio-economy Decoupling through dematerialisation & resource productivity
Research methods	Dynamic optimisation Production functions Growth models Econometric models	Ecological-economic (systems) modelling Macroeconomic models Econometric models Input-output models	Materials & energy flow analysis Historical analysis
Goals	Allocative efficiency Economic growth Optimal rate of resource depletion	Sustainable development Just distribution (intra- and inter-generational equity) Optimal scale Allocative efficiency	Sustainability Improved resource productivity Successful socio-ecological transition
Policies	Market forces Private property rights Rule of law Market-based incentives	Market incentives (e.g. ecological taxes & subsidies) Regulations Education/moral suasion Redistribution	Ecological taxes & subsidies Regulations (e.g. quotas, efficiency standards)

CHAPTER TWO

2. Theory, Evidence and Implications of Global Oil Depletion

"The steep ride up and down the energy curve is the most abnormal thing that has ever happened in human history."

M. King Hubbert

The issue of global oil depletion has been and remains the subject of an intense debate in the academic literature and increasingly amongst the general public and media. Broadly speaking, two main sides can be identified in this debate, often referred to as the 'pessimists' on the one hand, and the 'optimists' or 'cornucopians' on the other (Tilton, 2003; Heinberg, 2003). The former group is comprised mainly of natural scientists such as petroleum geologists, geophysicists and ecologists, who warn that we are near to (or already past) a peak and subsequent decline in global oil production (e.g. Campell & Laharrere, 1998; Duncan & Youngquist, 1999; Deffeyes, 2001; Bentley, 2002; Aleklett & Campbell, 2003; Goodstein, 2004; Leggett, 2005; Simmons, 2005; Aleklett et al., 2009). This event, they argue, poses a significant threat to oil-dependent industrial societies and should be managed proactively by governments and societies. The optimists, who are predominantly economists and engineers, argue that petroleum resources are still abundant and that there is no imminent global production peak (e.g. Adelman, 2003; Lynch, 2003; Maugeri, 2004, 2009; Watkins, 2006; Clark, 2007; Mills, 2008; Aguilera et al., 2009; Gorelick, 2010). In any event, they believe that market mechanisms and technology will solve any depletion issue and therefore they see no need for government-led mitigation programmes.

The aim of this chapter is to summarise and assess the primary issues in this debate, and to provide a synthesis of the physical science and economic perspectives. In order to do so, the chapter surveys the international literature dealing with theoretical arguments and empirical evidence concerning the nature of global oil depletion and its possible socioeconomic implications. Section 2.1 discusses the nature of global oil depletion, focusing on the possible future profile of annual world oil production and highlighting key issues such as net energy and world oil exports. Section 2.2 assesses the potential for declining oil supplies to be offset by alternative energy sources, conservation and efficiency at a global scale. Section 2.3 considers the major possible socioeconomic ramifications of oil depletion for the world economy, transport and trade, agriculture and geopolitics. The final section concludes.

2.1 The nature of global oil depletion

This section addresses three key questions, namely: (1) how much oil remains to be produced? (2) how long might it last?; and (3) what might the future profile of oil production look like? Section 2.1.1 discusses definitions and estimates of oil resources and reserves. Section 2.1.2 outlines the so-called Hubbert model and criticisms thereof. Section 2.1.3 surveys a range of estimates of when world oil production might reach its all-time maximum rate, and assesses their credibility. Section 2.1.4 addresses the possible shape of the global oil peak and the post-peak rate of decline in oil production. The following two subsections deal with net energy and energy return on investment, and world oil exports, respectively. Section 2.1.7 summarises the key issues.

2.1.1 Oil resources and reserves

Fossil fuels, including crude oil deposits, were formed through a combination of biological and geological processes that included the decaying, compressing and heating of plant and animal matter on a massive scale. Most oil was formed in two epochs, 100 and 150 million years ago, following episodes of global warming (Aleklett & Campbell, 2003). From a human time perspective, therefore, the total amount of oil existing in the Earth's crust is finite (Hubbert, 1956).

Table 2-1: Definition and classification of types of oil and other liquid fuels

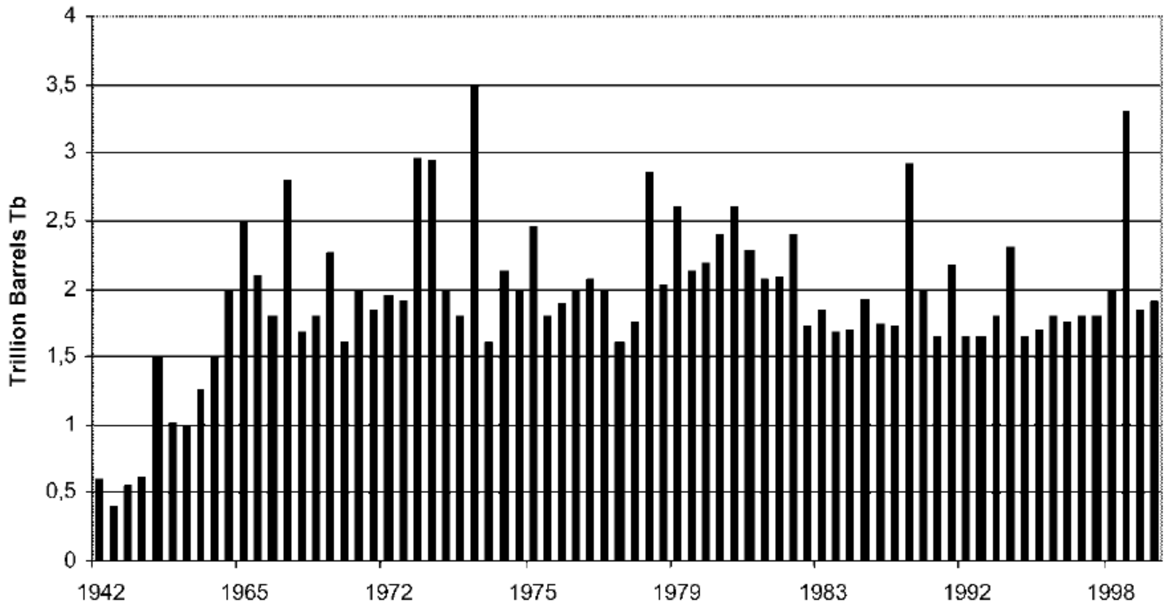
Resource	Definition
Crude oil - onshore - shallow off-shore - deep off-shore - polar	Oil with viscosity above 20^0 API gravity - land-based - < 500 metres deep - > 500 metres deep - North of Arctic circle and south of Antarctic circle
Condensate	Very light oil which condenses from natural gas at surface temperatures and pressures.
Heavy oil	Crude oil with viscosity between 10-20^0 API gravity, requiring special extraction and refining methods.
Extra-heavy oil	Crude oil with viscosity below 10^0 API gravity, requiring steam injection and special refining techniques.
Natural gas liquids (NGLs)	Light hydrocarbons found in association with natural gas that are either liquid at normal temperatures and pressures, or can be relatively easily converted into a liquid with the application of moderate pressure.
Refinery processing gains	The difference between the volumetric output of refinery products and the volumetric input of crude oil.
Oil (tar) sands	Sandstone impregnated with heavy or extra-heavy oil that can be mined and processed to produce synthetic crude oil ('syncrude').
Oil shale	Kerogen embedded in shale rock, requiring large amounts of energy for heating to derive synthetic crude oil.
Coal-to-liquids (CTLs)	Synthetic liquid fuel derived through the gasification of coal followed by a Fischer-Tropsch process.
Gas-to-liquids (GTLs)	Synthetic liquid fuel derived from the liquefaction of natural gas (methane) using the Fischer-Tropsch process.
Biofuels	Synthetic fuels derived from biomass, including ethanol (e.g. produced from corn or sugar cane) and biodiesel (e.g. produced from soybeans, canola, Jatropha, etc.).
Conventional oil	Crude oil, condensate, heavy oil & NGLs
Unconventional oil	Extra-heavy oil, oil sands, oil shale
All oil	Conventional + unconventional oil
All liquids	All oil + CTLs, GTLs and biofuels

Source: Sorrell et al. (2009); EWG (2007); ASPO Ireland (2009)

There are a variety of types of oil and related fuels. In the absence of a universally accepted set of definitions in the literature (Castro, Miguel & Mediavilla, 2009), this dissertation adopts the terminology and definitions summarised in Table 2-1. *Conventional oil* refers to oil extracted from traditional oil wells located in onshore and offshore basins, and includes lease condensates, heavy oil and natural gas liquids (NGLs). *Unconventional oil* includes extra-heavy oil, oil derived from oil (tar) sands, and oil shale. Together, conventional and unconventional oil are termed '*all oil*'. Synthetic fuels derived from coal (coal-to-liquids, CTL), gas (gas-to-liquids, GTL), and biomass (bio-ethanol and biodiesel) are treated separately from oil, and are included under the label '*all liquids*' (see IEA, 2008). Since various authors and agencies employ different definitions of oil and liquid fuels, the differences will be made explicit where necessary.[39]

ASPO Ireland (2009) reports that 1,054 billion barrels (gigabarrels, Gb) of 'regular' conventional oil (excluding deep water, polar and heavy oil, and NGLs) and 1,156 Gb of all oil (conventional and unconventional) had been extracted from the Earth as of December 2008. Thus more than 90% of the cumulative oil produced by 2008 was conventional. The quantity of oil that remains to be produced is more contentious. Geologists distinguish between *resources*, i.e. hypothetical estimates of all the oil existing in an area, and *reserves*, i.e. "the known quantity of oil that lies in fields and that can be produced with existing technologies, within a foreseeable time frame, at a commercially reasonable cost" (Rifkin, 2002: 15). The key concept from an economic perspective is therefore reserves, which is a flexible quantity that varies with technological progress and economic conditions, especially the price of oil. Despite the fact that as the price of oil rises, a higher proportion of resources become reserves (since it is economic to exploit them), reserves are always a subset of resources and consequently are also finite.

Figure 2-1: Published estimates of ultimately recoverable reserves of conventional crude oil



Source: Aleklett & Campbell (2003)

Ultimately recoverable resources

Ultimately recoverable resources (URR) (or, alternatively, Estimated Ultimate Recovery, EUR) refer to the total amount of oil that can be economically extracted from a region or field over all time (Sorrell et al., 2009: xvii). The vast majority of historical estimates for global conventional URR fall in a range between 1.5 and 2.5 trillion barrels (see Figure 2-1). However, URR estimates have been on a rising trend and "[c]ontemporary estimates now fall within the range 2,000-4,300 billion barrels (Gb)" (Sorrell et al., 2009: ix). On the pessimistic side, Campbell (ASPO Ireland, 2009) estimates URR

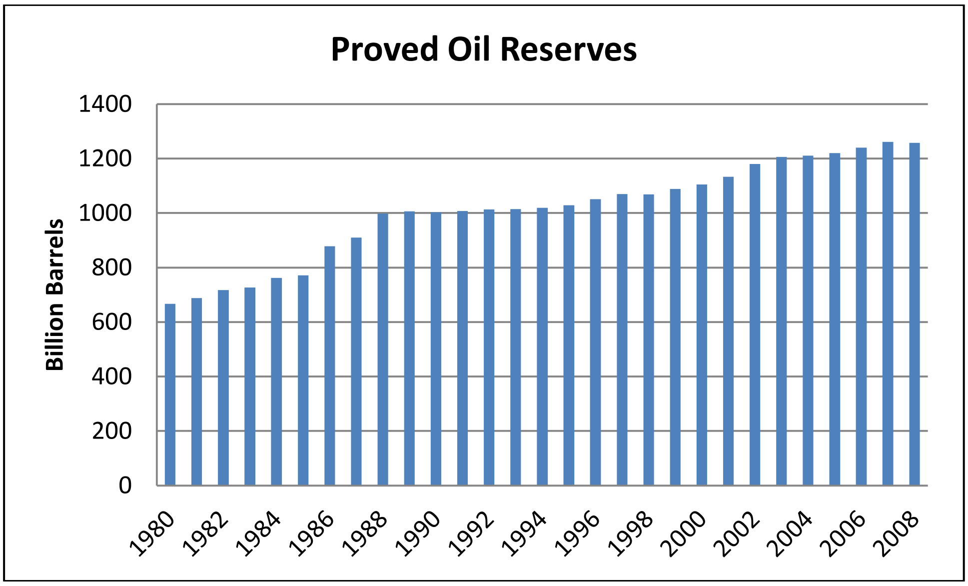
[39] For example, Campbell (ASPO, 2009) refers to 'regular' conventional oil, which excludes oil found in deep off-shore wells (i.e., greater than 500m depth) and polar regions, as well as natural gas liquids (NGLs). Most other authors include deep water and polar oil in 'conventional oil', but NGLs are often excluded. The US Energy Information Administration (EIA) includes CTLs and GTLs in its 'all liquids' category, but excludes biofuels.

for 'regular' conventional oil of 1,900 Gb and all oil of 2,425 Gb. At the optimistic end of the spectrum, the USGS (2000) mean estimate for conventional oil is 3,003 GB, while Aguilera et al. (2009) estimate 3,561 Gb for conventional oil. Estimates of remaining recoverable resources, i.e. oil contained in known reserves plus yet-to-be-discovered fields, lie between 870 and 3,170 Gb (Sorrell et al., 2009: 137), clearly a very wide range.

Proved reserves

'Proved reserves' of crude oil are defined by the EIA (2009: 31) as "the estimated quantities that geological and engineering data indicate can be recovered in future years from known reservoirs, assuming existing technology and current economic and operating conditions." Despite rising production of oil for most of the past century, official proved reserves (comprised mostly of conventional oil) have been rising for decades and by the end of 2008 stood at approximately 1,258 Gb (see Figure 2-2). The upward trend is explained both by new discoveries and by the fact that historical reserves are frequently revised upward as new technologies allow more oil to be extracted from old wells. However, the trend is also partly a result of accounting practices by oil companies, which often initially report conservative values for reserve and discovery estimates for financial reasons (Aleklett & Campbell, 2003; Bentley, 2002).

Figure 2-2: Proved oil reserves, 1980-2008



Source: BP (2009)

Note: These figures refer to conventional crude oil except for the inclusion of Venezuelan extra-heavy oil; Canadian oil sands are excluded.

Unreliability of official reserve data

The reliability of official proved reserve estimates, as published annually in periodicals such as *World Oil* and *Oil & Gas Journal*, is contestable on several counts. First, these figures are aggregated estimates from individual oil-producing countries, which are not subject to independent audit, and are thus vulnerable to manipulation for political and economic reasons, such as bargaining power or collateral for loans (Campbell & Laherrère, 1998). Second, the data from individual countries "have not been evaluated according to consistent criteria" (Jakobsson et al., 2009: 4812). Third, official reserve estimates for many countries often reflect no changes from year to year, despite the fact that these nations were extracting oil and may or may not have been making any new discoveries (IEA, 2004: 92-3; Bentley et al., 2007). Thus "proved reserves" might refer to URR rather than remaining reserves in certain cases. Fourth, Campbell and Laherrère (1998) pointed out that six members of the Organisation of Petroleum Exporting Countries (OPEC) revised their proved reserves upward by between 40 and 200 per cent between 1985 and 1987, accounting for most of the growth in world reserves during that period. This occurred shortly after two notable events around 1985: (1) the collapse in oil prices to around $10 per barrel; and (2) OPEC's decision that production quotas would henceforth be based on proved reserves. Countries that were highly dependent on oil revenues therefore had every incentive to inflate their reserve estimates. Moreover, the OPEC producers did not announce significant new oil discoveries during this period. Bentley et al. (2007: 6371-72) state that proved reserve data "are quite unusable for calculating future oil production as they exhibit serious degrees of under-reporting, over-reporting, and nonreporting." Owen, Inderwildi and King (2010) conclude that official proved reserve figures are likely to be inflated by approximately 300 Gb from spurious OPEC revisions and up to an additional 173 Gb from the inclusion of Canadian oil sands.

Reserve/production ratio

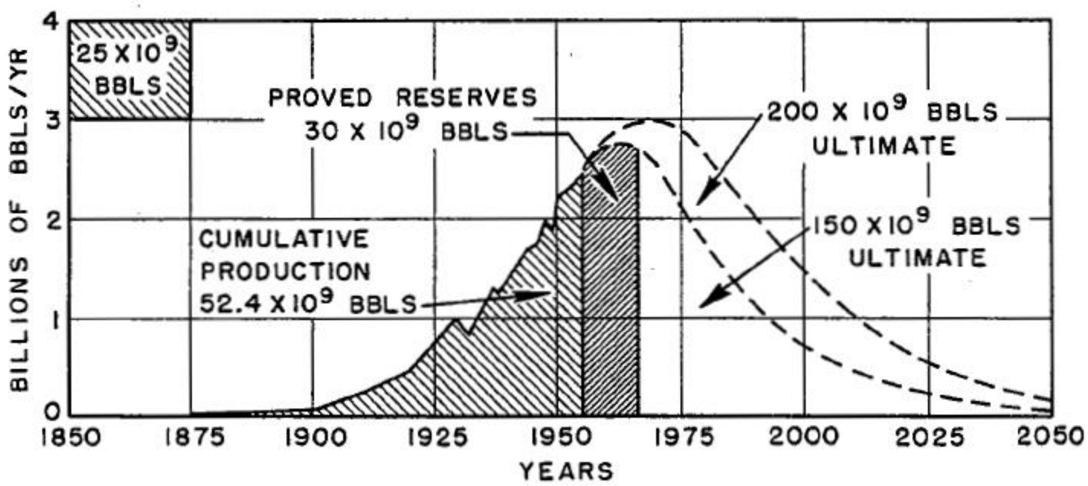
The second question posed at the beginning of this section, namely how long will oil last, clearly depends on the extent of ultimately recoverable reserves, as well as on future rates of production and consumption. A commonly cited metric is the reserve to production (R/P) ratio, i.e. the number of years at which production can be sustained at the current level, given estimated reserves. Based on the official proved reserve estimate of 1,383 Gb, the global R/P ratio stood at 46 years as of December 2010 (BP, 2011). For several reasons, however, the R/P ratio at best has limited usefulness, and at worst can be seriously misleading (Bentley, 2002). In the first place, it depends on the reliability of proved reserve estimates, which as discussed above is highly questionable. Second, even if the historical figures showing an upward trend in reserves are accurate, this does not logically imply that the R/P ratio will continue to rise indefinitely. The crux of the matter is the trend in discoveries and potential future reserve growth, which are discussed in the following subsection. Third, oil production will not remain flat for a certain number of years and then suddenly collapse to zero (Bardi, 2009: 324). Both geologically and economically, such a pattern of production would be impossible, for it says nothing about the way production from oil wells gradually declines after reaching a peak or plateau (Sorrel et al., 2010a), nor about how prices and demand will respond to diminishing supply.

2.1.2 The Hubbert model

The methodology developed by M. King Hubbert in the 1950s arguably represents a more realistic theoretical analysis of the evolution of oil production, and one which is supported by empirical evidence. Hubbert (1956) provided a seminal contribution to the understanding of the depletion of finite resources, including oil. He pointed out that the rate of production of a finite resource (such as oil) must begin at zero and end at zero (when the resource is exhausted), reaching one or more local maxima and a single global maximum in between. Hubbert theorised that the production profile (i.e. annual production plotted against time) would depict a symmetrical, bell-shaped curve with the peak being reached when approximately 50% of the recoverable resource had been extracted. Total lifetime production would be represented by the area under the production curve. Hubbert (1959) subsequently added a mathematical component to his theory by assuming that cumulative production would follow a logistic curve (whose first derivative, annual production, is bell-shaped).

The Hubbert curve methodology rests on the obvious point that you can only produce what you have discovered. Hubbert (1959) noted that oil discoveries in a particular region tend to rise to a peak and then fall over time and concluded that production must follow a similar trajectory, although after a substantial time lag since it takes some years to bring new discoveries into production (see also Rehrl & Friedrich, 2006). The theory also conforms to the observation that production from individual oil wells tends to rise to a peak or a plateau and then decline (Sorrell et al., 2009). Aggregating numerous such production profiles into a larger geographical area generates a roughly bell-shaped curve. Hubbert (1956) used the historical trend of oil discoveries to estimate ultimately recoverable resources, and fitted a symmetrical, bell-shaped production curve accordingly. Using this method, Hubbert (1956) controversially predicted that oil production in the lower 48 United States (US-48) would peak between 1965 and 1970, depending on the assumed URR (150 or 200 Gb; see Figure 2-3). The US-48 peak in fact occurred in 1970. Assuming world crude oil URR of 1250 Gb, Hubbert (1956) predicted that global production would reach a peak in approximately the year 2000.

Figure 2-3: Hubbert's model of US-48 oil production



Source: Hubbert (1956)

Criticisms and rejoinders

Variants of Hubbert's approach have since been used by many researchers attempting to forecast the date of 'peak oil'[40] in a particular region or for the world as a whole (e.g. Campbell, 1991, 1997; Duncan & Youngquist, 1999; Deffeyes, 2001; ASPO Ireland, 2009; Maggio & Cacciola, 2009). The Hubbert model, and those who use it for forecasting purposes, has been the subject of intense criticism, mainly from the 'optimist' camp (e.g. Lynch, 2002, 2003; Adelman, 2002; Tilton, 2003; Clark, 2007). Others have in turn sought to defend or clarify the usefulness and limitations of Hubbert's approach (e.g. Bentley, 2002; Bardi, 2005, 2009; Bentley et al., 2007). The issues under debate include data reliability, methodology, forecasting, and determinants of oil supplies.

The first issue is the reliability of the data used by Hubbert modellers. For example, Adelman (2003) and Lynch (2003) argue that Campbell's (1997) database is proprietary and not available for public scrutiny, and therefore lacks credibility. However, these critics do not interrogate the reliability of published data sources such as those contained in *Oil & Gas Journal* and *World Oil*, or those of prominent agencies such as the USGS, EIA and IEA. The (un)reliability of oil reserve (and to a lesser extent production) data is an issue for all oil forecasters, no matter what method they use.

[40] The term "peak oil", which was coined by geologist Colin Campbell in 2001 (Bardi, 2011; Oil Drum), refers to the maximum rate of oil production in any given region; most often the term is applied to the world as a whole. It should ideally be made explicit whether 'oil' refers to 'conventional oil', 'all oil', or 'all liquids' (see Table 2-1). "Peak oil" has also become a short-hand for the era in which oil supplies are no longer able to meet *desired* demand (*actual* demand can only exceed available supply in the short term through the draw-down of oil stocks; in the long term, the quantity demanded must equal the quantity supplied).

A second criticism of the Hubbert approach relates to methodology. Lynch (2003) points out that oil production in a country or region very rarely exhibits a bell-shaped curve as Hubbert assumed. Similarly, Bardi's (2005) computer simulations of resource-constrained production show that there is no solid basis for assuming that the Hubbert curve is symmetrical or that the 'peak' occurs at the half-way mark of production. Thus Jakobsson et al. (2009: 4810) suggest the Hubbert curve be viewed "as a strictly empirical rule-of-thumb rather than as a rigorous scientific hypothesis." Although the standard Hubbert model produces only one peak, which is valid for only a subset of countries and regions, a multi-peak Hubbert curve can be modelled (e.g. Maggio & Cacciola, 2009). Brandt (2007) compares the fit of Hubbert, linear and exponential models (each with symmetrical and asymmetrical variants) to data for 139 regions including US state level, sub-national level, national level and the world as a whole. He finds that "no simple, single cycle model fits all historical production curves from oil producing regions" and that "the asymmetric models trump the symmetric models in most cases" (Brandt, 2007: 3084).

A third common criticism, levelled in particular by economists (e.g. Lynch, 2003; Adelman, 2003; Watkins, 2006), is that reserves are dynamic, rather than static as assumed by Hubbert modellers. Tilton (2003) refers to the economic approach as an "opportunity cost paradigm", which considers prices as a key determinant of reserves; whereas the geological approach he calls a "fixed stock paradigm" that focuses on physical quantities of resources. There are two main sources of reserve growth, namely new discoveries and more sophisticated extraction methods (enhanced oil recovery, EOR). Economists such as Lynch (2003) and Adelman (2003) correctly point out that higher oil prices tend to stimulate increased exploration activity. In addition, improved technology (e.g. for locating oil reservoirs and for drilling) allows oil to be extracted from new areas, such as deep water off-shore fields. However, more *exploration* does not necessarily translate into more *discoveries*: it depends on the extent to which undiscovered oil fields still exist. At some point, no matter how high the price of oil rises and how sophisticated the exploration techniques become, these factors cannot overcome the physical limitations of a finite resource. Episodes of much higher prices and decades of technological improvements have not reversed a long-term declining discovery trend that is due to declining energy return on investment (EROI) of exploration (Bardi, 2009: 325). A second stimulus for reserve growth comes from technological developments which allow enhanced oil recovery (EOR) from both old and new fields (Lynch, 2003; Adelman, 2003). Hubbert (1956: 24) was aware of reserve growth through enhanced recovery, but in the case of the USA conjectured that it would not significantly delay the peak, but rather ameliorate the subsequent rate of decline. However, more recent studies suggest that the application of advanced extraction technologies could delay the production peak, but likely at the expense of a more rapid subsequent rate of decline (Bardi, 2005; Hook et al., 2009). In any event, EOR is ultimately limited since the oil resource is finite (Bardi, 2009). Sorrell et al. (2009: viii) point out that "[r]eserve growth tends to be greater for larger, older and onshore fields, so as global production shifts towards newer, smaller and offshore fields the rate of reserve growth may decrease in both percentage and absolute terms." In addition, production costs tend to rise as new oil fields are more difficult to locate and access, and as the return on investment for EOR declines over time (Bardi, 2009). Tilton (2003: 35) argues that "the long-run availability of mineral commodities is now determined by a race between the cost-increasing effects of depletion and the cost-decreasing effects of new technology." According to Gagnon et al. (2009), depletion appears to be winning the race because the EROI of exploration, discovery and production is on a declining trend (see also Heun & De Wit, 2011, for the impact of declining EROI on oil prices).

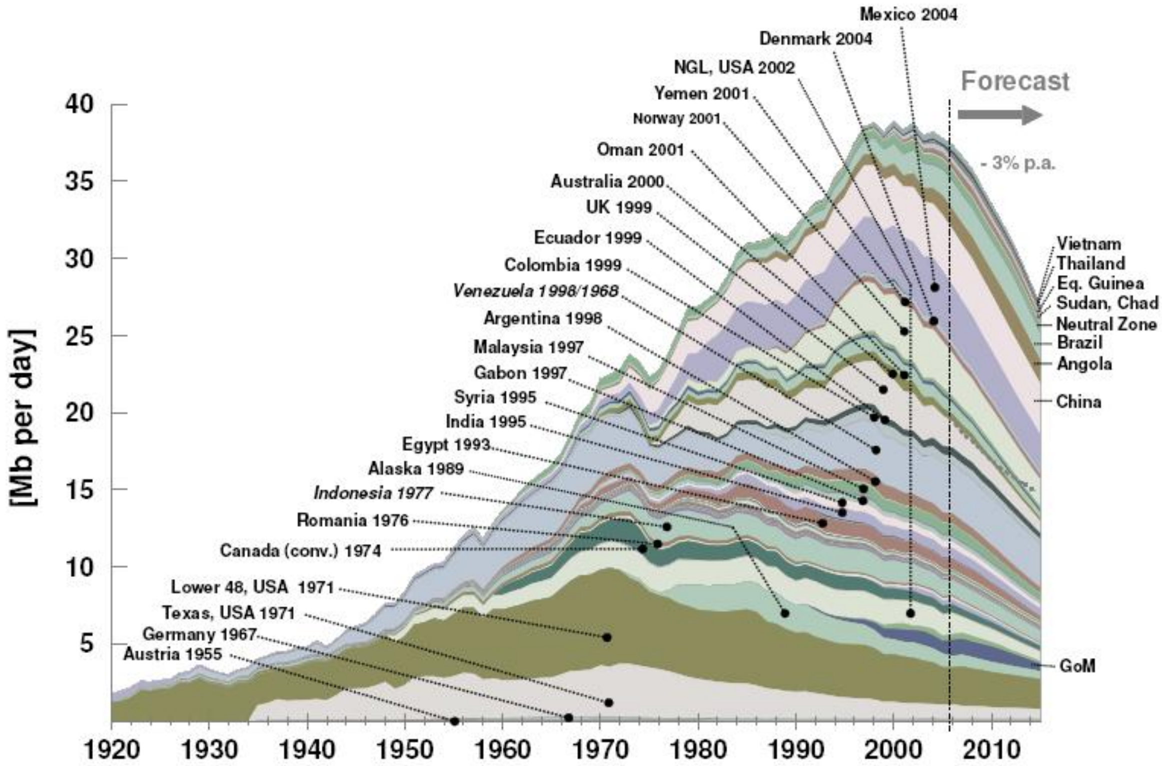
A fourth criticism of the Hubbert model is that it neglects non-geological factors that also determine oil supply and influence production profiles (Watkins, 2006; Lynch, 2002; Cavallo, 2002). For example, geopolitical events (e.g. wars or sanctions), political factors (e.g. ethnic conflict within oil producing countries), and/or government policies might alter the production profile of a particular country or even region (e.g. OPEC supply reduction agreements). Economic factors, especially oil prices and the rate of investment in the oil industry, are also important determinants of supply. Production of oil in any region is unlikely ever to exhaust the resource completely, since costs will become prohibitively high before then (Houthakker, 2002). However, the Hubbert curve does take account of the economic dimension of oil exploration, production and consumption, and not simply geological availability. Initially, costs are low, profits are high, and production increases rapidly as the larger and easier to access oil fields are exploited. Over time though, extraction becomes progressively more difficult and costly, both in individual fields as the pressure inside the reservoir drops, and across different fields as the more accessible fields (e.g. onshore fields) are exploited first, leaving less hospitable areas (e.g. off-shore fields) for later. Thus the Hubbert model actually rests on a foundation of assumptions that include a free market economy; in reality, of course, these assumptions may not hold (Bardi, 2009: 324). Integrating these viewpoints, it is clear that "[o]il supply is determined by a complex and interdependent mix of 'above-ground' and 'below-ground' factors" (Sorrell et al., 2009: vi) and that "given the potential for political, economic, or technological disruptions, no model can provide estimates of great precision" (Sorrell et al., 2009: x). Thus geological depletion alone may not determine the date of the global oil production peak.

Given the above limitations, Lynch (2002) contends that the Hubbert model is not useful for forecasting purposes. He notes the poor historical record of oil supply forecasting and argues that some modellers have a pessimistic bias partly as a result of focusing solely on geological determinants. For example, Lynch (2002: 377) notes that Hubbert's prediction for world peak oil production in 2000 turned out to be too early and too low (by a factor of 50%). This was partly as a result of an underestimate of URR, but also because Hubbert made his prediction before the 1970s oil shocks, which reduced consumption and delayed the global peak. Lynch (2002) and Adelman (2002) also criticise Hubbert modellers (e.g. Campbell, 1991, 1997; Campbell & Laharrère, 1998) for repeatedly revising their forecasts after having been proved wrong. However, the criticism of shifting forecasts applies equally to some forecasters who use alternative methods. For example, in recent years the International Energy Agency (IEA, 2004, 2008, 2010) has systematically revised downward their forecasts for future oil supply, while projections by the US EIA have fluctuated from year to year (EIA, 2007, 2009, 2011). Lynch (2002) does concede that economic models have also performed poorly, mainly because there are too many relevant variables that influence oil supplies. Bardi (2009: 324) contends that "modelling based on the Hubbert curve is robust, in the sense that the uncertainty in the [underlying reserve] estimates does not strongly affect the year predicted for the peak." Finally, according to Jakobsson et al. (2009: 4817), "[r]esource-constrained models [including but not limited to the Hubbert model] are presently the only feasible tools for long-term oil production scenarios."

Evidence on the Hubbert Peak

Irrespective of these academic debates, the peaking of conventional oil discoveries and production is an empirical phenomenon that is observable in an increasing number of countries and regions (Sorrell et al., 2009: vii). In the Lower 48 United States (US-48), which is the most intensively explored and drilled region on Earth, oil discoveries peaked in the 1930s despite large discoveries in Alaska's Prudhoe Bay (in the 1970s) and more recently in deepwater areas in the Gulf of Mexico. Hubbert's (1956) forecast for the US-48 turned out to be correct: production peaked in 1970 and has followed a declining trend since then. By 2007, conventional oil production (excluding that from ultra-deep off shore fields) had passed its peak in 54 of the world's 65 main producing countries (Soderbergh et al., 2007: 1946). Of the top 20 oil producing countries, which together accounted for approximately 85% of global production (including crude oil, NGLs and unconventional oil), at least 10 were almost certainly past peak production as of 2010 (ASPO-USA, 2011). In contrast, relatively few countries have had significantly increasing oil production since 2000, including Russia (whose production likely reached a second peak in 2007), China (where production is likely to peak in 2011 (Feng et al., 2008)), Angola and some of the former Soviet Republics. On a regional basis, oil production has already peaked in North America (1985) and Europe (2000) (Hirsch, 2008). Figure 2-4 displays the countries that have passed peak production.

Figure 2-4: Oil producing countries past peak production

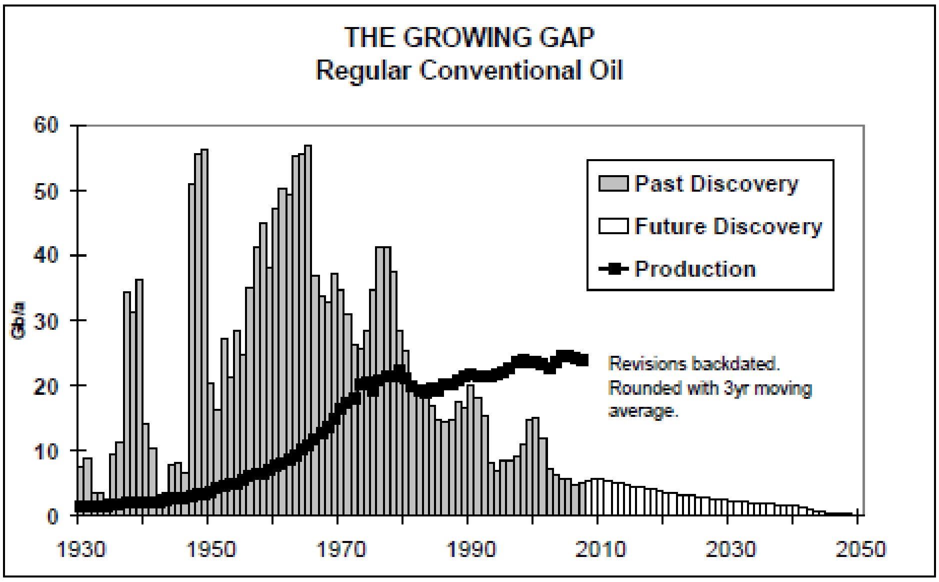


Source: Energy Watch Group (2007)

The historical pattern of world oil discoveries provides further evidence pointing towards a near-term global production peak. Giant oil fields (defined as those fields with URR greater than 0.5 Gb) accounted for approximately 65% of global ultimately recoverable resources of conventional oil and 60% of world oil production in 2005, with the 20 largest fields contributing roughly a quarter of total output (Hook, Hirsch & Aleklett, 2009: 2262). Discoveries of giant oil fields, both by URR volume and by number of fields, have been on a declining trend since the 1960s and most of the largest giants are more than 50 years old. Consequently, total production from giants is on a declining trend and the majority of individual giant oil fields are already in decline (Hook et al., 2009).

Global new oil discoveries reached a peak in the 1960s and have been on a declining trend ever since (see Figure 2-5), despite remarkable improvements in exploration, drilling and extraction technologies, and episodes of high prices in the 1970s and 2000s. Annual world oil production has exceeded annual discoveries every year since 1981. It therefore seems clear that for a near-term peak in world oil production to be avoided, the historical trend of falling discoveries will have to be reversed soon and fairly dramatically.

Figure 2-5: World conventional oil discoveries and production



Source: ASPO Ireland (2009)
Note: Units are Gigabarrels per annum (Gb/a)

2.1.3 The timing of the global oil peak

Predictions about the timing of the world oil production peak vary widely amongst individual oil forecasters and energy agencies. A number of factors influence forecasts, including: (1) sources of data on discoveries, production and reserves, and in some cases corrections of perceived anomalies; (2) forecasting methods (e.g. resource-constrained models such as Hubbert's model; bottom-up studies aggregating production profiles of individual fields and/or countries; or demand-driven forecasts); (3) estimates of URR; and (4) depletion rates and production decline rates (Bentley & Boyle, 2008). Forecasts can broadly be divided between 'early peakers', who predict a near-term peak (before 2030) and 'late peakers', who do not foresee a peak before 2030 (Sorrell et al., 2009). Table 2-2 summarises a range of prominent forecasts for the global oil peak.

At the pessimistic end of the spectrum, several analysts using variants of the Hubbert curve methodology estimated that conventional oil production (and in some cases all oil production) had most likely already peaked by 2008 (e.g. Deffeyes, 2005; Duncan, 2003; Bhaktiari, 2004; ASPO, 2009; Aleklett et al., 2009). Using a bottom-up approach, EWG (2007) estimated that all oil production peaked in 2006. Campbell (ASPO, 2009) estimates that regular conventional oil (which excludes heavy oil, shale oil, tar sands, deep water and polar oil, and natural gas liquids) peaked in 2005, while all petroleum liquids were projected to peak in 2008. In a fairly dramatic reversal of earlier predictions, the IEA (2010) in their *World Energy Outlook 2010* state that conventional crude oil production (excluding natural gas liquids) probably peaked in 2006. An intermediate group of forecasts, based on various methodologies (e.g. bottom-up, field-by-field studies) put the peak date at between 2008 and 2020 (Robelius, 2007; Skrebowski, 2008; Smith, 2008). Using a "multi-Hubbert" variant of the Hubbert model, Maggio and Cacciola (2009) forecast a world peak of crude oil and NGLs between 2009 and 2021, depending on URR assumptions. The optimistic set of forecasts do not predict a peak as likely before 2020 or even 2030 (Wood et al., 2004; Kontorovich, 2009), or predict no peak at all for all oil production by 2030 (IEA, 2010; OPEC, 2008).

Table 2-2: Forecasts of the world oil production peak

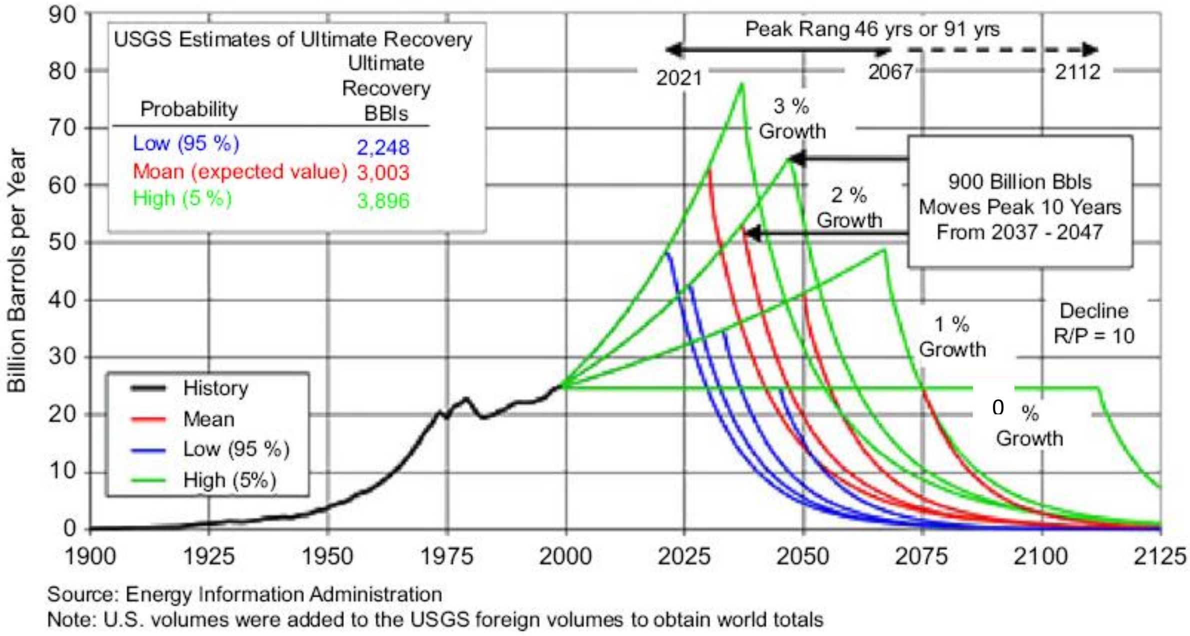
Source	Peak Date(s)	Notes
	Pessimistic	
Deffeyes (2005)	2005	Conventional oil
Duncan (2003)	2006	Conventional oil
Bakhtiari (2004)	2006-2007	Conventional oil
Energy Watch Group (2007)	2006	All oil
IEA (2010)	2006	Conventional oil
ASPO (2009)	2005 2008	Conventional oil All oil
Uppsala (Aleklett. et al., 2009)	2008	All oil
	Intermediary	
Robelius (2007)	2008-2018	Conventional oil
Peak Oil Consulting (Skrebowski, 2008)	2011-2013	All oil
Energyfiles (Smith, 2009)	2017	All liquids
Maggio & Cacciola (2009)	2009-2021	Conventional oil
	Optimistic	
Kontorovich (2009)	2007-08 2020-2030	Conventional oil; “conservative” Conventional oil; "most likely"
EIA (Wood et al., 2004)	2016 2037 2112	Conventional oil; F95 (high prob.) F50 (median) F5 (low probability)
IEA (2010)	none	All oil; ‘New Policy Scenario’
OPEC (2008)	none	

Sources: Authors cited and Sorrell et al. (2009)

Two prominent public agencies provide regular forecasts of world oil supplies and have a significant influence on energy policies in many countries. One is the International Energy Agency (IEA), an organ of the Organisation for Economic Cooperation and Development (OECD). The second is the Energy Information Administration (EIA) of the US Department of Energy. The two agencies have historically produced long-term scenarios that are on the optimistic end of the range of forecasts, suggesting that total oil production could continue to grow at least until 2030.

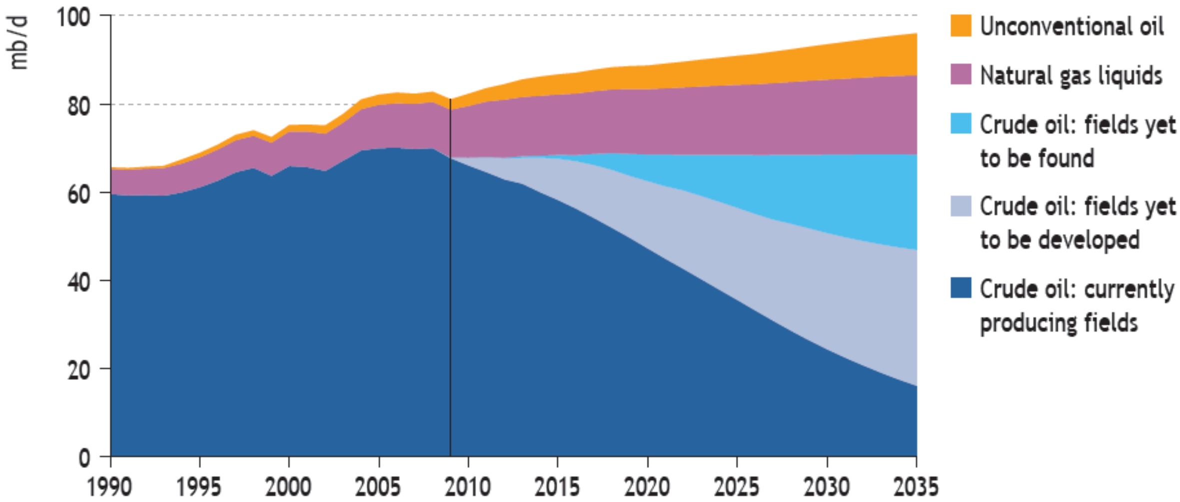
The EIA’s scenarios are based on a study by Wood et al. (2004), which generated a set of forecasts based on various combinations of oil production growth rates (0%, 1%, 2% and 3%) and URR estimates, drawn from the USGS (2000) (see Figure 2-6). The assumed post-peak decline rate is a rapid 10% per annum. In the resulting scenarios, the production peak occurs between 2021 and 2112. In the ‘mean’ scenario (assuming a 2% growth rate), conventional oil production peaks in 2037. These EIA scenarios have been critiqued on at least two counts. First, the USGS’s mean and high resource estimates were based on assumptions about future discoveries that have not been borne out by subsequent experience and thus are likely to be over-optimistic (Jakobsson et al., 2009: 4816; Campbell, 2005: 39-41). However, Sorrell et al. (2009) regards these criticisms as premature. Second, Jakobsson et al. (2009) argue that although the resource-constrained model employed by the EIA to produce its long-term scenarios is sound, the application of it contains a methodological error, namely a confusion of resource categories, which renders the scenarios unrealistic. When the error is corrected, these authors conclude that crude oil production may begin to decline considerably earlier than 2030 and that an “*imminent* peak in production cannot be ruled out” (Jakobsson et al., 2009: 4817; original italics).

Figure 2-6: US Energy Information Administration's crude oil production scenarios



Source: Wood et al. (2004)

Figure 2-7: World oil production in the IEA World Energy Outlook 'New Policies Scenario'

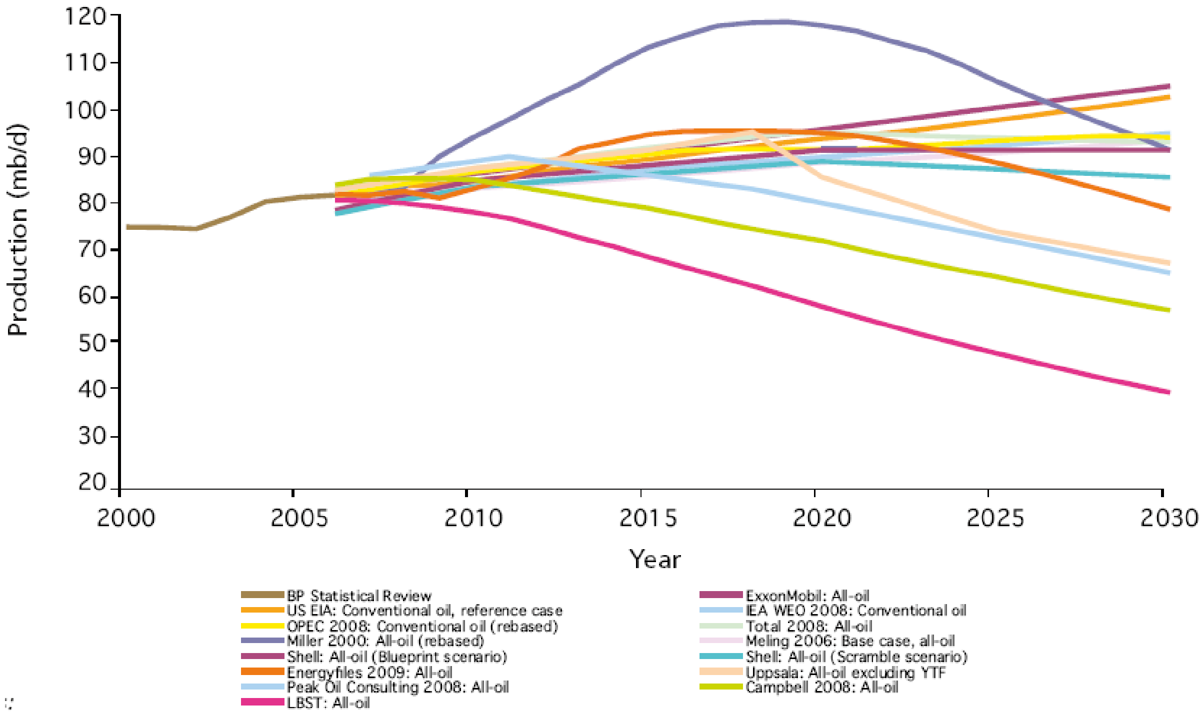


Source: IEA (2010; Figure 3.19)

The IEA (2008), in its *World Energy Outlook (WEO) 2008*, presents forecasts of energy demand based on extrapolations of economic growth, and assumes that oil supply will adjust to meet demand. In its 'Reference Scenario' it sees all (conventional and unconventional) oil production rising steadily by approximately 1% per annum to 106 million barrels per day (mbpd) in 2030. This scenario is critiqued by Aleklett et al. (2009). Although these authors regard the IEA's assessment of declining production of conventional crude oil from currently producing fields (in 2007) and future increases from enhanced oil recovery techniques to be sound, they show that the IEA's projections for future production from fields yet to be developed and yet to be found are based on unrealistically high depletion rates that are not supported by historical experience (see also Cavallo, 2002). In addition, the IEA's projections for a doubling of NGL production does not take into account NGL's lower energy content compared to oil. Furthermore, as will be discussed in Section 2.2.1 the IEA's prognosis for unconventional oil has been challenged. In the *World Energy Outlook 2010*, the IEA (2010)'s 'New Policies Scenario' assumes that total oil production will reach 96 mbpd by 2035, comprised of 68.5 mbpd conventional crude oil, 9.5 mbpd unconventional oil and 17.9 mbpd NGL (Figure 2-7).[41] The same criticisms apply to these new figures.

The IEA has over the past several years consistently revised downward its forecasts for future oil supplies, from 121 mbpd by 2030 its *WEO 2004* (IEA, 2004) to 99 mbpd by 2035 in its *WEO 2010* edition (IEA, 2010).[42] Whereas up to and including 2006 the IEA made no mention of 'peak oil' in its major publications, the *WEO 2010* (IEA, 2010: 125) contains a 'spotlight' box entitled "Peak oil revisited: is the beginning of the end of the oil era in sight?" As mentioned above, the IEA (2010: 125) states that conventional crude oil appears to have peaked in 2006, although it claims that "resources of NGLs and unconventional oil are, in principle, large enough to keep total oil production rising for several decades." However, the oil supply projections in the *WEO 2010* rest on the optimistic assumptions of the USGS (2000) and on the official proved reserve figures from OPEC countries, which have been shown to be over-estimated by as much as 300 billion barrels (Owen et al., 2010). The forecasts also make the very strong assumption that there will be "cumulative infrastructure investment along the oil-supply chain of around $8 trillion over 2010-2035, or $310 billion per year" (IEA, 2010: 139). All things considered, the IEA projections seem overly optimistic.

Figure 2-8: Comparison of 13 forecasts of all-oil production to 2030



Source: Sorrell et al. (2009)

The UK Energy Research Centre provides a comprehensive review and comparison of oil supply forecasts and scenarios (Sorrell et al., 2009; see also Sorrell et al., 2010a; 2010b). Thirteen contemporary forecasts of global oil production are depicted in Figure 2-8. Sorrell et al. (2009: ix)

[41] The New Policies Scenario assumes that "governments put in place the energy and climate policies to which they have committed themselves" (IEA, 2010: 125).
[42] The 99 mbpd in 2035 includes 3 mbpd of refinery processing gains. See also Miller (2011).

find that forecasts for the date of the world peak in conventional oil production are not very sensitive to assumptions about the extent of global oil resources (see also Brandt, 2007). The key findings are that: (1) "forecasts that delay the peak of conventional oil production until after 2030 rest upon several assumptions that are at best optimistic and at worst implausible"; (2) "On the basis of current evidence... a peak of conventional oil production before 2030 appears likely and there is a significant risk of a peak before 2020." It should be noted that official agencies (e.g. IEA, EIA and OPEC) have political agendas that may influence their assumptions, forecasts and scenarios (Bentley, 2002; De Almeida and Silva, 2009). For example, in late 2009 a whistle-blower from the IEA claimed that political pressure had forced the agency to downplay the issue of peak oil in order to avert panic reactions (Macalister, 2009). Similarly, the commercial incentives of international oil companies might have a bearing on their public stance on future oil supplies.[43] By contrast, it is interesting to note that two prominent military reports have recently warned of an impending oil supply crunch.[44] As illustrated by the discussion of the IEA's forecasts, there has been a gradual convergence over time in the range of forecasts for the date of the global oil peak, mostly because optimistic forecasts have been tempered.

Ultimately, as Heinberg (2003: 202) points out, the timing of the peak in total world oil production may only be apparent several years after the fact. This is partly because there is likely to be considerable supply volatility in the years immediately before and after the peak as a result of economic and political disruptions. The following section explores these issues in greater detail in the context of the possible shape of the global peak.

2.1.4 The shape of the peak and rate of decline

The severity of the oil peak's impact on society will depend to a large degree on the shape of the production profile and the trajectory of the post-peak decline in oil production. The flatter the peak and slower the decline, the easier it will be for societies and economies to adjust in a more orderly and planned fashion. A sharper peak and faster decline will raise the probability of severe oil shortages and price spikes.

The shape of the peak

Historical examples and model simulations provide some guidance as to the possible shape of the global oil peak. In the US-48 oil production has been largely unimpeded by political influences and determined chiefly by geological and economic factors within a largely free-market environment. This resulted in a 'classic' Hubbert curve profile, with a well-defined, absolute peak being reached in 1970 and a fairly symmetrical shape (Hirsch, 2008). In other countries, however, notably some members of OPEC and Russia, production has been more volatile, having been influenced by political events or economic turmoil, respectively. Such factors have resulted in two or more local peaks in the production curve of some oil producers. Historical production in two large regions, North America and Europe, both exhibited significant periods of plateau production, although the former

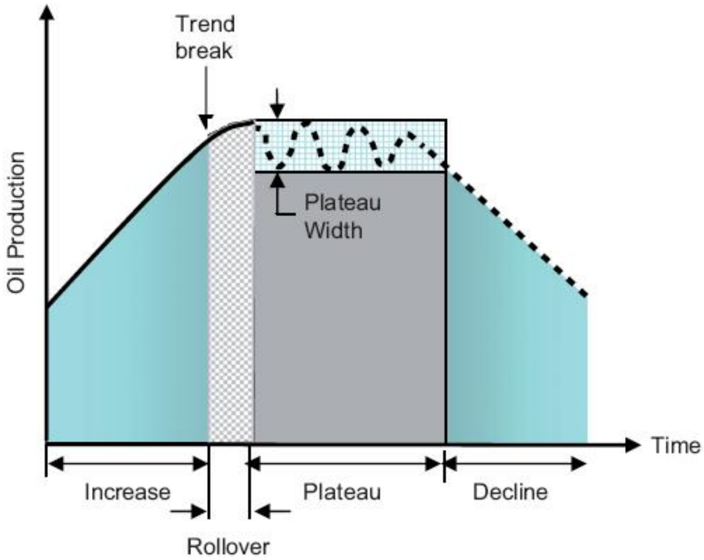
[43] De Almeida and Silva (2009) analyse the evolution of crude oil futures price curves between 2005 and 2008, and find that the historical trend of backwardation (lower prices for contracts further into the future) changed to a situation of contango (higher prices for later contracts), indicating the expectation that prices would rise in the near term (five years). They conclude that participants in the oil market, notably oil producing companies, are most likely expecting a global peak in oil production in the near term.

[44] The United States Joint Forces Command's *Joint Operating Environment 2010* contains a section dealing explicitly with peak oil. It states that in the absence of a major increase in investments in the oil sector, "[b]y 2012, surplus oil production capacity could entirely disappear, and as early as 2015, the shortfall in output could reach nearly 10 MBD" (USJFC, 2010: 29). In 2010 the Bundeswehr Transformation Centre (BTC, 2010) compiled a report on peak oil for the German military, without committing to when the global oil peak might be reached.

region initially experienced a relatively sharp peak and decline (Hirsch, 2008). In both cases, there was next to no 'rollover' period giving warning of an impending maximum rate of production and subsequent decline. In an analysis of many regions, Brandt (2007) finds no historical evidence that rates of decline are in general steeper than rates of increase, but that the peak tends to be sharper than predicted by the Hubbert model. Several world oil production forecasts show a multi-year rollover period, representing a "pseudo-plateau" that could afford an opportunity for mitigation while economic impacts are less severe (Hirsch, 2008: 885). Based on simulation exercises, Bardi (2005) finds that the post-peak descent might be substantially steeper than the pre-peak upward slope, i.e. the Hubbert curve might be asymmetric.

For the world as a whole, therefore, production will not necessarily (or even likely) reach a well-defined, sharp peak. Many experts predict a 'bumpy plateau' lasting for several years (Heinberg, 2004: 34-37). The plateau is due partly to the smoothing effect of aggregating national or regional production profiles which peak at different times. The bumps are expected to result from complex supply/demand interactions (such as cycles of supply constraint, price spike, demand destruction, price fall, demand recovery, etc.), as well as possible political upheavals (see Sorrell et al., 2009: 164). Hirsch (2008) identifies three stylised shapes of the global oil peak:[45] (1) a sharp break; (2) a smooth rollover/roll-down; and (3) a plateau, defined as production fluctuating within a 4% range. He further proposes a general model which includes periods of increase, rollover (slower growth), fluctuating plateau and relatively monotonic decline (see Figure 2-9).

Figure 2-9: A general model of the global oil production peak



Source: Hirsch (2008)

The rate of decline

Estimates of the world post-peak decline rate for conventional oil vary between approximately two to eight per cent per annum (Heinberg, 2006). The decline behaviour of giant oil fields provides a useful indication of possible global decline rates given the dominance (60%) of giant fields in total production. Three detailed studies of post-plateau decline rates of giant oil fields yielded comparable results, namely: average decline rates of 6.5% (Hook et al., 2009) and 6.3% (Jackson & Eastwood, 2007); and production-weighted decline rates of 5.5% (Hook et al., 2009), 6.5% (IEA,

[45] Hirsch (2008) does not specify whether his model refers to conventional oil or all oil; it can probably be taken to apply to the latter.

2008) and 5.8% (Jackson & Eastwood, 2007). Hook et al. (2009: 2271) found that decline is faster in off-shore compared to land-based fields, and slower in OPEC fields relative to non-OPEC fields. Furthermore, smaller oil fields typically decline at least as fast as giant fields (Hook et al., 2009; IEA, 2008). Observed decline rates for conventional oil in large post-peak regions (North America and Europe) have been of the order of 3-5% per annum (Hirsch, 2008).

According to Sorrell et al. (2009: x), "[t]he average rate of decline from fields that are past their peak of production is at least 6.5%/year globally, while the corresponding rate of decline from all currently-producing fields is at least 4%/year." However, the global decline rate has been on a rising trend and is expected to continue to increase as the relative contribution of smaller, newer and offshore fields to total production increases while more giant fields enter decline (IEA, 2008; Hook et al., 2009). Furthermore, improved technologies for extracting oil tend to prolong production plateaus, but at the expense of higher subsequent decline rates (Hook et al., 2009: 2267). These factors taken together imply great challenges and incentives for the development of new oil fields, enhanced oil recovery, and production from unconventional sources to offset depletion from currently producing fields. As Sorrell et al. (2009: x) note, for production to be maintained at 2008 levels capacity equivalent to that of Saudi Arabia (the world's second largest producer in 2009) would need to be added every three years.

Table 2-3: Projections of future oil production in 2030

Source	**Production in 2030 (mbpd)**	**Category[a]**
Energy Watch Group (2007)	39	All oil
ASPO (2009)	55	All oil
Uppsala University (Aleklett et al., 2009)	55 67 76	Conventional oil (excl. NGL) All oil All liquids
Peak Oil Consulting (2008)	65	All oil
Energyfiles (2008)	79	All oil
Total (2008)	93	All oil
OPEC (2008)	94	All oil
IEA (2008)	75 106	Conventional oil (excl. NGL) All liquids
IEA (2010)	68.5[b] 99[b]	Conventional oil (excl. NGL) All oil
EIA (2009)	93 103 107	Conventional oil (incl. NGL) All oil All liquids
ExxonMobil	105	All oil

Source: Original authors and Sorrell et al. (2009)

Notes:

a) *For definitions of oil categories, refer to Table 2-1.*
b) *Forecast for 2035.*

Estimates of future oil production rates vary considerably, depending on forecasting methodologies (e.g. resource-constrained or demand-driven) and assumptions (e.g. about rates of EOR, the amount of oil yet to be discovered, the scaling up of unconventional oil production, etc.). At the optimistic end of the spectrum, IEA (2008), EIA (2009) and ExxonMobil (in Sorrell et al., 2009) project production of all liquid fuels to increase to over 100 mbpd by 2030 (see Table 2-3). In contrast, Aleklett et al. (2009) foresee all liquids production declining gradually from 2008 to reach approximately 75 mbpd in 2030. On the pessimistic side, ASPO (2009) and EWG (2007) forecast all-oil production in 2030 of 55 mbpd and 39 mbpd, respectively.

Non-geological factors

In addition to geological constraints, several "above ground" political and economic factors are likely to play a significant part in the evolution of oil supply and increase the likelihood that oil production will decline rapidly rather than slowly after the peak/plateau. Possibly the most significant of these factors is resource nationalism on the part of oil producers. Hirsch (2008: 886) notes that the "growth of resource nationalism has been so significant that the International Oil Companies (IOCs) today control only a small fraction of world oil reserves." Indeed, some oil exporting countries – notably Russia and Venezuela – have in recent years taken steps to further nationalise their oil industries, the main motive likely being to capture a larger share of the revenues. In the process, they have excluded certain IOCs that have the knowledge, equipment and incentive to exploit reserves more rapidly and possibly more efficiently. National Oil Companies (NOCs) have a tendency to pursue political and social objectives over-and-above commercial functions, and sometimes neglect needed maintenance and investment, which can result in reduced oil production (Hirsch, 2008). Furthermore, some oil exporting nations might decide to conserve oil reserves for their own domestic consumption and strategic use, which Hirsch (2008: 887) terms an "Oil Exporter Withholding Scenario". Another possible motivation for withholding oil exports might be anticipation of future price rises, which would yield higher revenues (Bentley et al., 2007). Either way, the result would be less oil available on world markets.

Second, there is a risk of an increasing prevalence of conflict and wars in oil producing countries, which could constrain production. This could take the form of internal conflict such as civil wars or militant attacks (as has been occurring in Nigeria for many years), motivated in part by a desire to control oil revenues. Another possibility is international wars in oil producing regions as major powers compete for access to dwindling oil supplies (Klare, 2005).

A third factor that could raise the rate of decline is the negative impact of economic and financial crises on investment in the oil industry. In 2009, energy investment declined precipitously as many projects were delayed or cancelled as a result of the credit crunch and a fall in demand for final energy (IEA, 2009: 5). This fall in investment could precipitate a supply crunch by 2016 (Sorrell et al., 2009; IEA, 2009). In addition, continued volatility in oil prices will cause greater uncertainty for oil investors and may further dampen oil exploration and new investment, leading to higher decline rates. On the other hand, Heun & De Wit (2011) show that economic interactions (oil shortages leading to higher oil prices, which trigger recession and reduced demand, leading to lower oil prices) could extend the oil 'plateau' and delay the onset of decline.

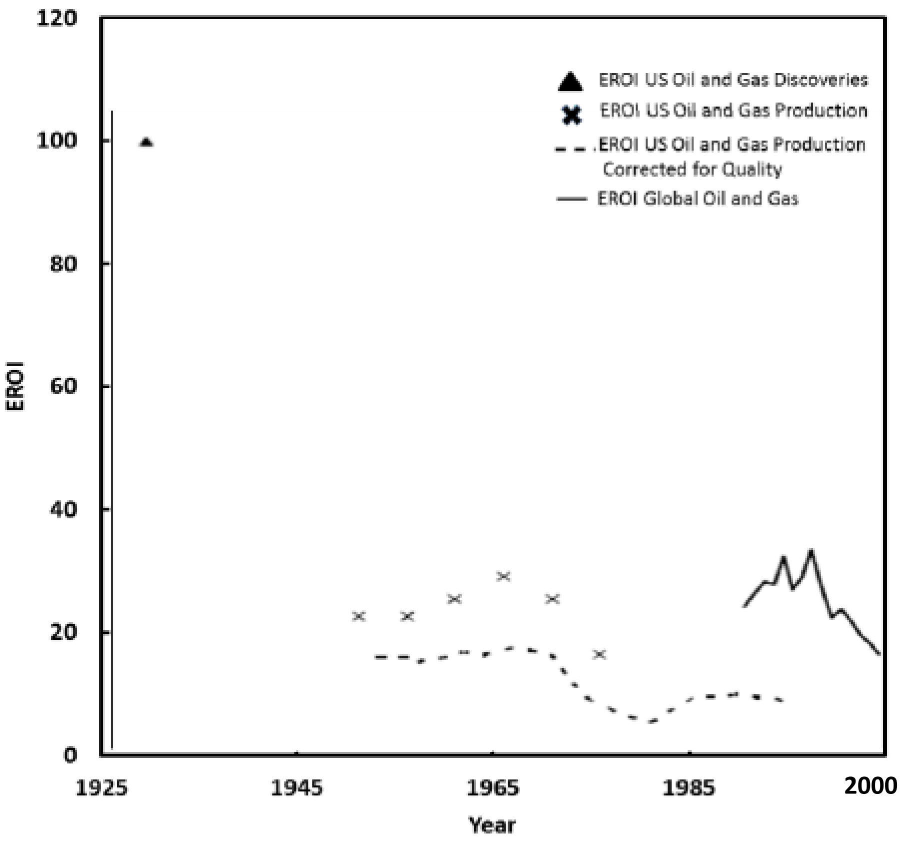
Fourth, much of the infrastructure supporting the production, refining and distribution of oil is rapidly ageing and corroding, without being replaced or adequately maintained (Simmons, 2007; 2008). The incentives to replace such long-lived capital may diminish even more when oil production is in decline. This may lead to shortages induced by faulty infrastructure rather than a lack of crude oil itself. In a similar vein, the average age of skilled personnel in the oil industry is high and rising, resulting in an increasingly acute shortage of adequate skills (Simmons, 2007; 2008). This is likely to hamper further exploration and production, especially in less accessible oil provinces.

By way of summary, Hirsch (2008: 888) develops three scenarios for the shape of the global oil peak and subsequent rate of decline. In the "Best Case Scenario", global production reaches a maximum plateau lasting several years and subsequently declines by 2–5% per annum. In the "Middling Case Scenario", oil production rises to a relatively sharp peak and then declines monotonically at 2–5% per annum. In the "Worst Case Scenario", the sharp peak is exacerbated by oil exporter withholding, which steepens the decline to a rate potentially greater than 2–5% per annum. It is worth noting that world production of all liquids has already been on an undulating plateau since 2005.

2.1.5 Net energy and energy return on investment

Another two crucial aspects of global oil depletion, which are neglected by many studies, are the *net* energy available from oil as opposed to the *gross* energy content, and the related concept of energy return on investment (EROI).[46] Although the precise relation between net and gross energy at the global level is unknown, based on the experience of the US-48 the net energy derived from global oil is likely to reach a peak at approximately the same time as gross energy (production) peaks (Cleveland, 2008). However, after the peak net energy is likely to fall faster than gross energy as production shifts to fields that are smaller, more remote and harder to access, and to unconventional oil sources that have lower EROI. Another important factor is that not all types of liquid fuels contain the same energy content per unit volume. For example, crude oil contains about 5.8 million British thermal units (mBtus), compared to 4.2 mBtus for NGLs and 4.1 mBtus for ethanol (Koppelaar, 2010). Thus as crude oil depletes and is replaced by NGLs and biofuels, the net energy content of 'all liquids' will decline relative to the volume as measured in barrels.

Figure 2-10: Energy return on investment for US and world oil and gas



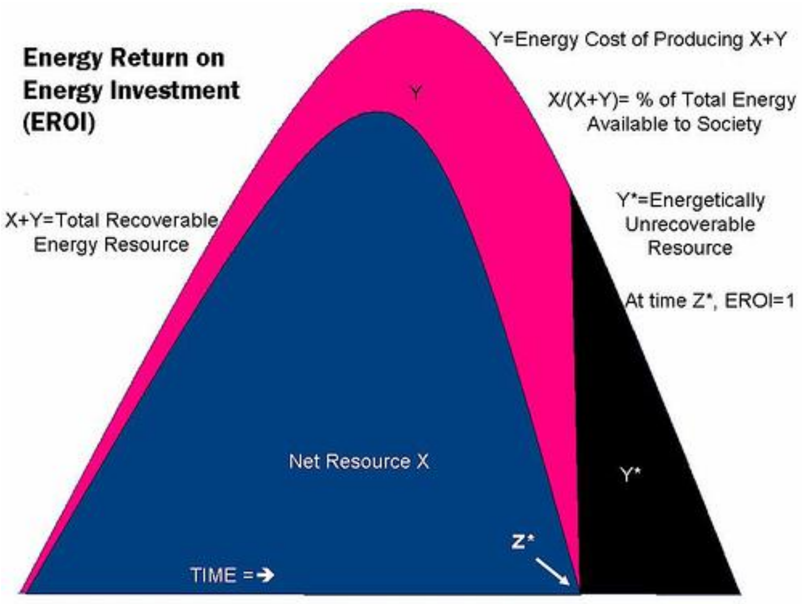
Source: Gupta & Hall (2011: Figure 1)

[46] The terms 'net energy' and EROI were defined in Section 1.2.2. Net energy (respectively, EROI) is the difference (ratio) between the energy output delivered by an energy producing process and the energy inputs (including the energy embodied in physical capital) used in that process. More precise definitions of EROI are provided by Murphy and Hall (2010).

In general, the EROI for any energy source, including oil, is expected to increase with improving technology and decrease with depletion;[47] EROI for oil and gas is also inversely related to drilling activity in the short term (Gupta & Hall, 2011: 1797). Estimates of EROI from historical data clearly demonstrate that the EROI of oil has declined over time (see Figure 2-10; also Guilford et al., 2011). The EROI for new oil and gas discoveries in US in the 1930s was about 100:1, but EROI for production fell to 30:1 by the 1970s and to between 11-18:1 in 2005 (Cleveland et al., 1984; Cleveland, 2005). Gagnon, Hall and Brinker (2009) found that the EROI for global oil and gas is on a declining trend, having nearly halved from 35:1 to 18:1 between 1999 and 2006. They warn that "[i]f the decline in EROI continues, then the amount of energy that will be available to sustain and grow the economy, both nationally and worldwide, will decline as well" (Gagnon et al., 2009: 500). The EROI of unconventional oil and other energy sources is discussed in Section 2.2.1.

Importantly, when the EROI approaches 1:1, the net energy approaches zero, in which case it makes no energetic sense to continue extracting the resource; i.e., the remaining resource is effectively unrecoverable (see Figure 2-11). Based on linear extrapolation, Gagnon et al. (2010) estimated that the EROI for global oil and conventional natural gas could approximate 1:1 by about 2022, but note that the uncertainty surrounding this point estimate is large and that an exponential decline might be more realistic. Heun and de Wit (2011) find statistical confirmation that a declining EROI for oil is associated with a rising oil price, and show that when the EROI ratio falls below 10:1, the oil price increases non-linearly. Hall et al. (2009) estimate that the minimum EROI necessary to support a sustainable society is approximately 3:1, but that such a society would be significantly less complex than the current industrial socioeconomic system. Given these findings, it seems clear that the importance of net energy is seriously neglected by the neoclassical economic perspective on oil resources and depletion, and within the energy literature more broadly (Gupta & Hall, 2011).

Figure 2-11: EROI, gross and net energy delivery over time



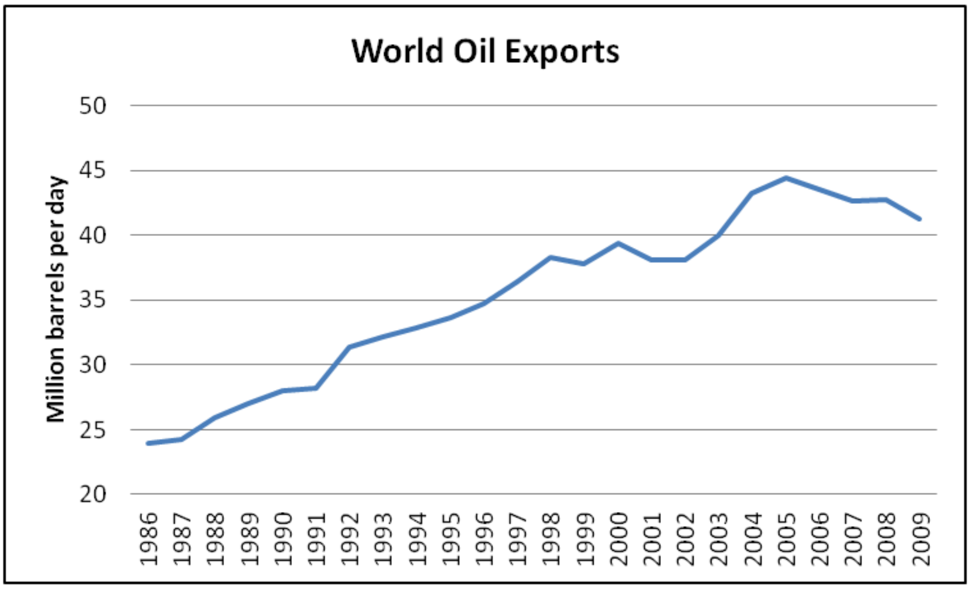
Source: Helix (2010)

[47] In the case of renewables such as solar and wind energy, the analogy to depletion is that the most favourable sites (highest solar radiation or wind potential) tend to be used earlier on; the resource itself is not depleted.

2.1.6 World oil exports

For oil importing nations, including South Africa, the quantity of oil traded on international markets is of more immediate significance than total world oil production. World oil exports constituted 50% of total world oil production in 2008 (EIA, 2011a). Historical data show that world oil exports reached a peak of 44.4 mbpd in 2005, declining to 41.3 mbpd in 2009 (see Figure 2-12).[48] It is highly likely that world oil exports have passed their all-time peak because domestic consumption of oil is on a rising trend in most oil-producing countries.[49] The top six net oil exporting countries in 2009 (Saudi Arabia, Russia, Iran, Nigeria, the United Arab Emirates and Iraq) together accounted for almost half of world net oil exports. Domestic consumption between 2004 and 2009 grew by an average of 5.4% in Saudi Arabia, 0.4% in Russia, 2.9% in Iran, -0.7% in Nigeria, 6.9% in the UAE, and 5.7% in Iraq. This trend is likely to persist as global oil production peaks, since a rising oil price boosts oil revenues and economic growth in oil exporting nations, typically leading to higher domestic oil consumption and diminishing volumes available for export. Thus world oil exports will in all likelihood continue to shrink by several percent per annum, and an increasing number of current net oil exporters will become net oil importers over time. Once global oil production peaks, the decline in world oil exports will be faster than the decline in gross production, putting even more upward pressure on oil prices.

Figure 2-12: World oil exports, 1986-2009



Source: EIA (2011a)

Note: Includes all conventional and unconventional oil sources but excludes biofuels.

The geopolitical aspect of world oil exports is also important. In 2008, 11 of the world's top 15 oil exporting nations were members of OPEC, which collectively supplied 67% of world oil exports (EIA, 2011). As world oil exports decline, the pricing power of OPEC will increase significantly, although

[48] In 2009 OPEC curbed its supply of exports by approximately 3 mbpd in response to the collapse in the oil price (OPEC, 2009).

[49] For individual oil exporters, the Export Land Model (Brown, 2006; Brown & Foucher, 2008) describes a situation in which production is declining at a modest rate, but because domestic consumption is rising, exports decline at a more rapid rate. This has been observed in several countries, such as Indonesia and the United Kingdom. The United Kingdom changed from being a significant net oil exporter (more than 1 mbpd) to a net oil importer in just 7 years, following its production peak in 1999 (Brown & Foucher, 2008).

cooperation among the members might be increasingly difficult. In fact, in 2011 Saudi Arabia went against the majority decision by OPEC members, unilaterally raising its oil output to partially compensate for the approximately 1.2 mbpd of lost oil exports from Libya following the armed rebellion in that country. It seems possible that once world oil production begins to decline annually, there will be little incentive for any oil exporters to limit production, other than in the short term if prices fall following severe economic recessions.

2.1.7 Summary of global oil depletion

Although there are many uncertainties regarding the nature of global oil depletion, the literature reveals several undeniable features and some that are likely given the evidence to date. Indisputably, oil is a finite resource subject to depletion, i.e. the successive and irreversible draw-down of resources as a consequence of production and use. Consequently, oil production in any region begins at zero, reaches a maximum at some point in time, and subsequently declines towards zero. Ongoing depletion will ultimately result in the economically extractable resources diminishing towards zero. The Hubbert curve makes it clear that the important point in the production lifecycle is the peak of production, not when oil reserves are (nearly) exhausted. The peak marks the transition from an era of increasing annual supply to one of progressive decline in production, and also marks the end of the era of cheap oil. The most credible forecasts put the date of the global conventional oil peak or plateau between 2006 and 2020. The shape of the global oil production peak and the rate of subsequent decline will depend on a complex, interacting mix of ‘below-ground’ (geological) and ‘above-ground’ factors (including technology, politics and geopolitics, resource nationalism, demand, economic interactions, rates of investment, infrastructure and availability of skilled personnel). The production curve might not be symmetrical; the longer any plateau is maintained, the higher the likelihood of a steeper ultimate descent. The decline rate could be between 2-5% in a best case scenario, or greater than that in a worst case scenario in which oil production is shut in as a result of deliberate withholding by oil producers or wars in oil producing regions. Furthermore, the net energy delivered by global oil production is likely to peak slightly before the gross energy, and will decline more rapidly thereafter as the EROI of oil continues its historical decline. Finally, world oil exports appear to have peaked in 2005 and can be expected to decline more rapidly than gross world oil production.

Given society’s dependence on oil, the inevitable peaking and decline in global oil production raises two vital questions, which are addressed in the next section: (1) can other forms of energy adequately substitute for dwindling oil?; and (2) to what extent can improved energy efficiency and other conservation measures offset declining oil production?

2.2 Energy substitutes and conservation

The potential role of substitute energy sources and technology in mitigating oil depletion is another issue of debate between optimistic perspectives (chiefly held by neoclassical economists) and conservative viewpoints (e.g. held by certain oil geologists and ecological economists). The former group assumes that there will be a smooth transition from oil to alternatives, mediated by markets and energy prices. The latter argue that the alternatives have serious limitations and that markets may be inadequate to ensure a painless transition. Section 2.2.1 considers the main advantages and limitations of a range of potential substitutes for conventional oil. Section 2.2.2 discusses energy efficiency and conservation. Section 2.2.3 provides a summary of the scale and temporal challenges involved in mitigating oil depletion.

2.2.1 Substitute energy sources

As discussed in the introduction, oil is put to a variety of uses, namely: as a transport fuel; for space heating; for electricity generation; as a lubricant; and as a feedstock for the manufacture of petrochemical products. Thus as oil depletes, substitutes for all of these uses – of which energy is the primary one – should ideally be found and developed. At least ten criteria can be identified for assessing the quality of alternative energy sources. These are: energy return on investment (EROI); size and scalability of the energy surplus; energy density or yield (by volume, mass or area); ease of storage and transportability; location of the resource; dependence on additional resources; renewability; reliability; direct monetary cost and financial risk; and environmental impacts (Heinberg, 2009a; Cleveland, 2008). Oil became the dominant energy source for industrial societies precisely because it performs well on most of these criteria: it has yielded a very large energy surplus with high (although declining) EROI; it has high energy density per unit volume (38 megajoules per litre) and mass; it can be easily transported and stored in both raw and refined states; it is very versatile and reliable; it is found in many regions around the world but has a relatively small land footprint; thus far its use has not been constrained by a lack of other resources; and until quite recently it has been very cheap, apart from a few short-lived price spikes (Heinberg, 2009a). The major disadvantages of oil are that it is non-renewable and its use results in serious environmental pollution, including carbon dioxide (CO_2) emissions. Furthermore, it is becoming increasingly scarce geographically, which is fuelling conflicts. A wide range of potential substitutes for oil are evaluated below in terms of the foregoing criteria.[50]

Unconventional oil

There are three types of unconventional oil resources, namely heavy oil, oil sands and oil shale (Aguilera et al., 2009: 154). Heavy oil, which is mostly located in Venezuela's Orinoco Belt, is denser and more viscous than conventional oil and requires special extraction techniques. Oil sands (also termed tar sands and natural bitumen) are combinations of sand, water, clay and bitumen, from which oil can be extracted either by open-cast mining or by in-situ recovery. The majority of oil sands lie in Canada's Alberta province. Oil shale, found predominantly in the western United States, is comprised of an organic material, known as kerogen, embedded in shale rock. Oil is extracted from oil shale by surface or sub-surface mining, or by in-situ recovery techniques.

In 2008, unconventional oil accounted for just 4% of total petroleum production (Maggio & Cacciola, 2009: 4764), or about 1.5 mbpd (Strahan, 2009). However, unconventional oil resources are apparently abundant compared to conventional oil. Aguilera et al. (2009: 154) cite estimates for heavy oil, oil sands and oil shale of 4, 5 and 14 trillion barrels of oil equivalent (BOE), respectively (compared to between 2 and 4 trillion barrels of conventional oil). Nonetheless, proved reserves as of 2008 for Venezuelan extra-heavy oil and Canadian oil sands stood at 99 Gb and 151 Gb, respectively (BP, 2009), while US shale oil reserves had yet to be categorised as 'proved'. The US Geological Survey recently estimated that Venezuela's Orinoco belt could hold in excess of 500 Gb of recoverable oil (BBC, 2010).

Production of unconventional oil has several major limitations and disadvantages. Possibly of greatest importance is that the EROI of unconventional oil sources is considerably lower than that of conventional oil (Cleveland et al., 1984; Hall, 2008). For example, the extraction and refining of Canadian oil sands consumes large and unsustainable quantities of natural gas (Soderbergh et al., 2007). The EROI of Canadian oil sands has been estimated at approximately 5:1, while that of oil shale has been estimated in the region of 3-4:1, but could be closer to 1:1 if adjusted for the quality of energy inputs and outputs (Gupta & Hall, 2011). Second, greater exploitation of unconventional oil would require very large amounts of costly capital investment (de Castro et al., 2009: 1829).

[50] This review draws substantially on Heinberg (2009a), as well as Heinberg (2003).

Production costs are also likely to be high, partly as a result of the low EROI and also because extraction and refining are more difficult (Aguilera et al., 2009). Murphy and Hall (2010) report the marginal cost of Canadian oil sands as $85/bbl. The IEA (2008) estimated that it would cost between $50 and $110 to produce a barrel of oil equivalent from shale oil and $32-68/bbl for heavy oil and bitumen. Third, and largely as a result of the foregoing constraints, some experts argue that production flow rates will always remain relatively low. For instance, Soderbergh et al. (2007) show that even under a crash programme scenario, oil sands production in Canada is unlikely to surpass 3.6 mbpd by 2018 and 5 mbpd by 2030. Finally, unconventional oil resources have serious negative environmental impacts (Aguilera et al., 2009; Soderbergh et al., 2007). These include: greenhouse gas emissions that are significantly greater than those of conventional oil; the consumption and contamination of fresh water resources; and general land degradation.

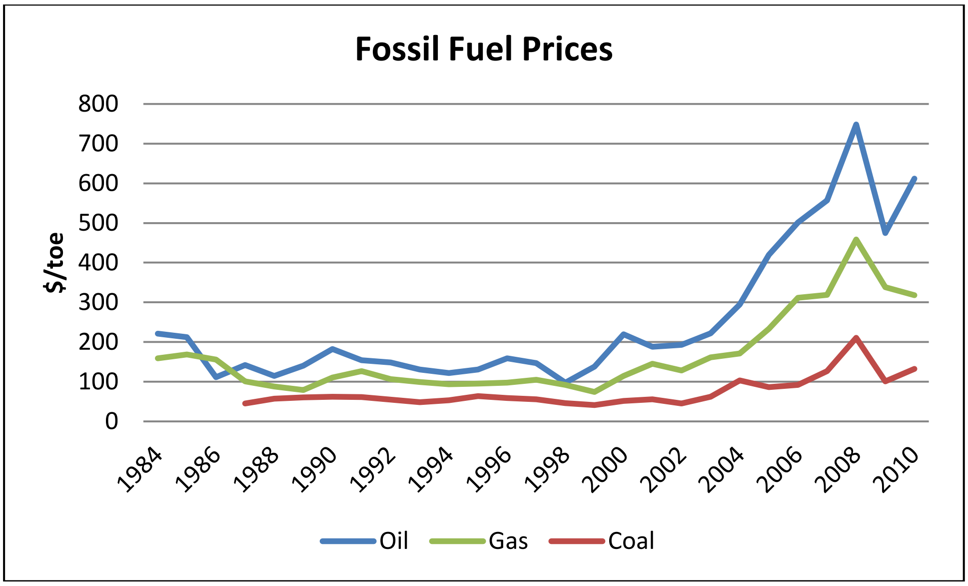
As a result of these various constraints, it is highly unlikely that unconventional oil sources will be scaled up rapidly enough to compensate for declining conventional oil (Robelius, 2007; Greene et al., 2006). Employing a system dynamics model, de Castro et al. (2009: 1830) find that, even under optimistic assumptions (e.g. ignoring low EROI and capital expenditure requirements), offsetting the post-peak decline in conventional oil requires that unconventional oil grow by 10 per cent per annum for 20 years or more, whereas the average annual rate of growth in the 1990s and 2000s was 4.5%. Neither the IEA (2008) nor Aleklett et al. (2009) anticipate significant contributions from unconventional oil over the next two decades. Comparing a number of forecasts, Foucher (2008) found that the addition of unconventional oil did not in general alter the date of peak oil production by more than a few years. In conclusion, unconventional oil sources would at best delay the global oil peak by a few years and lessen the steepness of the post-peak decline, but this would come at the cost of higher oil prices and greater environmental impacts.

Coal

Coal can be substituted for oil directly in the form of coal-to-liquids (CTLs), i.e. synthetic liquid fuels created via the gasification of coal followed by liquefaction using the Fischer-Tropsch process. CTLs have been successfully commercialised in South Africa by Sasol Limited, which has been in operation since the late 1970s, and China had completed its first CTL plant by 2009 (Aleklett et al., 2009). Coal can also potentially substitute for oil indirectly, for purposes other than liquid fuels, such as electricity generation, heating and the manufacture of petrochemical products. Coal scores relatively well on several of the energy criteria. It has historically provided a huge energy surplus, kick-starting the industrial revolution. In 2007 coal constituted 27% of world primary energy supply (IEA, 2009) and was used to generate 40% of electricity globally (Heinberg, 2009a). The EROI of coal has historically been high compared with most other fuels. Cleveland (1992) estimated that the EROI for US coal was approximately 100:1 in the 1960s, fell to about 50:1 and subsequently increased to approximately 70:1 by 1987; however, the ratios were much smaller if adjusted for quality. The energy density of coal is variable (between 5.5 and 30 MJ per kilogram) and somewhat lower than that of oil, but still relatively high (Heinberg, 2009a). Coal can be easily stored and transported by rail or ship, although transport by truck is expensive due to its bulk.

Nonetheless, coal also has several major limitations. First, like oil it is a non-renewable, depleting fossil fuel, whose EROI is expected to decline over time. Official reserves of coal stood at 826 billion tonnes in 2008 (BP, 2009). However, several studies have raised important questions about the reliability of official coal reserve data and suggest that recoverable reserves may be much smaller (see Heinberg, 2009b for a review). EWG (2007) estimates that global coal production could reach a peak by 2025. Mohr and Evans (2009) forecast global peak coal output in energy terms between 2011 and 2047. Hook, Zittel, Schindler and Aleklett (2010) estimate that “a global peak in coal production can be expected between 2020 and 2050”. Rutledge (2011) estimates that 90% of recoverable world coal resources will have been exploited by 2070. Patzek and Croft (2010), using a multi-Hubbert cycle model, estimate that globally the energy derived from coal could peak as early as 2011 owing to declining resource energy density. Second, over 80% of recoverable coal reserves are concentrated in just six countries: the USA, Russia, China, India, Australia and South Africa (BP, 2009), which might imply future scarcity and high prices for many coal-importing countries. Demand for coal (chiefly for electricity generation and industrial processes) rose rapidly between 2003 and 2009, mainly in China and India, contributing to a price surge and shortages in some countries. Third, the CTL conversion process involves a considerable loss of energy; approximately one to two tons of coal are required to make one barrel of synthetic oil, and consequently the EROI of CTL is very low (Hook & Aleklett, 2009), possibly as low as 0.5:1 (Hughes & Anslow, 2007). As a result of resource constraints, Hook and Aleklett (2009) maintain that CTL cannot feasibly be regarded as a solution to oil depletion, but merely part of a broader set of responses. Fourth, several years are required to construct a new CTL plant and the capital costs are very high (Aleklett et al., 2009). The IEA (2008) estimated that CTL production costs ranged between \$60-113 per barrel, higher than all other sources of oil. Fifth, coal is highly polluting, giving rise to smog, acid rain and the highest CO_2 emissions of any hydrocarbon per unit of energy consumed. CO_2 emissions from CTLs are approximately double those of oil (Strahan, 2009). Although sequestration of carbon dioxide has been proposed, this depends on the suitability of local geology and on effective monitoring and policing, and would raise costs substantially. Finally, although coal has historically been very cheap, its price tends to be relatively closely linked to the oil price and hence the oil peak might well signal the end of cheap coal (see Figure 2-13).

Figure 2-13: Fossil fuel prices, 1984-2010



Source: BP (2011)

Note: toe = tonnes of oil equivalent

Natural gas

Natural gas, the third conventional fossil fuel, can also substitute directly or indirectly for oil. As of 2009 the gas-to-liquid (GTL) process was used in just a few plants around the world, and contributed less than 0.2 mbpd to ‘all liquids’ supply in 2008 (IEA, 2008). In addition, compressed natural gas (CNG) is used in several countries to fuel road vehicles powered by internal combustion engines. Natural gas is also used as a feedstock for petrochemical products, and in many such applications it can substitute for oil. Like oil and coal, natural gas has historically provided a large energy surplus. It contributed 21% of world primary energy supply in 2007, being used mainly to generate electricity and to provide heat for buildings and industrial processes (IEA, 2009b). Gas is a highly versatile and efficient energy source with a high energy density by weight, although not by volume. The EROI of gas tends to be higher than that of oil as it flows more readily from wells (Gagnon et al., 2009). Gas can be easily and relatively cheaply transported by pipeline, although transport by ship is more expensive as it requires special infrastructure to create liquefied natural gas (LNG) by pressurising the gas at low temperatures.

On the other hand, natural gas suffers similar limitations to the other fossil fuels. First, it is non-renewable and depleting, and its EROI tends to decline over time as more marginal sources are exploited. Although a gas glut is likely until about 2015 (IEA, 2009), conventional gas production could reach a peak between 2020 and 2030, depending on the extent of infrastructure created to extract and transport the gas (Bentley et al., 2007). Furthermore, since gas is often co-produced with oil, as more oil wells become uneconomic, some of the associated gas will no longer be produced. In any event, natural gas will most likely be needed for other purposes (e.g. electricity production, heating and manufacture of fertilisers) rather than for GTL in the future (Bentley, 2002; Darley, 2005). Second, natural gas reserves are highly concentrated: 77% are located in 10 countries, with Russia (23%), Iran (16%) and Qatar (14%) possessing the largest shares (BP, 2009). This poses risks of geopolitical conflict. Third, GTL has high production costs relative to oil (Aleklett et al., 2009); the IEA (2008) estimated production costs of GTLs to be between $38-113 per barrel in 2008. Fourth, although CO_2 emissions for natural gas are lower than those for oil on a per unit energy basis, emissions for GTLs are higher than those of conventional oil because of the energy consumed in the conversion process (Strahan, 2009). Lastly, since oil and gas are partial substitutes, their prices are to an extent correlated, meaning that oil depletion will likely place upward pressure on the price of gas and GTLs (see Figure 2-13 above). The IEA (2010: 186) foresees GTL production rising to just 750,000 bpd by 2035.

In recent years, there has been much discussion of unconventional gas resources, which include shale gas (natural gas trapped in shale rock formations), tight gas (gas that is more difficult and expensive to extract than conventional gas) and coal bed methane (gas associated with coal seams). A report commissioned by the US Energy Information Administration (EIA, 2011b) estimated world technically recoverable shale gas resources on the order of 6,622 trillion cubic feet (tcf), which would increase the total world gas resource by some 40% to 22,600 tcf. The US has witnessed a boom in shale gas production over the past decade, such that by 2010 shale gas contributed 23% of total US gas production (EIA, 2011b: 1). However, some independent researchers have demonstrated that shale gas is neither as plentiful nor as cheap as the industry routinely claims (Hughes, 2011; Berman & Pittinger, 2011).[51] Moreover, international evidence increasingly documents large-scale negative environmental impacts from the hydraulic fracturing ("fracking") technique that is used to exploit shale gas reserves (Hughes, 2011). First, the drilling and fracking process also requires massive quantities of fresh water. Second, fracking has in some instances contaminated water supplies with a wide range of toxic chemicals that are injected into the shale rock to release the gas. Third, recent research has indicated that the lifecycle GHG emissions from shale gas production might be worse than those from coal, mainly due to fugitive emissions of methane (Howarth et al., 2011). In light of these concerns, several states in the US and some countries (e.g. France) have placed moratoriums on shale gas drilling. Thus the global potential for shale gas production remains uncertain, but is probably much smaller than the EIA (2011b) report suggests.

[51] Berman (2010) points out that the commercially successful areas of production turn out to be small subsets of the indicated shale gas basins, and describes the investment in US shale gas as a classic economic bubble. Berman and Pittinger (2011) show that production decline rates for individual wells tend to be very steep, such that drilling activity must continually increase in order to maintain production levels; this makes shale gas production relatively expensive.

Biomass and biofuels

Traditional biomass, chiefly in the form of wood but also including other plant matter and animal dung, is still used by nearly half the world's population for heating and cooking. Biomass is increasingly being used to generate electricity and/or heat for industrial purposes (including combined heat and power (CHP) plants). It can also potentially substitute for oil as a feedstock for chemical products (Brehmer, Boom and Sanders, 2009). Biogas can be produced efficiently from waste materials and used for residential or industrial purposes. The main advantages of biomass are that it is renewable and can in principle be carbon neutral, and it is very widely available geographically. However, if exploited at unsustainable rates, as is occurring in many parts of the world, use of biomass can lead to deforestation and desertification and it can destroy carbon sinks. The EROI of biomass is highly variable due to differences in soil quality and climatic conditions.

Biomass can also be converted into liquid fuels as a direct substitute for petroleum fuels. Ethanol, produced from crops such as corn and sugar cane, can be blended with conventional petrol in various ratios and used in existing internal combustion engines (ICEs), or used in 100% concentration in modified ICEs. However a litre of ethanol has only 80% of the energy content of a litre of oil (Lloyd, 2005). Biodiesel can be made from various oil-bearing crops, including soybeans, palm, canola, sunflower and the Jatropha tree, as well as from algae, although the latter has yet to be successfully commercialised. Biodiesel can be blended with conventional diesel or used alone in diesel engines.

However, biofuels have several important disadvantages. First, they have relatively low EROI compared to oil. Evidence suggests that the EROI of corn-based ethanol is statistically not significantly different to 1:1 (Murphy et al., 2010), while that for Brazilian sugar-based ethanol could be as high as 8:1, and 3:1 for biodiesel (Farrell et al., 2006). Second, crop-based biofuels will inevitably compete for suitable arable land and water with food production, which is required to meet the needs of a large, growing world population (Brown, 2008). Growing production of biofuels between 2004 and 2008 was identified as one of the primary factors contributing to a massive rise in global crop and food prices (Baier et al., 2009), which resulted in the number of hungry persons in the world increasing to over one billion. Third, production of biofuels often entails environmental problems such as soil degradation, excessive fresh water consumption and pollution. In addition, if new lands are converted to biofuels production then net CO_2 emissions over the full life cycle might be substantially positive and therefore contribute to global warming (Pineiro et al., 2009).

As a result of these problems, support for biofuels has waned in many countries. The EIA (2009) projected that in 2010 biofuels would contribute just 1.9 mbpd (2.2%) to total world liquid fuels supply, and 5.9 mbpd (5.5%) by 2030. Calculations by Brehmer, Boom and Sanders (2009) show that at best, biomass could replace oil as a petrochemical feedstock, but not contribute meaningfully as a transport fuel.

Nuclear power

Nuclear energy provides electricity and therefore is an indirect substitute for oil as an energy source. All nuclear electricity generated in the world as of 2009 was produced in fission reactors using uranium as a feedstock. Nuclear power accounted for 5.9% of world total primary energy supply in 2008 and 14% of global electricity generation in 2007 (IEA, 2009b). The main advantages of nuclear power are that the technology of pressurised water reactors is well known and they provide a reliable source of base-load electricity at a comparatively low operating cost. Also, CO_2 emissions during operation are very low compared to those of coal-fired power plants.

On the other hand, nuclear power has a number of major limits and disadvantages. First, it relies on a non-renewable, depleting feedstock. EWG (2006) estimates that uranium production could peak before 2050, but that severe shortages could arise as early as 2020 since a significant portion of demand is currently met from decommissioned nuclear weapons from the US and Russia. Dittmar (2011), using a model based on actual historical uranium mining production, estimates that uranium production is likely to peak around 2015 at approximately 58 kilotonnes (kt) per annum, which is about 85% of 2010 demand (68 kt). More US and Russian stockpiles would have to be made available from 2013 to make up the shortfall. To avoid serious uranium shortages and price spikes, Dittmar (2011) recommends a planned global, gradual phase-out of nuclear power starting in 2011. Despite years or decades of research, nuclear energy derived from breeder reactors that recycle spent fuel, from thorium (which is a more abundant element than uranium) and from nuclear fusion have yet to be successfully commercialised and are likely to be decades away at best. Furthermore, since it can take a decade or more for new nuclear power stations to be designed, constructed and commissioned (Goodstein, 2004: 19), and old power stations need to be decommissioned after an average of about 40 years, by about 2015 the global generating capacity of nuclear power might be limited by plant availability (EWG, 2006). Second, available estimates of EROI for nuclear electricity are highly variable, but usually relatively low when measured over the full life-cycle (Power & Hall, 2008).[52] Gupta and Hall (2011) consider the most reliable estimates of EROI to fall in the range 5-8:1. Uranium ore concentrations are declining over time, exerting downward pressure on the EROI.[53] On the other hand, a new generation of nuclear power plants might offset this to some extent through improved efficiency. Third, the initial capital investment is extremely costly, while costs of decommissioning plants and disposing of radioactive waste are possibly even higher.[54] Fourth, nuclear power carries environmental risks, both from uranium mining and from radiation spills (such as occurred after an explosion at the Ukrainian Chernobyl plant in 1986, and after an earthquake and tsunami caused multiple meltdowns at Japan's Fukushima nuclear power plant complex in 2011). In addition, the mining of uranium and the manufacture of cement for construction of power plants require fossil fuels and emit substantial quantities of CO_2. Fifth, as yet no permanent solution has been found for long-term radioactive waste disposal. Finally, there is a risk that enriched uranium and plutonium may be obtained by terrorists for use in 'dirty bombs' (van Leeuwen, 2006).

Renewable energy

Renewable energy sources, which include hydro, wind, solar, geothermal, wave and tidal power, can be harnessed to generate electricity or, in the case of solar and geothermal, heat.[55] Renewable electrical power is not a direct substitute for oil that is used for transportation or for the manufacture of petrochemical products. Rather, renewable electricity is an indirect substitute for petroleum fuels only so long as an alternative, electricity-based transport infrastructure and electricity storage capacity are built as well.

Hydroelectricity constitutes the world's largest source of renewable energy, contributing nearly 16 per cent of electricity generation and 2.2% of primary energy supply in 2007, while the remaining renewables together contributed just 0.7% of world primary energy supply (IEA, 2009b). Hydroelectric power can be generated on a large scale using water stored in dams, or on a micro scale using "run-of-river" flows. The EROI of hydro power is highly variable, depending on the

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[52] Power and Hall (2008) "found the information about the EROI of nuclear power to be mostly as disparate, widespread, idiosyncratic, prejudiced and poorly documented as information about the nuclear power industry itself."

[53] Van Leeuwen (2006: 1) states that "After about 60 years the world nuclear power system will fall off the 'Energy Cliff' – meaning that the nuclear system will consume as much energy as can be generated from the uranium fuel."

[54] According to Thomas (2005: 24), "it seems clear that none of the nuclear power plants built in Britain has ever represented an economic source of power." Smith (2011) states that the decommissioning of a nuclear power plant in Portland, USA cost nearly as much as the $450 million construction cost, while the spent fuel is still stored on site since there is no depository for it to be taken to.

[55] Biomass and biofuels, which were discussed above, are also renewable energy sources.

location and size of the reservoir, with estimates falling in the range 11–267:1 (Gupta & Hall, 2011). Operating costs are comparatively low, although large-scale hydro requires large initial capital outlays. Reservoirs have the additional advantage of being a convenient means of storing electrical energy. On the downside, some hydro plants are affected by seasonal rainfall, and this is likely to be increasingly problematic as climate change intensifies. Moreover, dams are generally very damaging to the local and downstream environments and often involve social dislocations. It has been estimated that one third of the global potential for hydropower is already being utilised (Heinberg, 2009a).

Wind power is a relatively clean, renewable source of electrical energy. It is widely available around the world and the potential resource is immense (Resch et al., 2008). The EROI of wind power has been estimated to average 18:1, which compares favourably with other energy sources including fossil fuels (Gupta & Hall, 2011). Unit costs have fallen over time as the technology has advanced, and by 2008 were comparable even with coal- and gas-fired electricity in some areas. The disadvantages of wind power include: (1) its intermittency and consequent need for load-balancing and/or storage; (2) it is often located in remote regions and has a large land footprint; (3) construction and transport of wind turbines currently relies on fossil fuels; and (4) turbine components currently rely on scarce rare earth metals (see Hirsch et al, 2010).

Solar energy can be utilised directly for space heating and light, as well as indirectly to make electricity via photovoltaic (PV) cells or concentrated solar power (CSP) plants. The latter use arrays of mirrors to focus the sun's rays sufficiently to convert water to steam and drive a turbine. Solar shares many of the same advantages and disadvantages as wind, namely an immense resource that is widely distributed, but with low area density and temporal intermittency. EROI estimates are somewhat lower than wind power: around 3-10:1 for PV and as low as 1.6:1 for CSP (Gupta & Hall, 2011). Unit costs remain comparatively high for solar energy, although they have fallen considerably over the years as technical efficiency has improved. CSP plants located in desert regions may require costly transmission lines and water for cooling and/or the cleaning of mirrors. PV cells currently rely on scarce minerals, which might be a significant constraint unless the technology evolves to use more abundant materials.

Geothermal energy (i.e. heat energy from the Earth's crust) can be used for heating buildings as well as for generating electricity in power plants. The theoretical potential for geothermal energy is immense, but as can be expected there are technical difficulties in harnessing it (Resch et al., 2008). Geothermal energy for small-scale heat pumps is available everywhere. However, large scale geothermal heat and power plants are limited geographically as only some countries have the necessary geology. Many of the more conventional geothermal sites utilising hot springs are already exploited. In addition, natural replenishment of underground water may take many decades, which effectively limits the useful lifespan of most geothermal fields (Heinberg, 2003: 151). The EROI for geothermal electric power has been estimated to fall within a range of 2–13:1 (Gupta & Hall, 2011). Capital costs are high, but power output is constant and CO_2 emissions are very low once the plant is constructed.

The technologies for tapping the energy of the oceans – through tidal fluctuations, waves or currents – are still in their infancy. Tidal power is restricted to specific locations such as estuaries and bays with large tidal ranges. Hughes and Anslow (2007) suggest the EROI of tidal range power could be as high as 87:1, but these authors did not provide details of the calculation methodology and in any case the estimate is probably premature given the infancy of the technology (Murphy, 2010). A single wave power installation was operated in Portugal until 2008. The EROI for wave power has been estimated at 15:1 (Halloran, 2008). Operating costs for both tidal and wave power are comparatively low and CO_2 emissions are negligible. However, capital costs are relatively large and there could be negative ecological consequences, especially for river estuaries. Corrosion and storm damage are other problems associated with ocean power.

Energy from waste

Waste matter is another source of energy: waste can be incinerated to produce electricity, and methane gas can be captured from landfills. The advantage is that no new resources are required as feedstock, but the disadvantages include the release of atmospheric pollutants (toxic chemical and CO_2) and lack of scalability (Heinberg, 2009a). It would be more efficient to create less waste in the first place through the reduction of consumption as well as recycling and re-use of materials.

Summary of alternative energy sources[56]

As noted above, conventional oil performs very well on most of the energy quality criteria. All of the potential alternative energy sources have advantages and limitations, which are summarised in Table 2-4. The other fossil fuels (unconventional oil, coal and natural gas) share some of oil's desirable qualities, although in most cases to a lesser degree. The main disadvantages are that they are all finite resources subject to depletion, with declining EROI, and they have severe environmental impacts. Nuclear power has limited substitution possibilities for oil, is based on a non-renewable mineral, is very costly, and carries significant safety and environmental risks.

The main advantages of renewables are as follows: (1) they are non-depleting; (2) the potential scale of many renewable energy resources is immense;[57] (3) EROI tends to rise and costs fall over time as technologies are improved; (4) environmental impacts, including CO_2 emissions, are generally much less severe than those of fossil fuels; and (5) many renewables are more widely available geographically than fossil fuels.

However, renewables have several major drawbacks: (1) aside from biofuels, they cannot be directly substituted for liquid petroleum fuels as they provide electricity or heat; (2) the EROI of most renewable energy sources is lower than historical ratios for fossil fuels; (3) they currently require fossil fuels (and in some cases scarce minerals) for manufacture, distribution and maintenance; (4) the most abundant renewables, solar and wind, are intermittent sources of power; (5) most are found in low concentrations and thus produce energy on a much smaller scale than conventional power plants; and (6) in some cases (e.g. solar PV and CSP) the unit costs are still relatively high.

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[56] Hydrogen, which is an energy carrier rather than an energy source, is discussed briefly in Chapter 5.

[57] Resch et al. (2008) calculate that the technical and theoretical potentials for renewable energy (RE) are 16 and 300,000 times current primary energy consumption, respectively. This suggests that the constraints on future energy supplies will relate to factors such as policy frameworks and the construction of renewable energy infrastructure, rather than to resource availability. However, Resch does not address the issue of EROI.

Table 2-4: Advantages, limitations and EROI of alternative energy sources

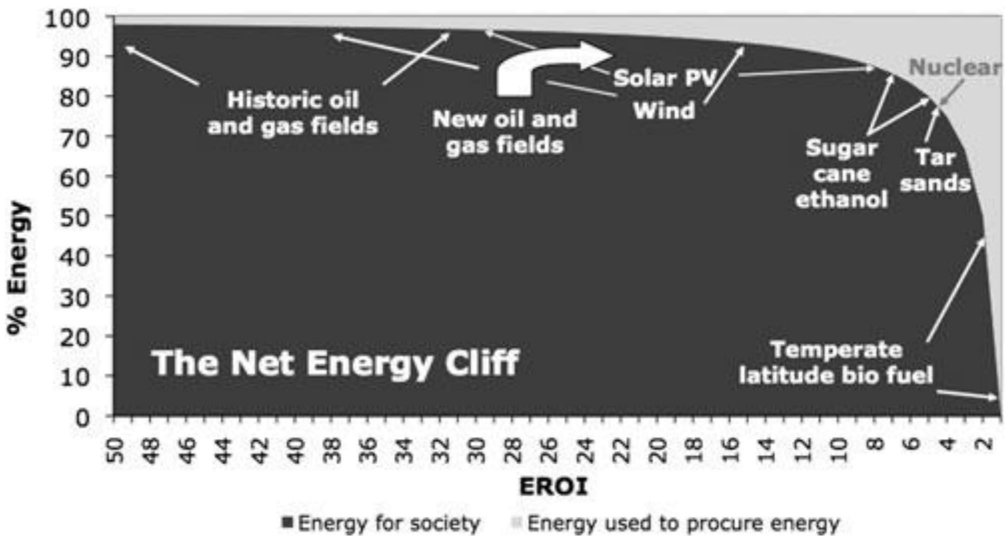
Energy source	EROI	Advantages	Limitations
Conventional oil	18:1 (global average)	huge energy surplus historically high EROI versatile easy transport & storage historically cheap small land footprint	non-renewable declining EROI serious environmental impacts (pollution, CO_2) geographical scarcity source of conflict
Unconventional oil - extra-heavy oil - oil sands - shale oil	 5:1 3-4:1	large resources versatile	non-renewable low EROI lower energy density low flow rates highly polluting high production costs geographical scarcity
Coal - CTL	50-80:1 0.5-8:1	large energy surplus historically high EROI fairly high energy density versatile CTL synthetic liquid fuels cheap, reliable fuel for electricity & process heat easily stored & transported (but bulky)	non-renewable declining EROI severe pollution geographical concentration (80% in 6 countries) water consumption CTL costly & inefficient rising prices
Natural gas - GTL	10:1	large energy surplus historically high EROI high energy density (by weight) versatile GTL synthetic liquid fuels easily transported (pipelines) small land footprint	non-renewable declining EROI pollution (esp. CO_2) geographical scarcity GTL costly & inefficient likely rising prices
Biomass	variable	renewable wide geographical distribution biogas combustion very efficient carbon neutral suitable for CHP EROI highly variable	deforestation lower efficiency power plants biomass needed to maintain agricultural fertility
Biofuels - corn ethanol - sugar ethanol - biodiesel	 0.8-1.6:1 0.8-10:1 1.9-9:1	renewable portable & flexible use use in existing vehicles CO_2 emissions may be lower than oil	mostly low EROI need for arable land & water compete with food corrosion of pipelines net CO2 emissions could be high potential deforestation ethanol mostly uneconomic
Nuclear	5-8:1	reliable source of electricity relatively low operating costs lower CO_2 emissions than fossil fuel power plants	uranium is non-renewable low EROI over life-cycle high construction & decommissioning costs

			environmental impacts (esp. mining & processing) radioactive waste storage risk of radioactive spills long lead times
Energy source	**EROI**	**Advantages**	**Limitations**
Hydro - large-scale - small-scale	11-267:1	renewable EROI can be very high low operating costs potential for expansion	high initial investment costs GHG emissions from construction & from rotting vegetation social impact (relocation) 'run-of-river' power has low density vulnerable to climate change geographically limited
Wind	18:1	renewable huge scale of resource widely distributed fairly high EROI relatively low cost	intermittent may require storage need for load-balancing and transmission grids locations often remote large land footprint construction & transport depends on fossil fuels
Solar - photovoltaic - concentrating thermal	 3-10:1 1.6:1	renewable massive scale of resource widely distributed EROI improves and costs decline as technology improves	intermittent & seasonal may require storage low area density fairly low EROI high up-front costs require scarce materials transmission lines to deserts CSP requires water
Geothermal - heat pumps - power plants	2-13:1	renewable low carbon emissions constant power geothermal heat available everywhere	electric power geographically limited high capital costs water requirements
Tidal power	~ 6:1	renewable low operating costs negligible CO_2 emissions	geographically limited intermittent power capital intensive ecological impact
Wave energy	15:1	renewable low operating costs negligible CO_2 emissions	geographically limited intermittent power high capital costs corrosion & storm damage
Energy from waste - electricity from incineration - methane from landfills		not using new resources	toxic emissions high CO_2 emissions unsustainable source not scalable

Source: EROI figures from Heinberg (2009a), Gupta & Hall (2011), Murphy & Hall (2010) and Hall (2008)

It is thus clear that all substitute energy sources have several limitations, which limit their substitutability for oil, at least in the short- to medium-term (see IMF, 2011b: 91). Perhaps most importantly, given both the declining trend in EROI for fossil fuels and the generally lower EROI for alternative energy sources, "the EROI of the future seems unlikely to be high enough to support society as a whole in the format we are familiar with" (Guilford et al., 2011: 1881). This situation is illustrated well in Figure 2-14, which shows that there is a highly non-linear relationship between the percentage of energy delivered to society (dark shading) and EROI: as EROI falls, the net energy percentage declines very slowly until an EROI of about 5:1, after which there is a "net energy cliff".[58] As can be seen in the above table, many of the alternatives to conventional oil have EROI ratios near to or below 5:1. This raises an important question: to what extent might conservation of energy ameliorate declining oil availability in the future?[59]

Figure 2-14: The 'net energy cliff'



Source: Murphy & Hall (2010: Figure 3)

2.2.2 *Energy conservation*

There are two principal conservation strategies, namely increasing energy efficiency and curtailment, i.e. reducing consumption (Heinberg, 2003: 160). The scope for both of these conservation measures is technically large, although politically difficult. For instance, energy consumption per capita in North America is twice that in Europe and Japan, due partly to consumer preferences (e.g. for large vehicles in the US) as well as to differential taxes on gasoline. Despite these differences, since 1980 the US economy has become considerably more energy efficient, measured by a declining ratio of energy consumption to GDP (Stern & Cleveland, 2004).

Increasing energy efficiency through the use of improved technologies is an example of dematerialisation (as discussed in Chapter 1): less (energy) resources are required for the production of the same quantity of goods or services. Efficiency gains can be achieved at each of three stages, namely production, distribution and consumption of energy. One example of production efficiency is enhanced oil recovery. Another is power generation using technologically superior electric power plants and industrial processes (for instance cogeneration techniques). Transmission efficiencies can

[58] Heun and De Wit (2011) show that oil prices increase non-linearly as the EROI for oil falls off this 'cliff'.
[59] Oil conservation measures are explored more fully in Chapter 5.

be improved for example by replacing road tankers with oil pipelines, or developing smart electricity grids with high-voltage cables to transmit electricity. At the final consumption stage, there are numerous ways of enhancing energy efficiency. In transport, fuel can be saved through the replacement of inefficient internal combustion engine vehicles with hybrids and fully electric vehicles, as well as by shifting from less to more efficient modes of transportation, such as from road vehicles to trains. Other examples include improved building insulation and more efficient lighting. According to the IEA (2009: 8), "[e]nergy-efficiency investments in buildings, industry and transport usually have short pay-back periods and negative net abatement costs, as the fuel-cost savings over the lifetime of the capital stock often outweigh the additional capital cost of the efficiency measure, even when future savings are discounted."

Despite the advantages of energy efficiency, however, it is subject to certain limitations. First, improvements in efficiency are subject to diminishing returns: the low-hanging fruit are reaped earlier, rendering further gains progressively more difficult and expensive (Heinberg, 2003: 161). Second, enhanced energy efficiency requires investment in new infrastructure, which may be constrained by financial and economic conditions. It also requires a substantial amount of time. For example, Hirsch et al. (2005) found that replacing the US vehicle fleet with more fuel-efficient cars would take at least a decade. Third, the so-called 'rebound' effect holds that innovations in energy efficiency can lead to greater aggregate energy consumption as the money saved by consumers is spent on other energy-using goods and services (Berkhout et al., 2000).[60] In addition, new appliances and infrastructure embody a considerable amount of energy in their manufacture, thus offsetting efficiency gains (Heinberg, 2003: 162). Studies of energy and material throughput have shown that absolute decoupling of energy use from economic activity has hardly ever been attained at the national level (Haberl et al., 2004). Even instances of relative decoupling appear to be the result mainly of switching to higher quality energy sources, such as electricity instead of coal (Stern & Cleveland, 2004), or the outsourcing of energy-intensive production to other countries (UNEP, 2011).

These considerations suggest that there may be a need to conserve energy through direct curtailment of energy use as well as through efficiency gains. Curtailment simply involves decisions to terminate the use of energy in specific situations. It is the quickest and least costly option for dealing with energy supply constraints (Heinberg, 2009a: 69). Examples of energy curtailment in transport include car-pooling and greater use of bicycles, as well as decisions to reduce discretionary driving or to travel more locally. Other examples include switching off lights and heating in unoccupied rooms and buildings. Reducing wastage of energy should be the first step in energy conservation, since it carries little or no costs.

Measures aimed at curtailment and efficiency of energy use are vital components of any strategy to deal with oil depletion. However, given current systems of energy, transport and building infrastructure, there are limits to the amount of energy that can be conserved while maintaining current patterns of economic and social activity (Heinberg, 2003: 163).

2.2.3 Summary of substitutes and conservation

Oil has several special characteristics which explain why it is the world's predominant source of primary energy: it is highly versatile both as a fuel (especially for transport) and as an input into the petrochemical industry; historically its EROI and net energy yield have been very large; and it has a high energy density and is easily transported and stored. Although there are a wide variety of

[60] Some estimates of the rebound effect (i.e., the percentage of efficiency gains that are offset by increased consumption) for personal transportation are of the order of 20-25% for the short run and 80% for the long run (Sorrell et al., 2009: 1360).

potential substitutes for oil, none performs well on all of the energy quality criteria: each has advantages and limitations and none is a perfect substitute for oil. In particular, the net energy yield of oil and other fossil fuels has historically been much higher than that of most other energy sources including nuclear power and most renewables. Nevertheless, as fossil fuels and uranium continue to deplete, human society will have no option but to move increasingly to sustainable, renewable sources of energy. As renewables such as solar and wind power currently contribute a miniscule fraction (less than one percent) of the world's energy supply, a large amount of time and resources will be required to scale them up sufficiently.

Various authors differ as to whether alternative energy sources can compensate for declining use of fossil fuels, so that total energy supply remains constant or even continues to grow. At the pessimistic end of the spectrum, Heinberg (2009a: 7) contends that "there is no clear practical scenario by which we can replace the energy from today's conventional sources with sufficient energy from alternative sources to sustain industrial society at its present scale of operations. To achieve such a transition would require (1) a vast financial investment beyond society's practical abilities, (2) a very long time—too long in practical terms—for build-out, and (3) significant sacrifices in terms of energy quality and reliability." Similarly, Hall et al. (2009: 35) argue that both the quantity and the EROI of the main sources of energy for contemporary society are likely to decline in the future. Nel and Cooper (2009) predict that total world primary energy supply could peak and decline from around 2030 as a result of fossil fuel depletion and constraints on nuclear and renewable energy. Moriarty & Honnery (2009) argue that global energy consumption is likely to decline significantly in the future as a result of economic, social, political and environmental factors that will constrain technical potentials for annual energy production. In a seminal report entitled "Peaking world oil production: impacts, mitigation and risk management" prepared for the US Department of Energy, Hirsch, Bezdeck and Wendling (2005) examined a range of energy substitutes and conservation options as part of a crash programme of mitigation, and concluded that "[v]iable mitigation options exist on both the supply and demand sides, but to have substantial impact, they must be initiated more than a decade in advance of peaking."

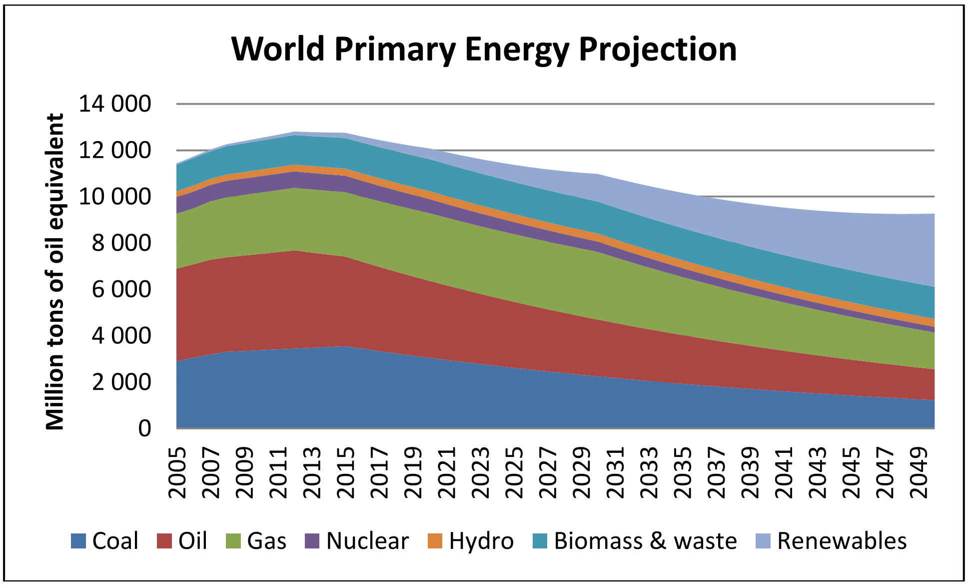
There are, however, more optimistic studies. Jacobson and Delucchi (2009) present a plan for a 100% conversion of world energy to renewables by 2030.[61] The authors assume that sufficient materials will be available, or substitutes will be found for those used currently and likely to face supply constraints. They calculate that the costs of their renewable system would become competitive with traditional energy sources over time. The main obstacle they identify is political will, rather than a shortage of energy or economic resources. In another study, de Vries et al. (2007: 2590) contend that "[t]heoretically, future electricity demand can be amply met from [wind, solar-PV and biomass] sources in most regions by 2050 below 10c/kWh, but major uncertainties are the degree to which land is actually available and the rate and extent at which specific investment costs can be reduced." These authors also claim that "[t]he potential to produce liquid biofuels from primary biomass exceeds the potential transport fuel demand in 3 out of 4 scenarios" (de Vries et al., 2007: 2608), but this seems unrealistic in the face of climate change and population pressures on food supplies and future declines in fossil fuel based fertilisers.

Figure 2-15 shows a projection of world primary energy supply by energy types, based on assumptions about future growth or decline rates that are informed by the foregoing discussion. Notably, the decline in oil production (assumed to begin in 2013) marks the peak in total energy supply. Even assuming a sustained, rapid rate of growth (15% for the first decade and 10% for the second) in renewable energy, this is not sufficient to offset declines in conventional fossil fuels and

[61] The plan involves 3.8 million 5-megawatt wind turbines, 89,000 solar PV and CSP power plants (averaging 300 MW each), and 900 hydroelectric plants (of which 70% are already constructed), and smaller contributions from tidal and wave power.

nuclear power beginning later this decade. At the very least, these projections show that a massive mobilisation of societal resources to develop alternative energy sources will be required to sustain (let alone grow) the current level of energy consumption. Just to offset a 3% p.a. decline in oil production would require the *annual* addition of more renewable energy capacity than exists in the world at present.

Figure 2-15: Projection of world primary energy supply, 2009-2050



Source: Figures for 2005-2008 are from the IEA (2011a); subsequent figures are the author's projections based on the following assumptions:

- *Coal production grows by 1% p.a. until 2015 and thereafter declines by 3% p.a.*
- *Oil production grows by 1% p.a. until 2012 and thereafter declines by 3% p.a.*
- *Gas production grows by 1% p.a. until 2020, plateaus for 10 years, and thereafter declines by 3% p.a.*
- *Nuclear energy remains constant until 2015 and thereafter declines by 3% p.a.*
- *Hydro-electrical energy grows by 2% p.a. until 2020, and thereafter remains constant.*
- *Biomass and waste energy grows by 1% p.a. until 2020 and thereafter remains constant.*
- *Renewable energy (solar, wind, geothermal and ocean) grows by 15% p.a. until 2020, then grows by 10% p.a. until 2030, and thereafter grows by 5% p.a.*

On balance, it appears as if the more pessimistic perspectives on substitutes for oil (and coal) are informed by greater attention to a comprehensive set of energy quality factors, including net energy and EROI, while the optimistic scenarios rest on several very optimistic assumptions. Prudence suggests that the conservative view be taken seriously. As a result of limitations on energy substitutes, therefore, improving energy efficiency is likely to be a necessary requirement for mitigating oil depletion. However, the potential of energy efficiency is itself limited by diminishing returns and the rebound effect. In addition, raising efficiency through replacing infrastructure requires a considerable amount of time and financial resources. Thus curtailment of energy usage, which is the easiest and cheapest mitigation option, appears to be imperative. The next section considers the major implications for the global economy and society if governments and citizens do not proactively mitigate the peak and decline in global oil production.[62]

[62] De Almeida and Silva (2009, 1268) state that, as of 2009, "…almost no country is acting consistently to implement effective mitigation changes." This was still true in late 2011.

2.3 Global implications of unmitigated oil depletion

The debate between so-called 'pessimistic' and 'cornucopian' perspectives on global oil depletion extends beyond its nature and the potential role of substitutes to its likely socioeconomic implications. The dominant view, espoused especially by neoclassical economists, is that global oil depletion does not pose a significant challenge that markets and human ingenuity cannot solve (e.g. Cavallo, 2002; Watkins, 2006; Clark, 2007). To the (limited) extent that future scarcity of oil is admitted, this view holds that resulting higher prices for oil will efficiently stimulate appropriate behavioural responses such as conservation and the adoption of substitutes, and will spur technological development, and thereby ensure a relatively painless transition away from oil. However, a growing body of literature, informed by more eclectic paradigms such as ecological economics and systems thinking, warns of serious implications for the global economy and society if the impending oil peak is not anticipated and proactively mitigated (e.g. Heinberg, 2003, 2004, 2006; Hirsch et al., 2005, 2010; Kunstler, 2005; Leggett, 2005; Campbell, 2006; Strahan, 2007; Leigh, 2008; Rubin, 2009; Global Witness, 2009; Murphy & Hall, 2011). This perspective emphasizes that markets and the price system function imperfectly, for instance because they are not competitive (chiefly because of the pricing power of the OPEC cartel (Adelman, 2003)) and distortions from subsidies and externalities (Hall et al., 2009)), and because oil prices reflect short-term consumption/production flow balances rather than long-term stocks (Daly & Farley, 2004: 113). Furthermore, higher energy prices cause real economic adversity, while the development and deployment of technology to a large extent depends on adequate supplies of reliable, affordable energy (Hall & Day, 2009: 232) and stable economic conditions.

As argued in the previous chapter, the ecological economics paradigm provides a more realistic treatment of the role of energy in the socioeconomic system than neoclassical economics does; it is therefore a more appropriate lens through which to analyse potential impacts of oil depletion. The following four sub-sections summarise the major potential implications of unmitigated global oil depletion in four key areas: (1) economy and financial markets; (2) transport and trade; (3) agriculture, food and population; and (4) geopolitics and conflict. The fifth subsection briefly places the oil depletion challenge within a broader complex of societal challenges, while the final subsection outlines four main scenarios for the future.

2.3.1 Economy and financial markets

Chapter 1 documented the close theoretical and empirical connection between energy consumption and economic growth, and noted the significant impacts of previous oil supply and price shocks. This suggests that oil depletion is likely to have very significant economic repercussions, at least under business-as-usual policies and behaviours. This section assesses the potential economic impacts of the global oil production peak and decline in the short- to medium-term, that is up to about 10 years; longer term scenarios are discussed in section 2.3.6.

On the upslope of the world oil Hubbert curve, supply was essentially driven by demand, except for the relatively minor politically-determined supply interruptions in the 1970s. On the down slope of Hubbert's curve, however, demand will be determined chiefly by (declining) available supply.[63] The

[63] There is a school of thought which maintains that a peak in *demand* will determine the long-term future of oil rather than a peak in *supply*. For example, Sankey et al. (2009) contend that the scaling up of electric vehicles will lead to declining demand for (and price of) oil from 2016. However, given the miniscule market penetration of electric vehicles to date and the lead times to change production lines and replace the current vehicle fleet (Hirsch et al., 2005), along with dependence on oil for other uses and constraints on electricity generation (see Section 2.2.1), this 'peak demand' view is highly questionable. In any event, Sankey et al.

peaking of global conventional oil production will result most immediately in a supply/demand crunch: growth in desired demand for oil will no longer be met by adequate supplies of conventional oil (with relatively high EROI). While production of unconventional oil (with lower EROI) could conceivably be ramped up over time, as discussed in section 2.2 it is very unlikely that this will be sufficient to offset declining conventional oil supplies for long. Thus future oil prices will be driven higher by (1) stagnant and then declining global supplies of oil and (2) declining average EROI for oil, which pushes up costs of oil production (Murphy & Hall, 2011; Heun & de Wit, 2011). Hence while the global Hubbert peak does not signal the exhaustion of oil, it does signal the end of the era of cheap oil[64] (Daly & Farley, 2004: 114; Owen et al., 2010: 4748). Once global production of all oil types enters its terminal decline phase, supplies may conservatively contract by 2-5% per annum (Hirsch, 2008). Thus on the down-slope of the Hubbert curve the world faces the equivalent of an endless sequence of supply-side oil shocks.

History has adequately demonstrated the sensitivity of the oil market to relatively modest supply disruptions, which reflects the highly inelastic nature of oil demand in the short run (Hirsch, 2008; Hamilton, 2009).[65] The Arab Oil Embargo of 1973/4 involved an approximately 5% reduction in global oil supply, and the oil price quadrupled as a result. In 1979/80, the Iranian Revolution resulted once again in an approximately 5% cut in world oil production and triggered a further trebling of the oil price. Both price spikes led to fairly severe economic recessions coupled with much higher rates of price inflation (i.e. 'stagflation') in the majority of industrial nations. Between 2005 and 2008, global oil production was effectively stagnant, compared to an average growth rate of approximately 1.5% p.a. between 1985 and 2004. Thus over four years, at least 6% of global oil supply was effectively not made available to the market, and the price roughly trebled from about $40/bbl to $120/bbl. Hamilton (2009) argues that the US economy would probably not have entered recession in 2007-08 were it not for the steep increase in the oil price during that period, while some scholars argue that this latest oil price shock was the initial impact of peaking global oil production.[66] Looking forward, the IMF (2011b: 89) notes that "[s]udden surges in oil prices could trigger large global output losses, redistribution, and sectoral shifts."

The recessionary impacts of oil price spikes will ensure that the oil price will continue to be (perhaps increasingly) volatile in the short term, especially as price movements are amplified by investor speculation and hoarding behaviour. In the medium term, however, various factors may establish both a floor and a ceiling for oil prices. The lower bound could be determined by the marginal costs of new oil supplies, which Murphy and Hall (2011) suggest will only be brought to market if a price of around $60/bbl is exceeded. However, Skrebowski (2011) notes that OPEC countries may need to maintain prices over $100/bbl in order to maintain their government expenditure levels and thereby political stability, and will impose production quota restrictions if necessary (i.e. limit production slightly to raise prices substantially, by exploiting the inelasticity of demand for oil). Thus it is unlikely that the price of oil will deviate below $100/bbl for long, unless perhaps there is a severe recession.

(2009) foresee a major price spike to $175/bbl in the medium term, which they see resulting from oil *supply* constraints. Thus 'peak demand' apparently occurs as a result of peak supply in any case, i.e. supply constraints act as a tipping mechanism for demand.

[64] The IMF (2011) notes that "[t]he persistent increase in oil prices over the past decade suggests that global oil markets have entered a period of increased scarcity", which they attribute to robust growth in demand in developing countries in the face of slower trend growth in world oil supply.

[65] The IMF (2011) estimated the price elasticity of oil demand to be -0.02 in the short run and -0.07 in the long run. Hamilton (2009) notes that income is a more important determinant of petroleum demand than is price.

[66] Murphy and Hall (2010: 114) argue that "the huge market "adjustments" of the second half of 2008 represent in part the market catching up to declining energy and EROIs." Whipple (2010: 1) states: "it is clear that the peaking of global oil production has already had economic consequences, which will become increasingly serious as time goes on, and that the global economic recession is due at least partially to the lack of significant growth in world oil supplies since 2005."

An upper bound on oil prices could result in the medium term from the recessionary impacts of high oil prices, i.e. when the oil price reaches a certain threshold, it will destroy demand, which relieves the pressure on price (Heun & de Wit, 2011). Based on the 2008 experience this oil price ceiling could be approximately $150/bbl.[67] Nevertheless, once the oil supply is diminishing each year, then the upper bound for oil prices will gradually rise over time as more and more demand has to be destroyed by the price mechanism.

This combination of floor and ceiling forces acting on the price of oil gives rise to "an economic growth paradox: increasing the oil supply to support economic growth will require high oil prices that will undermine that economic growth" (Murphy and Hall (2011: 52). A likely scenario is therefore a cycle of oil supply constraint, price rise, demand reduction, oil price fall, partial recovery in demand, renewed but lower supply constraint, etc (see Murphy & Hall, 2011). Thus various scholars predict that under business-as-usual, real GDP will oscillate around a declining trend (Murphy & Hall, 2011; Hirsch et al., 2010; Martenson, 2011). Based on the historical impact of the 1970s oil shocks and other estimates of the oil/GDP relationship, Hirsch (2008) suggests as a reasonable approximation that a one percentage point decline in oil production is likely to be associated with a one percentage point fall in gross world product (GWP) on average over time. In this case, a sustained 3% per annum decline in oil supplies would result in GWP contracting by nearly 30% over ten years.[68]

Oil price shocks are essentially a signal of short-term scarcity (notwithstanding supply shortfalls often being amplified by the reactions of market participants), and also mediate the economic impacts. The biophysical perspective on economics complements this price-based analysis by highlighting the fact that the fundamental impact of oil depletion is a reduction in the energy available to perform useful work in the economy. In this view, physical oil supply disruptions will have adverse economic impacts irrespective of the price dynamics, by curtailing real economic activities. For example, an exercise simulating the impact of prolonged global oil shortages on the US, named "Oil Shockwave", came to the conclusion that ''[i]t only requires a relatively small amount of oil to be taken out of the system to have huge economic and security implications" (Gates et al., 2005; in Hirsch, 2008: 881).

The peaking and decline of world oil production is likely to have a profound impact on global financial markets (Leigh, 2008: 23; Heinberg, 2011). For example, Sadorsky (1999) found empirical evidence linking negative stock market returns to oil price spikes and volatility. Kerschner and Hubacek (2009), using input-output analysis, found that the finance and insurance sector was one of the sectors most affected by oil supply shocks. More fundamentally, the integrity of the world's debt-based financial system is deeply dependent on continuous economic growth (Heinberg, 2011; Martenson, 2011). This is because new money is created as debt, on which interest payments are required. The only way that the interest can be repaid in the future is if more new money is issued, which itself increases the stock of debt. The collateral for this expanding debt is continuous economic growth, which historically has relied on growing supplies of energy. Should economic growth fail for an extended period as a result of energy constraints, the global financial system may

[67] In 2011 a sustained oil price in the region of $100-120/bbl seemingly brought growth to a near halt in many heavily-indebted industrialised countries, but most developing countries were still growing fairly robustly.

[68] According to Owen et al. (2010: 4748), the "world average oil price–GDP elasticity is estimated at -0.055". This implies that the price of oil would have to rise by 55% in order for GDP to contract by 3%. However, it seems highly unlikely that the price of oil would rise by this percentage every year for a sustained period of years. In any event, the question of how high the price of oil might rise is of secondary importance; it will rise as far as necessary to curb demand such that consumption equals available supply.

implode, compounding the economic adversity (see Tverberg, 2007; Heinberg, 2011).[69] The combination of oil price shocks and a major financial market collapse could lead to a prolonged economic depression, price deflation and soaring unemployment. If, however, monetary authorities reacted by 'printing' money in vast quantities, hyperinflation could result.

In the medium to longer term, to be sure, rising oil prices and physical oil shortages will elicit behavioural responses by both producers and consumers. There will be heightened efforts to conserve oil (and energy more generally) and to find alternative fuels and technologies, which will tend to become relatively more competitive as the price of oil rises (Cavallo, 2002: 194). However, several factors will complicate this adjustment process and militate against a smooth transition away from oil. First, the costs of energy will be higher than before, which implies real economic hardship for households. As the International Monetary Fund (IMF, 2011b: 90) cautions, "a persistent decline in oil supply levels could have sizable negative effects on output even if there is greater substitutability between oil and other primary energy sources." Second, since most alternative energy sources require some quantity of oil or gas for their production, their costs will tend to rise (all other things being equal) when the prices of oil and gas rise (Hall et al., 2009: 27). Future alternative energy price declines would depend on further technological innovations and economies of scale in production. Third, it will take many years – if not decades – to replace the vast infrastructure that currently relies on oil. The problem is that economic conditions will be far less conducive to such investment after the oil peak as a result of less net energy being available, costs having risen, and the business environment being characterised by greater volatility and uncertainty. In addition, Heun and de Wit (2011) "highlighted four factors indicating that a smooth transition away from oil is unlikely: insufficient oil-sector technological development to overcome depletion, declining mark-up, non-linear relationship between EROI and costs of production, and the non-linear relationship between EROI and oil price." For all these reasons, the end of the era of cheap oil will likely also herald the end of cheap energy in general.

The possible end of cheap energy raises another long-debated issue: will oil depletion impose permanent limits on economic growth (see Hall & Day, 2009)? The answer depends on two further issues: (1) will oil depletion lead to absolute limits on available net energy? and (2) is it possible to decouple economic growth from energy use? Several authors argue that the answers are 'yes' and 'no', respectively, i.e. that oil and hence energy scarcity will impose limits to growth. As discussed in section 2.2.1, it seems likely that the looming decline in world oil production will also result in a decline in aggregate net energy. For instance, Heinberg (2009a: 9) contends that "there is little likelihood that either conventional fossil fuels or alternative energy sources can reliably be counted on to provide the amount and quality of energy that will be needed to sustain economic growth—or even current levels of economic activity—during the remainder of the current century." Elsewhere, Heinberg (2009c; 2011) argues that the recession of 2008-9 was probably a result of the peaking of global oil supply and likely heralded the end of conventional economic growth. Similarly, Nel and Cooper (2009) predict that gross world product will decline along with energy supplies from 2030, despite a continuation of the trend of relative decoupling. However, some authors leave the door open to possible decoupling of economic growth from energy consumption. For example, Murphy and Hall (2011: 52; emphasis added) conclude that "the economic growth of the past 40 years is unlikely to continue in the long term *unless there is some remarkable change in how we manage our economy*."[70] Part of the answer depends on how one defines economic growth. If it is defined as increasing material and energy throughput (see Daly, 2004), then the answer is clearly 'no'. However, economic growth can be more broadly defined as an increase in the real *value* of goods

[69] Tverberg (2011) suggests that "[o]nce debt growth peaks (shifts from growth to decline), we can expect a feed-back loop that will tend to make post-peak oil supply decline even more rapidly than it would otherwise", since less credit will be available for investment in oil production infrastructure.
[70] The question of economic management to mitigate oil depletion is taken up in chapters 5 and 6.

and services provided in an economy; in this case, there may be space for growth in activities that are relatively non-intensive in their use of energy and materials, alongside major increases in resource productivity for existing activities (Fischer-Kowalski & Swilling, 2011; von Weizsacker et al., 2009). Chapter 5 explores concrete possibilities for (relative) decoupling of economic activity from oil consumption.

2.3.2 Transport, trade and globalisation

At least 94% of the energy consumed by the world's transport systems was derived from oil in 2007 (IEA, 2009b). All aircraft, most ships (apart from nuclear-powered military vessels), the vast majority of road vehicles and even most trains are powered by oil. Globally, the transport sector consumed 61% of oil supplies in 2007. Transport systems – for both passengers and freight – are therefore extremely dependent on oil and will be greatly affected by rising oil prices and growing shortages after the global production peak. However not all modes of transport will be equally affected, as their energy intensities vary; planes are least efficient, followed by cars, trucks, trains and ships (Heinberg, 2006: 41).

Many modern settlements, especially cities characterised by urban sprawl, are structurally dependent on cheap, largely oil-based transport. Passengers will face rising transport costs, especially those people living in suburban and rural areas who rely on private automobiles for accessing places of work and education, shops, health facilities, etc. In general, poorer people tend to spend a higher proportion of their incomes on transport than the more affluent suburbanites, and hence in proportional terms their household budgets could suffer even more (Heinberg, 2006: 43). Their access to alternative forms of transport is also often more limited. Public transit systems, despite being less energy intensive than private cars, are also vulnerable to rising oil prices. Moriarty and Honnery (2008) argue that it is unlikely that measures such as improved vehicle efficiency and the development of alternative fuels and propulsion systems can be expanded rapidly, widely and economically enough to compensate for oil depletion; consequently, in the future passenger mobility will decline rather than continue its historical rising trend. Although freight transport generally uses somewhat more energy-efficient modes of transport such as ships, trains and trucks, it will also suffer from higher fuel costs. Businesses that rely on freight will face declining profit margins whether they pass on the higher costs to consumers or try to absorb them internally.

All sectors of the economy that rely heavily on oil-fuelled transport will be affected by oil depletion. The aviation industry is particularly vulnerable, both because there are currently limited alternative fuels or propulsion technologies, and because fuel constitutes a large fraction of operating costs (Nygren et al, 2009; Curtis, 2009). [71] The oil price spike in 2007-2008 had a dramatic, negative impact on the global airline industry, with more than twenty airlines filing for bankruptcy in the first half of 2008 (Curtis, 2009: 430). The automobile industry also suffered heavy losses from the combination of high oil prices and falling consumption expenditure (Heinberg, 2009c). As a result of reduced international and national mobility, especially via air travel, the global tourism sector will probably shrink significantly in the post oil peak era.

As transport costs rise and the reliability of freight transport is undermined by oil supply disruptions, international trade in physical goods (particularly high-bulk, low-value added items) will decline and supply chains will become shorter (Curtis, 2009). Effectively, higher transport costs will act as a tariff on imported goods. As a result, the process of globalisation (at least as it pertains to trade in physical

[71] Smith (2006) argued that biofuels were not viable for airplanes and that hydrogen was too expensive. However, Nygren et al. (2009) report that two commercial airlines have conducted successful flights using bio-jet fuels. Sasol has been supplying jet fuel derived from coal to South African airports for a number of years (Prinsloo, 2010).

goods), which has depended on cheap, reliable transport, will move into reverse (Curtis, 2009; Rubin, 2009). Curtis (2009) argues that policies to mitigate oil depletion and climate change might delay the date of "peak globalisation", but they will not be able to avert it as they will be insufficiently large and too late, and will not reduce transport costs. More generally, production and consumption will become increasingly localised at all spatial levels, including regional, national and sub-national scales.

2.3.3 Agriculture, food and population

The globalised, industrial system of food production and distribution that sustains much of the world's population is highly reliant on fossil fuels. Natural gas is the major feedstock for the production of fertilisers, while oil is used to manufacture pesticides and to operate farm machinery, including tractors and harvesters. Furthermore, food processing utilises fossil energy and transport systems that distribute food products to consumers are overwhelmingly dependent on oil. Yet more energy is required for the storage and preparation of food. It has been estimated that 10 calories of fossil energy are required to produce one calorie of food in the United States (Pfeiffer, 2006). The use of fossil fuels boosted agricultural productivity by a factor of approximately four (Youngquist, 1999). In addition, cheap fossil energy has allowed larger areas of land (including more marginal soils) to be cultivated as well as irrigated, further raising agricultural output.

After global oil production has peaked, input costs for agriculture will rise substantially and many farmers could face bankruptcy (Heinberg, 2009c). Rising transport costs will further raise the prices of food for consumers. In the longer term, as fossil fuels deplete the world faces the prospect of declining agricultural production, rising food prices and increasing food insecurity. The impact on agriculture and food security of fossil fuel depletion will be compounded by other environmental and resource constraints, including soil erosion, pollution, depletion of fresh water resources, and climate change (Brown, 2009; 2010). In addition, rising oil prices create incentives for the production of biofuels, which either use food crops directly, or require arable land and water that could otherwise be used for food production. Brown (2008) warns of an epic contest between food and fuel if policies continue to allow and promote the production of conventional biofuels such as corn-ethanol. Indeed, the growing production of biofuels was highlighted as a contributing factor to the steep rise in price of many basic agricultural commodities between 2006 and 2008, which sparked food protests in several countries (Brown, 2009: 49).

The increasing use of fossil fuels in agriculture, which boosted crop yields dramatically, enabled the human population to grow from less than one billion in 1800 to approximately 6.7 billion in 2009 (Hall & Day, 2009). The so-called 'Green Revolution' in agriculture, which took place from the 1960s, involved the extension of Western farming methods (including fertilizer and pesticide use) and crop varieties to developing countries, massively boosting agricultural yields and thereby supporting rapid growth in their populations, whilst mostly averting famines. Nonetheless, world grain production per capita has been falling since the mid 1980s (Heinberg, 2006: 51). Some authors suggest that without fossil fuels, the sustainable world population is probably in the region of about two billion (see Heinberg, 2003: 177), although others are more optimistic about the Earth's carrying capacity based on sustainable agricultural practices (e.g. Brown, 2009).

2.3.4 Geopolitics and conflict

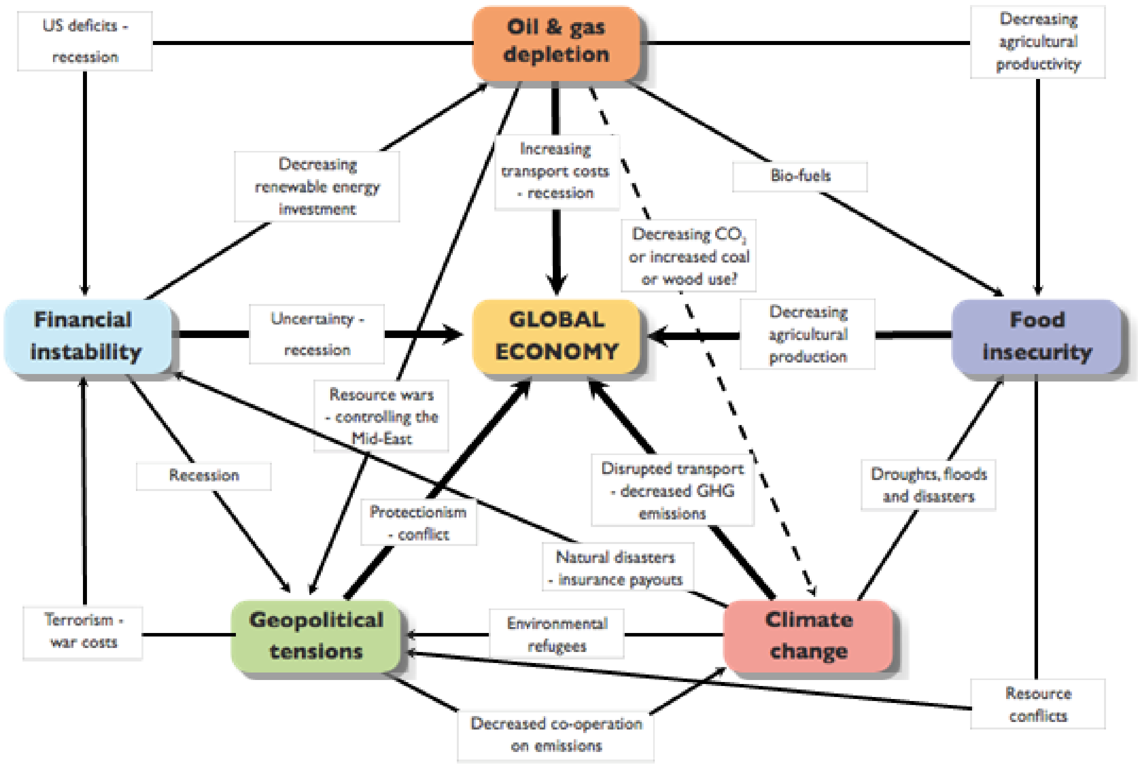
As oil production begins to wane after the global peak, international competition for remaining supplies will intensify and place additional strain on geopolitical relations. Such competition could arise in various non-military and military forms. Non-military competitive actions could originate from both oil consumers and producers. For example, the governments of China in particular, and to a lesser extent India, have been concluding exclusive long-term oil supply agreements with various producing nations in recent years, effectively removing future oil supplies from the international market. Chinese state-owned oil companies invested heavily in foreign countries from about 2005 (Dittrick, 2010), and the Chinese government has concluded bilateral investment and trade agreements with several countries including Venezuela, Angola, Iran and Canada. Such actions are likely to raise the price of the remaining oil traded on international markets. On the other hand, some energy producing nations could use their oil supplies as strategic weapons to gain economic and/or political advantage. An obvious example is OPEC, which is likely to use its increasing market share to maintain high oil prices (see section 2.2.4). Russia, by 2008 the world's leading producer of oil and natural gas, has already used its energy resources as a political weapon in Europe and Central Asia.

Given how critical oil is for both economic and military power, there is a strong likelihood of various types of armed conflicts over energy resources (Heinberg, 2004; Klare, 2005; Heinberg, 2006). First, powerful consuming nations may invade weaker producing nations in order to take control of their oil supplies (Heinberg, 2004). For instance, the US-led invasion of Iraq has been cited as an 'oil grab' (Strahan, 2007). Klare (2005) has argued that the US military performs a function as a global oil protection service, being strategically positioned in many parts of the world in order to ensure or control the flow of oil. The areas most vulnerable to widespread conflict over oil resources are probably the Middle East and Caspian, where the majority of remaining reserves are located, although other significant oil-producing regions such as West Africa and Latin America are also susceptible to conflict.[72] Regional conflicts over oil could result in a new military rivalry among the great powers: the United States, the European Union, China and Russia. A worst case scenario would be the outbreak of a Third World War. Second, producing nations could invade neighbouring oil producing countries in order to gain regional supremacy or eliminate a perceived future threat, although more subtle forms of intervention might be more probable (Howard, 2009). Third, domestic conflict and even civil wars could erupt within oil producing countries as factions fight each other for control over oil resources and revenues. In fact, sectarian conflict related to oil supplies is already evident in countries such as Iraq and Nigeria. Fourth, intervention by foreign countries – either militarily or through involvement of international oil companies – in (especially Islamic) oil producing nations could seed increased domestic and international terrorist activity (Heinberg, 2006; Howard, 2009).

Escalating geopolitical tensions, military conflict and terrorism would have negative impacts on the world economy by eroding economic confidence, hampering investment, and adding an uncertainty and risk premium to the price of oil. Wars in producing countries would further constrain global oil supplies and exports, exacerbating the other economic and social impacts of oil depletion. Such fallout would make the transition to alternative energy sources and infrastructure more difficult. Perhaps somewhat prophetically, Cavallo (2002: 194) warned two years before the US-led invasion of Iraq that the "transition will be manageable given one essential condition, which is that the industrial world does not intervene militarily in the Persian Gulf in order to control oil extraction rates directly."

[72] The US Joint Forces Command states that "[s]hould one of the consumer nations choose to intervene forcefully, the "arc of instability" running from North Africa through to Southeast Asia easily could become an "arc of chaos," involving the military forces of several nations" (USJFC, 2010: 27).

Figure 2-16: Systemic interactions and complexities



Source: Wakeford (2006)

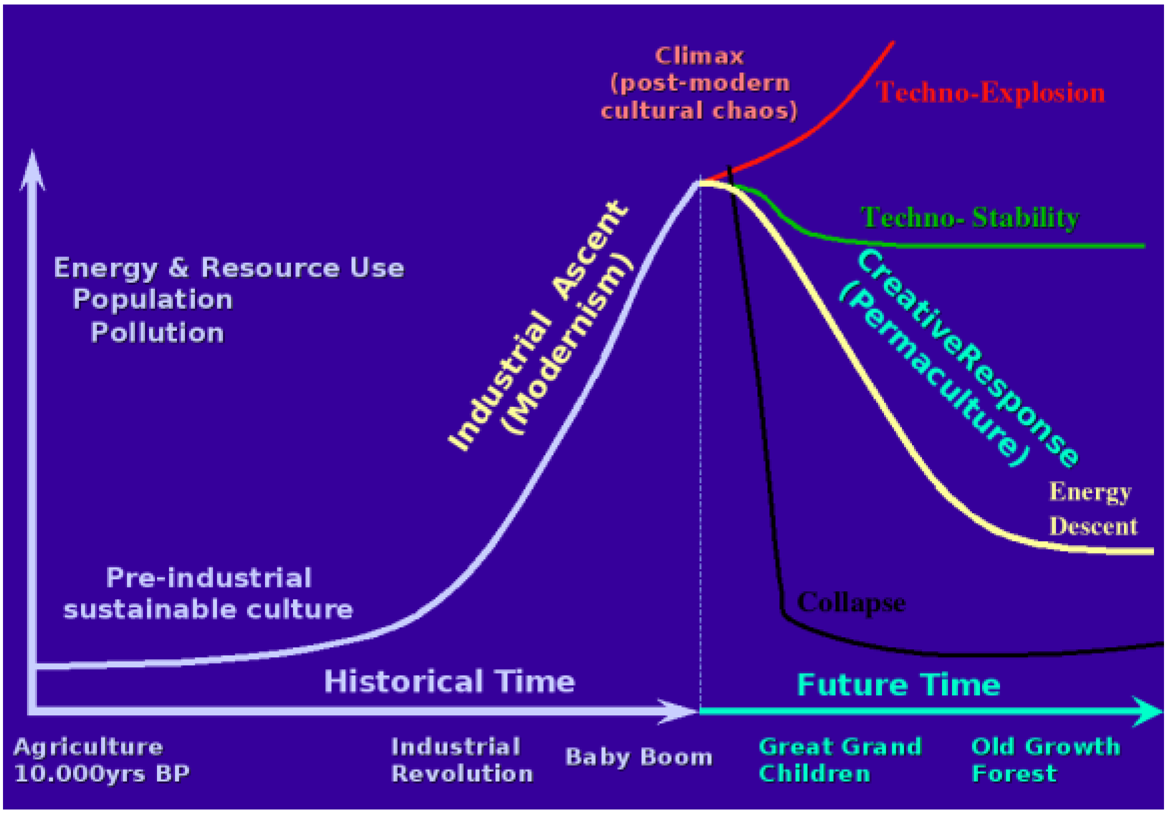
2.3.5 Systemic interactions and complexities

The possible ramifications of oil depletion for the various aspects of society discussed above will not occur in isolation of one another. The global socio-economy is an integrated, highly complex system. Consequently, there are likely to be many interactions and feedback effects both among the various impacts of oil depletion, and with other challenges to sustainability such as: accelerating climate change with an increase in associated extreme weather events; growing scarcity of fresh water as fossil aquifers are depleted; loss and degradation of topsoil; the on-going collapse of ocean fisheries; massive loss of biodiversity; financial instability; and geopolitical tensions (see for example Brown, 2010; IPCC, 2007; Millennium Ecosystem Assessment, 2005; Meadows et al., 2004; Heinberg, 2007; Martenson, 2011). Responses to any one of these challenges need to take cognizance of the others. Some of these likely interactions are summarised in Figure 2-16. The black arrows indicate directions of causation (with the mechanism described in the labels) among the major factors that influence the global economy. For example, oil depletion exacerbates food insecurity by decreasing agricultural productivity (i.e., less oil is available to power farm machinery). The dotted arrow line indicates uncertainty in the direction of causation between oil depletion and climate change: a decline in oil production would lead directly to a reduction in carbon dioxide emissions from oil combustion, but this might be offset by emissions from increased use of coal and/or wood.

2.3.6 Scenarios for the future

Scenario sketching is a useful way of presenting possible trajectories for an uncertain future. All authors who have written about the potential implications of global oil depletion are essentially suggesting one or more scenarios. This section presents a brief review of the main scenarios covered in the literature. Holmgren (2008) provides a useful categorisation of four basic alternatives (as illustrated in Figure 2-17):

Figure 2-17: Future scenarios



Source: Holmgren (2008)

Note: The diagram displays the historical path of energy and resource use, population and pollution (measured on the vertical axis) and four possible scenarios for the future, namely "techno-explosion", "techno-stability", "energy descent" and "collapse". Holmgren interprets the upward phase of the bell curve as an "industrial ascent" informed by a modernist culture, while the downward phase (which is most likely or at least desirable in his estimation) is termed "creative response", informed by the principles and values of permaculture. The intervening crisis period he sees as one of "post-modern cultural chaos".

- "*Techno-explosion* depends on new, large and concentrated energy sources that will allow the continual growth in material wealth and human power over environmental constraints, as well as population growth. This scenario is generally associated with space travel to colonise other planets.
- *Techno-stability* depends on a seamless conversion from material growth based on depleting energy, to a steady state in consumption of resources and population (if not economic activity), all based on novel use of renewable energies and technologies that can maintain if not improve the quality of services available from current systems.
- *Energy Descent* involves a reduction of economic activity, complexity and population in some way as fossil fuels are depleted.
- *Collapse* suggests a failure of the whole range of interlocked systems that maintain and support industrial society, as high quality fossil fuels are depleted and/or climate change radically damages the ecological support systems. It would inevitably involve a major "die-off" of human population..."

As already noted, the "techno-optimist" or "cornucopian" school believes in *techno-explosion* as their default scenario, and in fact consider little else as possible. Many environmental campaigners, especially those concerned primarily with environmental degradation (including climate change), advocate the *techno-stability* scenario. Most contributors to the "peak oil" literature, however, regard both of these scenarios as impossible once world oil production enters terminal decline. They therefore advocate measures to enhance the probability of a reasonably orderly *energy descent* so as to avoid *collapse*. These last two scenarios are considered in more detail.

Energy descent

A considerable number of writers argue that global oil depletion will most likely result in a gradual and cumulative reduction in usable energy supplies (at least down to a much lower level than current consumption), resulting in turn in a gradual but cumulative decline in aggregate economic activity and ultimately the size of the human population[73] (e.g. Heinberg, 2004; 2011; Meadows et al., 2004; Kunstler, 2005; Duncan, 1996). Some of these authors base this assessment on the historical experience of previous civilizations that have eroded their resource base and experienced an uneven process of disintegration and simplification, typically spanning one or more centuries (Holmgren, 2008). For example, in his book *The Long Descent*, Greer (2008) foresees the major trends of a "deindustrial age" as being depopulation, mass migration, political and cultural disintegration, and ecological change. Kunstler (2005) suggests there will at the very least be a "long emergency", perhaps lasting a couple of decades, characterised by economic and social turmoil. Friedrichs (2010: 4567) posits that "[a]fter peak oil, we should expect extremely slow and painful processes of social and technological adjustment that may last for a century or more."

In *The Ecotechnic Future*, Greer (2009) spells out distinct phases of the post-industrial (or post-technic) society. Following the 'age of affluence', whose end is marked by the peak of conventional world oil production, he foresees an 'age of scarcity industrialism' involving a reduction of energy wastage through the adoption of conservation and efficiency as survival strategies, a reorganisation of urban space, and growing resource nationalism as governments attempt to cling to power. Next comes an 'age of salvage', based on the reuse and recycling of the energy embodied in existing infrastructure and artefacts, including steel, copper, aluminium and other processed materials. Greer supposes that countries with no fossil fuels and limited salvage resources will revert to agrarian or hunter-gatherer societies. Finally, after one or more centuries when fossil fuels and salvage opportunities are effectively exhausted, an 'ecotechnic age' might emerge in which societies and their technologies are based on the efficient use of locally available renewable resources.

A rather more positive version of the energy descent is offered by Hopkins' (2008) "transition model" and Heinberg's (2004) "powerdown" scenario. These authors argue that declining material consumption could be compensated by a strengthening of community bonds, cultural renewal and improved quality of life. Eventually, the global economy will settle at a sustainable scale (i.e. within the Earth's carrying capacity) in a steady-state (zero growth) equilibrium. Nevertheless, the transition "may be extremely painful unless it is managed with skill and understanding" (Cavallo, 2002: 194), and "will require a revision of economic theories and a redesign of financial and currency systems" (Heinberg, 2009a: 69). Heinberg (2009a: 26) notes that "the transition to alternative energy sources must be negotiated while there is still sufficient net energy available to continue powering society while at the same time providing energy for the transition process itself."

Collapse

On the other hand, several authors warn of even more dire consequences of declining world oil production, suggesting that industrial civilisation could face a fairly rapid, cascading collapse as a

[73] This looks likely because humanity has already overshot ecological limits (e.g. WWF, 2008).

possible (e.g. Martenson, 2011; Heinberg, 2004; Meadows et al., 2004) and perhaps even most likely outcome (e.g. Tainter, 2011; Korowicz, 2010; Morrigan, 2010; Duncan, 1996).[74] Most of these authors emphasize the complexity and interdependence of industrial systems such as financial, energy, food, water, transport and telecommunications systems, and the potential for thresholds, tipping points and non-linear changes. Duncan (1996; 2006) proposed an "Olduvai Theory", which states that the life expectancy of industrial society is just 100 years, from 1930 to 2030, coinciding with the era of cheap and abundant fossil fuels. He forecasts that from 2012 onwards, industrial societies will experience worsening electrical blackouts resulting in the collapse of transport, communication and production systems. Martenson (2011: 220) asserts that "our future contains exceptionally high risks that could usher in political and social unrest, a collapsing dollar (and other fiat currencies), hyperinflation (or hyperdeflation), and even full economic collapse." Morrigan (2010: 89) warns that "[s]ystemic collapse will likely result in widespread confusion, fear, human security risks, social break down, changes in geopolitics and markets, conflict, and war."[75]

A compelling elaboration of the collapse scenario is painted by Korowicz (2010a, 2010b). He begins with the observation that the highly integrated global economy functions as a unified complex adaptive system. Such systems have several features which make them dependent on energy flows and prone to sudden, large state changes. First, in general a complex adaptive system requires a greater throughput of (net) energy to operate at a higher degree of complexity (see also Tainter, 1988; 2011). Thus declining (net) energy implies a reduction in complexity; "energy supply is the master platform upon which all forms of complexity depends" (Korowicz, 2010a: 20). Second, complex adaptive systems involve tipping points, or critical thresholds beyond which the system changes suddenly from one state to another (Korowicz, 2010a: 28). Some pertinent examples of tipping points in the socioeconomic system include: public awareness and expectations about the future path of the economy culminating in panic behaviours; inability of the electricity utility to finance its current operations or maintain fuel supplies to power stations, leading to grid failure; a panic amongst financial investors resulting in a collapse of stock markets; falling house prices triggering a systemic global banking failure; 'quantitative easing' monetary policies leading to hyperinflation and collapse of the monetary system; and electricity supply disruptions and/or fuel shortages resulting in massive crop failures and food shortages. Third, positive feedback loops can drive a system towards another very different state after just a small initial perturbation. For example, Korowicz (2010a: 29) argues that "[a] decline in oil production undermines economic production... and undermines the operational fabric,[76] which in turn constrains the ability of society to produce, trade, and use oil (and other energy carriers) in a reinforcing feedback loop." This implies that the rate of oil production decline could accelerate, and "[e]nergy flows through the economy are likely to be unpredictable, erratic and prone to sudden and severe collapse" (Korowicz, 2010a: 24). Economies of scale, which operate at every level of the production chain and in critical infrastructures, constitute another feedback loop, and can function in reverse: rising energy costs – declining purchasing power – reduced non-discretionary consumption – falling production and employment – reduced economies of scale – higher prices – reduced sales – and so on. Other positive feedback loops include: the erosion of trust in money systems; declining resources available for research and development resulting in a slowing rate of innovation and technological progress, which further reduces output; rising unemployment, poverty and inequality leading to crime and social fragmentation, which undermine productivity; eroding real incomes triggers industrial strikes,

[74] Atkinson (2007a, 2007b, 2008, 2009) develops a thesis on the collapse of cities specifically.

[75] Morrigan (2010: 90) further points out that "[t]he effects of global collapse will not be homogenous. Rather each region, nation, and community will be affected based on local and regional circumstances."

[76] Korowicz (2010a: 15) defines the *operational fabric* of a society as "the given conditions at any time and place which support system wide functionality", and includes "functioning markets, financing, monetary stability, operational supply-chains, transport, digital infrastructure, command and control, health services, research and development infrastructure, institutions of trust and socio-political stability."

which lead to a loss of production and corporate profits, leading to job losses and worsening poverty.

Certain components of the socioeconomic system are particularly vulnerable to collapse processes, namely critical infrastructure, supply chains, food and financial systems (see Korowicz, 2010a: 33-34). Critical infrastructures, such as electricity grids, oil pipelines, road and rail networks, ports and airports, water and sewage pipes and pumping stations, and communication networks, are highly integrated, which means that failure in some key systems can rapidly cascade into multiple failures. The fixed costs of maintaining and operating critical infrastructure systems is high, which means they must be utilised at or near to full capacity, which in turn requires large throughputs of energy. Thus if energy availability falls below a minimum threshold, the system is vulnerable to catastrophic collapse. The maintenance of complex infrastructures, as well as production in general, requires inputs manufactured in long (mostly globalised), just-in-time supply chains that are vulnerable to interruption on a localised basis. Food production and distribution is a prime example, as it depends on complex supply chains involving seeds, diesel, fertilisers, pesticides, and electricity. Financial systems are vulnerable to panic behaviour amongst market participants, which can precipitate runs on banks, stock market crashes, sovereign debt crises and defaults. These in turn impact negatively on the real economy, and can also be rapidly transmitted via contagion to other countries (as evidenced in the European sovereign debt crisis of 2010-11). In summary, Korowicz (2010a: 29) states that "[i]n the new post-collapse equilibrium state we would expect a collapse in material wealth and productivity, enforced localisation/de-globalisation, and collapse in the complexity as compared with before."[77]

In some respects, it appears that the major difference between the *energy descent* and *collapse* scenarios is one of timing, with the latter occurring over a century or longer and the former happening in a matter of at most a few decades. However, the scenarios also differ in that the former is managed while the latter is chaotic.

2.4 Conclusions

The nature and implications of global oil depletion have been the subject of debate for decades, but in recent years this debate has intensified greatly.[78] Issues under contention include: the size of conventional oil ultimately recoverable resources; possible reserve growth from new discoveries and enhanced oil recovery; the potential of unconventional oil and other energy sources to substitute for oil; the potential for improved technology to enhance energy efficiency; and the role of market forces in bringing about a transition to alternatives. So-called 'optimists' tend to focus on economic (and to an extent political) determinants of oil supplies and substitution between various energy resources. So-called 'pessimists' emphasize the physical depletion of finite resources and various constraints on alternatives. The alternative views appear to a large degree to reflect different theoretical paradigms, which tend to 'talk past each other': neoclassical economics on the one hand, and physical sciences on the other. An ecological economics perspective, which recognises the

[77] The German Bundeswehr Transformation Centre paints a worst case scenario based on the tipping point concept, which involves a complete collapse of the global economic system and market-oriented economies: collapse of the banking system and stock markets; hyperinflation and currency collapses; collapse of global and national value chains; mass unemployment; national bankruptcies; collapse of critical infrastructures; and famines (BTC, 2010: 58-59).

[78] Bardi (2009) characterises the evolution of the concept of "peak oil" in public discourse according to four stages: (1) "Never heard of it." (2) "It is wrong." (3) "It is right, but irrelevant." (4) "It is what I had been saying all along."

importance of geological, technological, economic and political factors, can help to bridge the intellectual gap and provide a synthesis view.

On the human time scale, oil is a finite, non-renewable resource subject to depletion. Estimates of ultimately recoverable oil resources (both conventional and unconventional) vary greatly and are influenced by a combination of geological, economic and technological factors, but the critical issue for our oil-dependent societies is not the size of remaining oil reserves, but the annual rate of oil production. Global oil production will inevitably reach a maximum peak or plateau at some point and thereafter decline irreversibly, marking the transition from an era of cheap and abundant oil to one of increasingly expensive and scarce oil. A review of forecasts suggests that the global oil peak will almost certainly occur before 2030, that there is a significant risk of it happening before 2020, and that it is even possible that conventional oil production had peaked by 2008. Various scenarios are possible for the shape of the global oil peak, ranging from sharp peak and steep decline (of 5% per annum or greater), to a multi-year, fluctuating plateau followed by a more gradual decline (of about 2-5% per year). However, the net energy derived from oil is of greater importance than the gross supply of oil, and will decline more rapidly as the EROI for oil continues its historical decline. In addition, world oil exports appear to have peaked in 2005 and will decline more steeply than total world oil production.

All potential substitutes for oil have important quality limitations, and will take considerable amounts of time and investment capital to develop and scale up. The EROI of oil (and other fossil fuels) has historically been high compared with most other energy sources, but is declining. Thus there is a strong possibility that the total surplus (net) energy available will decline this century. Moreover, most substitutes for oil are imperfect given the longevity of current oil-based infrastructures. For example, renewable electricity generated from solar and wind power are only indirect substitutes for oil, as they require additional infrastructure in the form of expanded and enhanced electric grids, electricity storage capacity and electrified transport infrastructure. Conservation of energy, through improved efficiency and curtailment of energy use, is therefore an essential response to oil depletion, and is generally cheaper than developing substitutes, though both are necessary.

Global economic, transportation and agricultural systems are highly dependent on oil. Historical experience has shown that even small disruptions to the supply of petroleum can have adverse economic impacts, such as rising inflation and unemployment. A sustained decline of oil production is likely to result in a sustained decline in economic activity (as measured by GDP) and could trigger a systemic financial crisis. It will also raise transport costs and curb mobility, and could result in a marked decline in agricultural production. Given the long lead times required to develop alternative energy sources and infrastructure, mitigation efforts should ideally be initiated about 20 years before the oil peak to have a chance of avoiding serious economic, social and political consequences. The ecological economics perspective argues that energy and resource scarcity – and oil depletion in particular – will impose limits on economic growth, at least in the sense of constraints on material throughput. Likely future scenarios include at worst, a cascading collapse of industrial societies to a lower level of complexity, or at best a managed transition to a sustainable socioeconomic regime, i.e. a steady-state economy based on renewable resources.

The following three chapters explore the ramifications of global oil depletion for South Africa. Chapter 3 sets the scene by describing South Africa's oil dependencies and vulnerabilities. Chapter 4 assesses the likely impacts of unmitigated oil depletion on the economy and society. Chapter 5 discusses a range of policy options for mitigation and adaptation to declining world oil supplies.

CHAPTER THREE

3. Oil Dependency, Strengths and Vulnerabilities in South Africa

"Transport is the heartbeat of the economy."

National Department of Transport

"If the trucks stop running, there will be no more [electrical] power. It is as simple as that."

Brian Dames, CEO of Eskom

This chapter aims to provide an empirical description of the 'As-Is' system in South Africa (following Hector et al., 2007). In particular, it seeks to identify energy and oil dependencies, and strengths and vulnerabilities in respect of oil shocks, in the each of the five subsystems, *viz.*: energy; transport; agriculture; macro-economy; and society. Oil shocks may take the form of either or both supply shocks (i.e. a restriction on the quantity of oil and derived products in the domestic economy) or price shocks (i.e. a substantial increase in the price of crude oil and consequently refined petroleum products).

The method employed in this chapter consists in a presentation and analysis of current and historical empirical data as well as a qualitative description of relevant system features. The analysis utilises the latest available data as of August 2009,[79] and draws upon a range of secondary databases provided *inter alia* by the Department of Minerals and Energy (DME, 2006), the South Africa Petroleum Industry Association (SAPIA, 2009), the Joint Oil Development Initiative (JODI, 2009), and the South African Reserve Bank (SARB, 2011). In addition, a systems perspective is used to identify interdependencies and feedbacks both within and among the five subsystems.

The chapter is organised according to the five subsystems. Each major section includes an overview of the subsystem, a description of its energy and oil dependency, an analysis of its strengths and vulnerabilities vis-à-vis oil shocks, and a brief synopsis highlighting systemic interconnections, where relevant. The concluding section provides a summary of key strengths and vulnerabilities in each of the five subsystems as well as an overview of the systemic interactions among them.

3.1 Energy

This section presents an overview of the energy system and the role of oil products in South Africa.[80] It begins with a summary of primary sources of energy supply, energy carriers and final consumption (demand) by major sectors, i.e. the national energy balance. The focus is then narrowed to the supply and demand for oil and petroleum products. Oil supply is discussed in terms of sources (imports and domestic production), refining, distribution and stockpiles. Demand for petroleum products is analysed according to product type, geographical region and economic sector. Strengths

[79] In some cases more recent data have been used.

[80] This section draws on material contributed by the author to a report written by the Association for the Study of Peak Oil South Africa (ASPO-SA) entitled "Energy and Transport Status Quo: Demand and Vulnerabilities", commissioned by the South African Department of Transport (see ASPO-SA et al., 2008a).

and weaknesses of the system are highlighted for both supply and demand. The final subsection briefly considers the complex interrelations among the various energy sources and carriers.

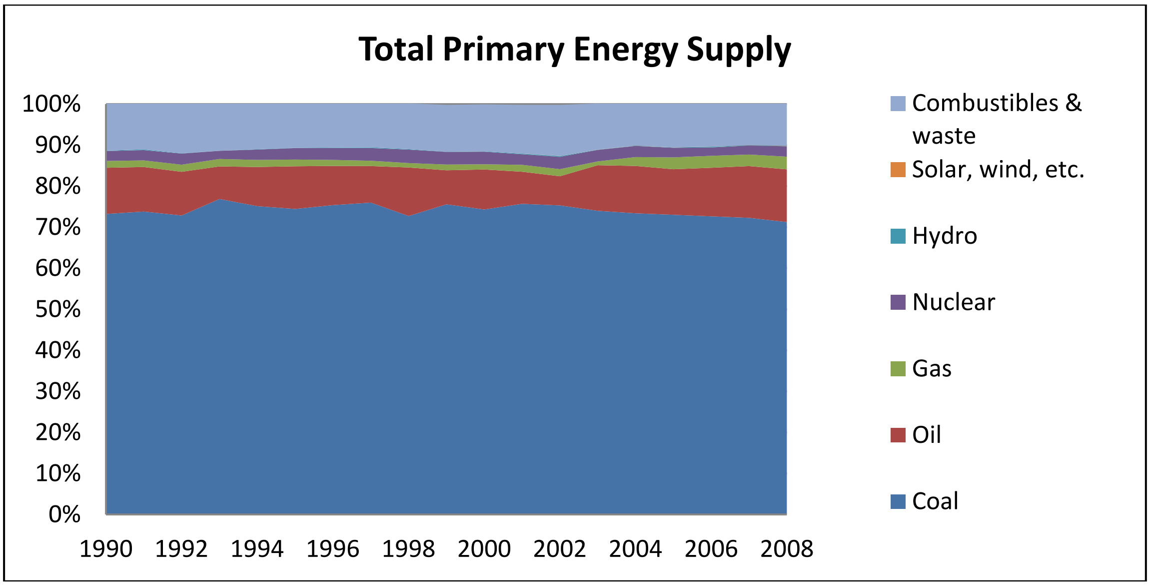
3.1.1 Overview of the energy system

The role of oil in South Africa's energy system needs to be placed in the context of overall energy supply and demand balances, i.e. alongside other sources of primary energy and within the final energy consumption mix.

Primary energy supply

Figure 3-1 displays the evolution of South Africa's primary energy supply mix between 1990 and 2008. None of the relative shares has changed appreciably. Throughout the period, coal has dominated with between 72% and 77% of primary energy. Oil's share rose marginally to 13% in 2007 and 2008 from a low of 8% in 1993 and 1998. The shares of gas, nuclear, hydro and renewables (solar, wind, etc.) have never exceeded 3%, while combustible renewables and waste have provided between 10% and 12% of primary energy.

Figure 3-1: Shares of total primary energy supply by source, 1990-2008

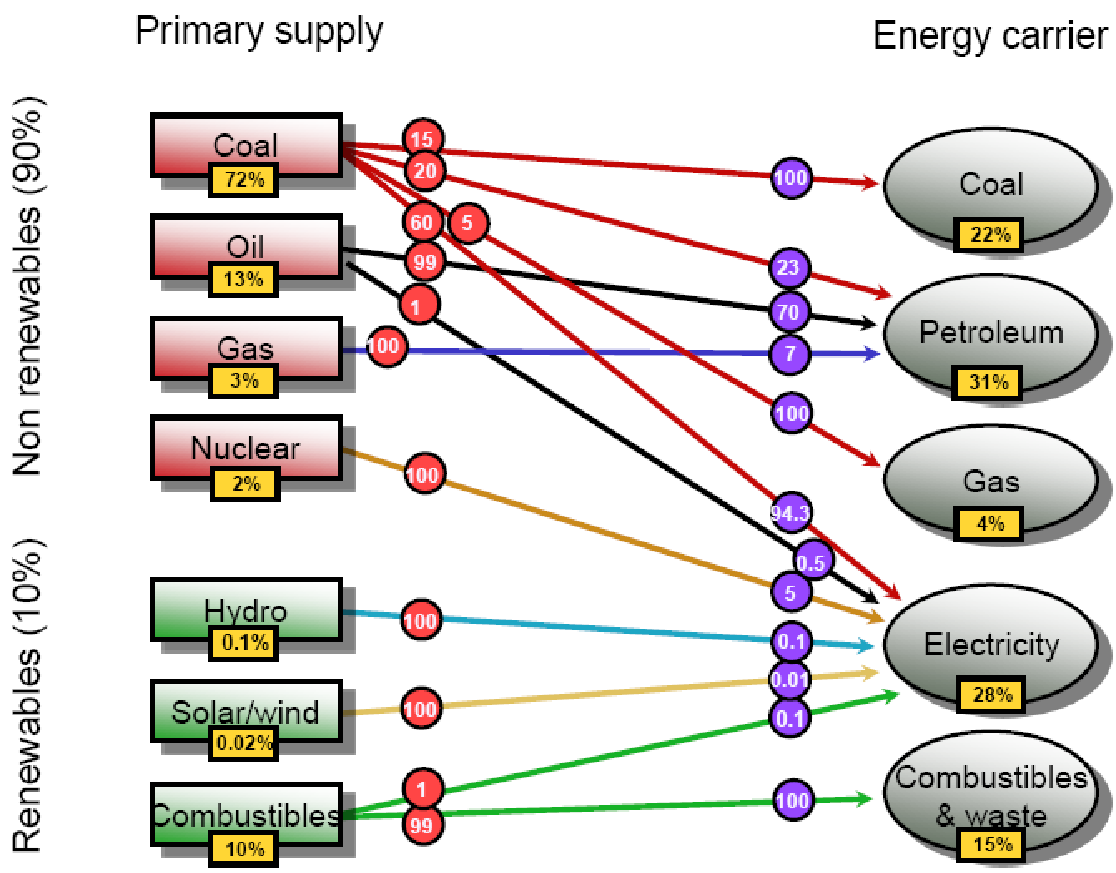


Source: IEA (2011a)

Figure 3-2 provides a snapshot summary of how South Africa's primary energy sources were converted into final energy carriers (as shown by the arrows) in 2007. Fossil fuels (coal, oil and gas) comprised 88 per cent of South Africa's total primary energy supply (TPES). Chief amongst these was coal, which provided 72% of primary energy. At that time, South Africa had the world's sixth largest coal reserves (BP, 2009). Approximately one third of the country's annual coal production was exported, and South Africa was amongst the world's top coal exporters. In 2007, 13% of South Africa's primary energy needs were met by oil. Natural gas, mostly imported from Mozambique, contributed 3% of primary energy. Combustibles and waste, which comprise wood and other biomass, made up approximately 10% of TPES. The Koeberg nuclear power station provided just 2% of primary energy, while renewable energy in the form of hydroelectricity (0.06%) and solar and wind (0.02%) contributed negligible amounts.

In Figure 3-2, the numbers in the red dots are percentages of the relevant primary energy source that are converted into the various energy carriers. For example, 15% of coal production was burned as is; 20% was converted into petroleum fuels by Sasol Limited; 5% was converted into gas; and 60% was used to generate electricity. All of the crude oil is converted into refined petroleum liquids; petrochemical products are manufactured by Sasol using coal and gas as feedstock (not shown in the Figure). The numbers in the purple dots are the percentages of the energy carrier that are derived from the respective primary energy sources. For example, 23% of petroleum fuels were derived from coal; 70% came from crude oil; and 7% was manufactured from gas by the national oil company, PetroSA. The vast majority of the country's electricity (94%) was generated from coal, with nuclear power providing 5% and hydro (0.1%), combustibles and waste (0.1%) and renewables (0.01%) contributing minute shares.

Figure 3-2: Transformation of primary energy sources to final energy carriers, 2007

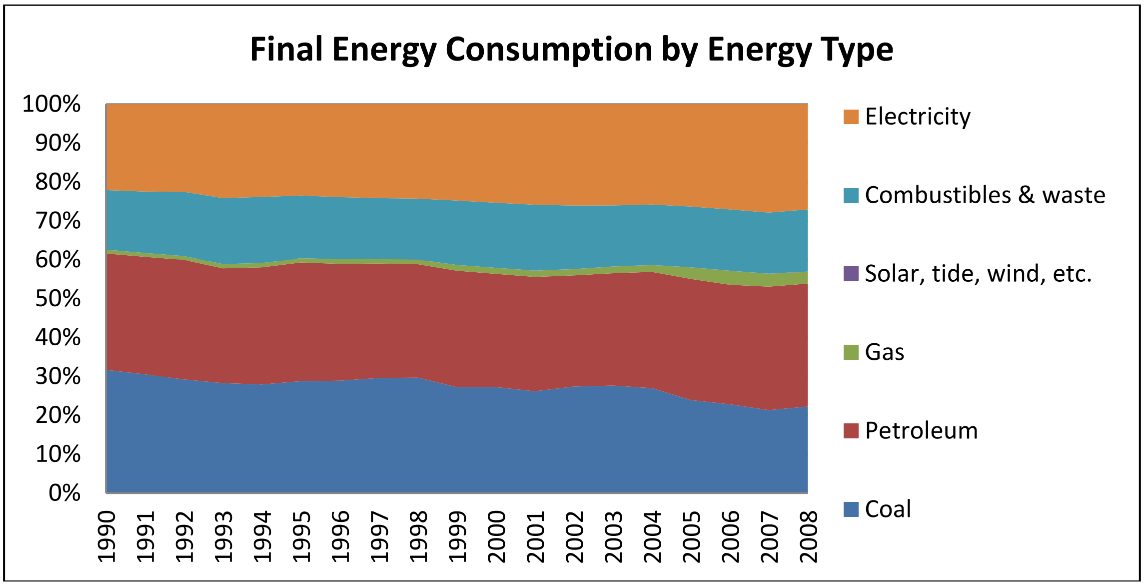


Source: Own calculations based on IEA (2011a)

Final energy consumption

Primary energy sources (e.g. oil) are converted into energy carriers (e.g. petroleum fuels), which are then consumed by end users. Coal, petroleum products, combustible materials and electricity have all contributed significant shares of final energy, while use of gas has grown somewhat but remains relatively small (see Figure 3-3 below). Over the period, the direct use of coal has shrunk from over 30% to 21%, having made way for more efficient energy carriers such as electricity, petroleum and gas.

Figure 3-3: Shares of total final energy consumption by energy type, 1990-2008



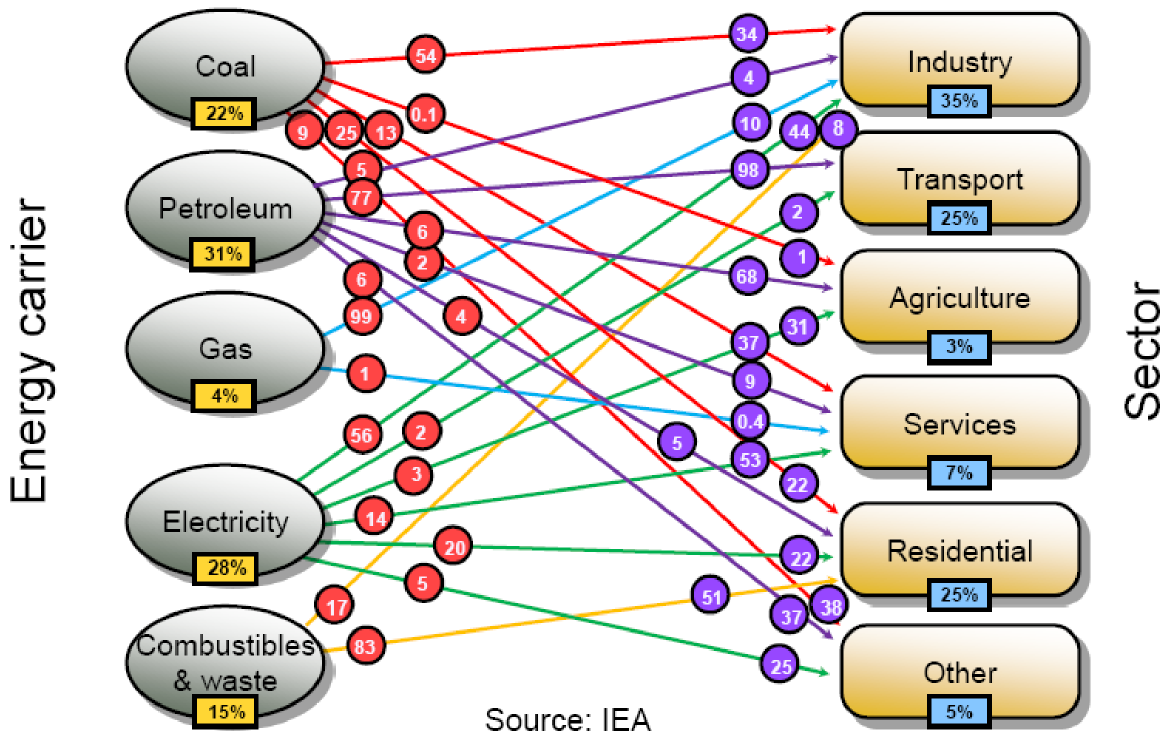
Source: IEA (2011a)

Figure 3-4 provides an overview of how the various energy carriers were consumed by the different sectors of the economy in 2007. The left hand column shows the various energy carriers and their percentage shares of final energy. Petroleum fuels constituted the largest share (31%), followed by electricity (28%) and coal (22%), combustibles and waste (15%) and gas (4%). The consumption of final energy by sector in 2007 is depicted in the right hand column of Figure 3-4. Industry consumed the lion's share (35%), followed by the transport sector (25%). The residential sector consumed a quarter (25%) of the country's energy, while commercial and public services (7%) and agriculture (3%) consumed relatively small shares of final energy. The 'other' category, which accounted for 5% of final energy consumption, comprises miscellaneous sectors and non-energy use (e.g. petrochemical feedstock).

Figure 3-4 also shows how each energy carrier was allocated among the various consuming sectors. The numbers in the red dots are percentages of the relevant energy carrier that are consumed by the various sectors, as indicated by the coloured arrows. When it comes to consumption of petroleum fuels (purple arrows), the transport sector dominates with 77% of the total. All of the other sectors consume small fractions of petroleum fuels, with agriculture (6%) being the next largest followed by 'other' sectors (6%), industry (5%), the residential sector (4%) and services (2%). The consumption of electricity follows a very different pattern (green arrows): industry accounts for 56% of consumption, followed by the residential sector (20%) and commercial and public services (14%), while transport uses just 2% of the nation's electrical energy and agriculture, 3%. Some 9% of coal was converted into petrochemical products (reflected in the 'other' sectoral category), while the majority (54%) was consumed by industry.

Finally, Figure 3-4 shows the proportionate reliance of each sector on the various energy carriers. The numbers in the purple dots are the percentages of energy consumption by the respective sector that are derived from each of the energy carriers. For example, industry obtains 34% of its energy from coal, 4% from petroleum, 10% from gas and 44% from electricity. Transport relies overwhelmingly (98%) on petroleum fuels. Agriculture, which derives 68% of its energy from petroleum, is also highly dependent on oil. Industry (4%), the residential sector (5%) and services (9%) obtain relatively small shares of their energy requirements from petroleum.

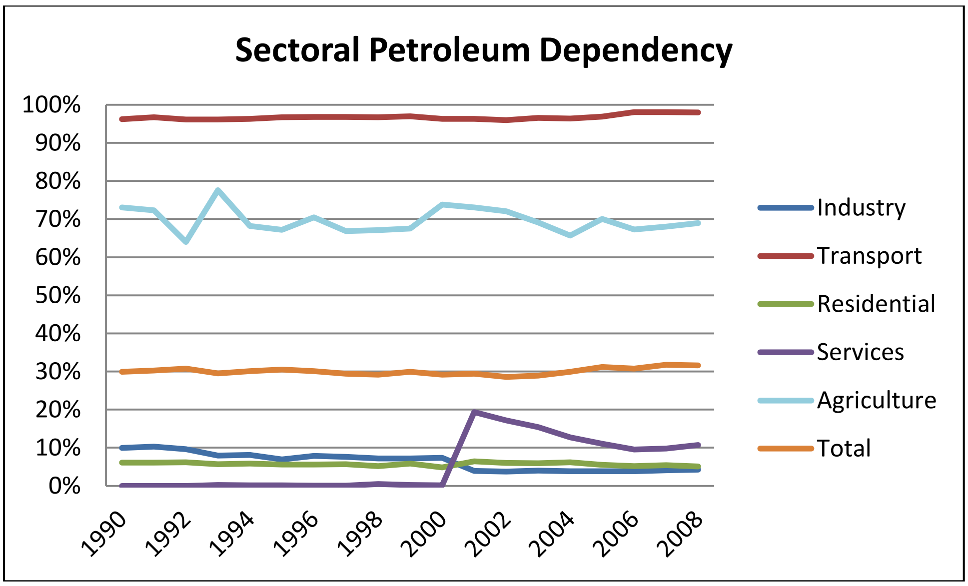
Figure 3-4: Final energy consumption in South Africa: energy carriers and sectors, 2007



Source: Own calculations based on IEA (2011a)

The shares of petroleum products in final energy consumption by sector and for the economy as a whole between 1990 and 2008 are displayed in Figure 3-5. In almost all sectors, the share of total final energy consumption accounted for by petroleum products has been fairly stable, and for the country as a whole has ranged between 29% and 32%. The underlying data for the services sector are clearly anomalous.

Figure 3-5: Share of petroleum products in final energy consumption by sector, 1990-2008



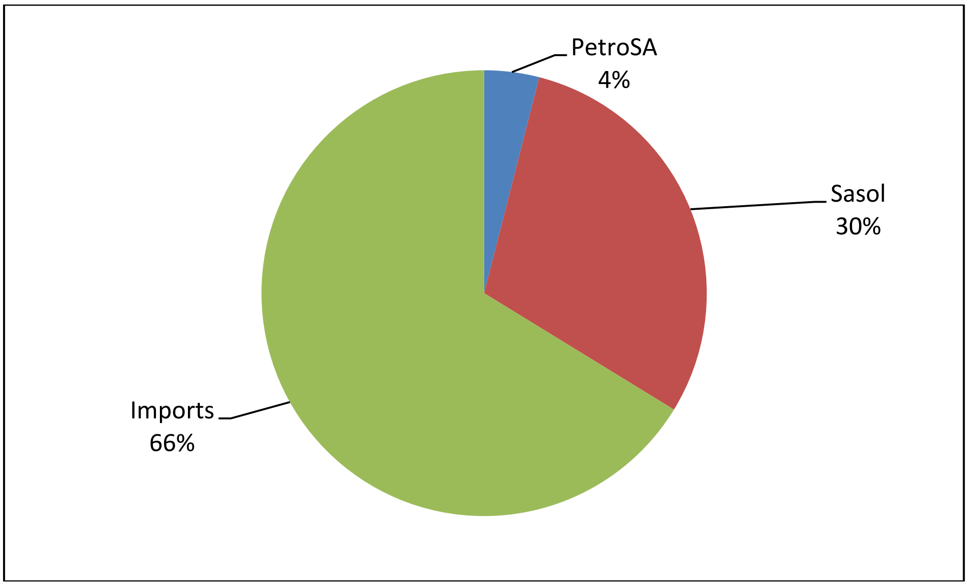
Source: Author's calculations based on IEA (2011a)

The data presented in this section illustrate that liquid fuels are important to the economy overall, are consumed by all major sectors, and play particularly crucial roles in transport (which has been almost completely dependent on petroleum fuels for nearly two decades) and agriculture. Both of the latter sectors are especially important not only to the economy, but also to the well-being of both individuals and communities. The role of oil in these sectors is explored in more detail in sections 3.2 and 3.3, respectively. Next, the supply and demand for oil are considered in finer detail.

3.1.2 Supply of oil

The sources of petroleum fuels are shown in Figure 3-6 below. Imported crude oil and refined products contributed approximately 66% of South Africa's annual consumption of petroleum products in 2010.[81] The remainder was derived from Sasol's coal-to-liquids (CTL) synthetic fuels (30%) and state oil company PetroSA's production of gas-to-liquid (GTL) synthetic fuels plus a very small amount of domestic crude oil (4%).[82] South Africa's crude oil reserves stood at a meagre 15 million barrels as of January 2010 (EIA, 2010), and were likely to be depleted within a few years in the absence of significant new oil field discoveries.

Figure 3-6: Sources of petroleum fuel supply in South Africa, 2010



Source: Author's calculations based on Sasol (2010), PetroSA (2010) and BP (2011)

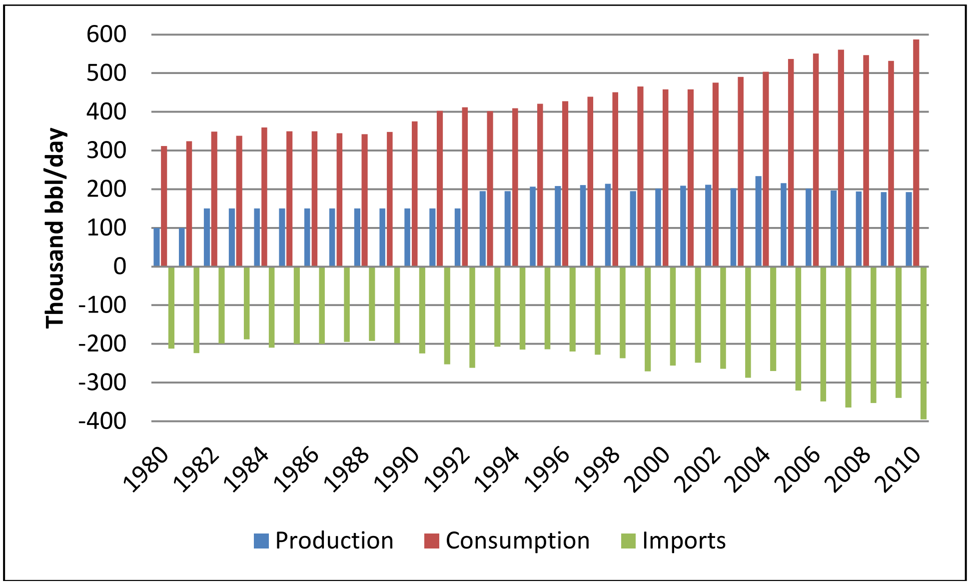
Figure 3-7 displays South Africa's total annual production, consumption and imports of oil (crude oil plus refined petroleum products). Domestic production has remained relatively constant at around 200,000 barrels per day (bpd) since 1993, while consumption has followed a rising trend albeit with some cyclical downturns. In 2010 domestic production was approximately one third of consumption, with the balance of oil products (395,000 bpd) imported. Oil imports have been on a gradually rising trend since 1993.[83]

[81] According to the IEA's (2010) energy balance for South Africa in 2007, imports accounted for 62% of oil supply and synthetic fuels the remaining 38%.

[82] In the 2009/10 financial year, PetroSA produced 6,000 bpd of crude oil and 14,521 bpd of GTL synfuels on average. Sasol produced 155,000 bpd of synfuels in the same financial year.

[83] The EIA figures for 2010 are provisional; historically, estimates have often subsequently been revised downward.

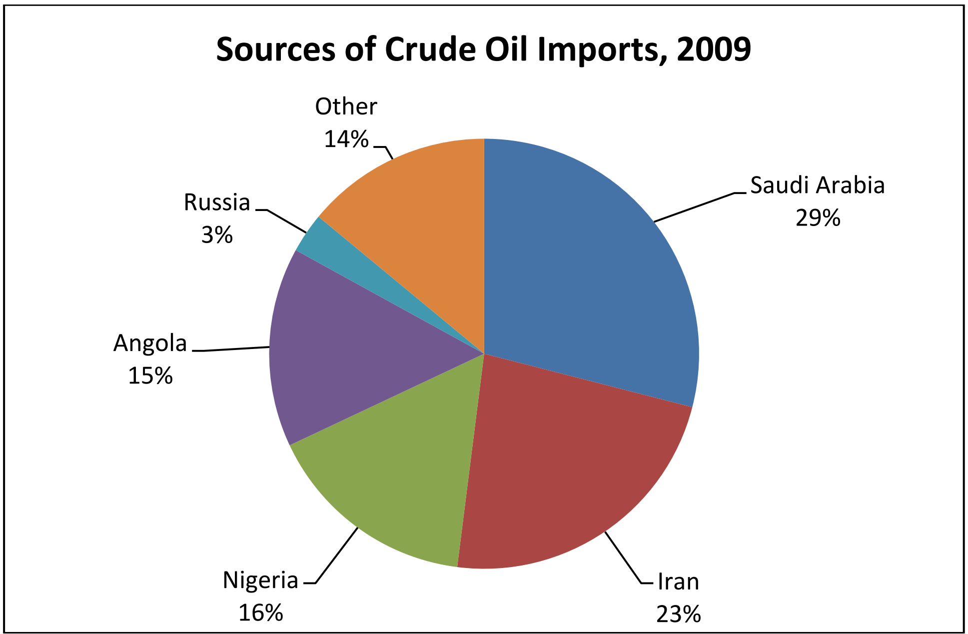
Figure 3-7: South African oil production and consumption, 1980-2010



Source: EIA (2011a)

In 2006, South Africa relied heavily on Middle Eastern suppliers of crude oil, especially Saudi Arabia and Iran, which together provided approximately 68% of crude imports (EIA, 2008). This represented a significant risk to supply security, given the Middle East region's perennial geopolitical instability. In its *Energy Security Master Plan – Liquid Fuels*, the DME (2007a) advocated a diversification of crude oil import sources. By 2009, South Africa had achieved a considerable diversification of its sources of oil imports, reducing the shares of Saudi Arabia (29%) and Iran (23%), and increasing imports from Nigeria (16%), Angola (15%), Russia (3%), Venezuela, Iraq, Yemen and the United Arab Emirates (see Figure 3-8) (EIA, 2010).

Figure 3-8: Sources of crude oil imports, 2009



Source: EIA (2010)

Another potential threat to domestic oil security is that Saudi Arabia announced its intention to construct a new refinery to process heavy oil, and indicated to South Africa that its exports to this country would be cut substantially from 2012 (Loubser, 2009). In view of these concerns, in September 2008 the South African government signed an energy cooperation agreement with Venezuelan President Hugo Chavez. The agreement included a deal for state oil company, PetroSA, to import heavy oil from Venezuela and also to become involved in oil and gas exploration in the South American country (Radebe, 2008). At the time, Venezuela was the world's fifth largest oil exporter.

Refining capacity

South Africa has the second largest oil refining capacity in Africa, after Egypt. Refineries are owned and operated by several large international oil companies (BP, Shell, Chevron and Engen) as well as by local firms Sasol and PetroSA. Total refining capacity in 2010 amounted to 703,000 barrels per day, of which 72% was comprised of crude oil refining with the balance of 28% being synthetic fuel refining capacity (see Table 3-1).

Table 3-1: Domestic crude oil and synthetic fuel refining capacity, 2008

Refinery	Barrels/day	Location	Company
Natref	108,000	Sasolburg	Sasol
Sapref	180,000	Durban	BP/Shell
Enref	120,000	Durban	Engen
Chevref	100,000	Cape Town	Chevron
Total crude oil refining	*508,000*		
Secunda	150,000	Secunda	Sasol
Mossgas	45,000	Mossel Bay	PetroSA
Total synthetic fuel refining	*195,000*		
TOTAL	*703,000*		

Source: SAPIA (2010)

For many years South Africa has exported refined petroleum products to other countries in Southern Africa. From 2006 demand for refined fuels in the region (including South Africa) outstripped domestic refining capacity so that increasing amounts of refined fuels had to be imported. According to the DME (2006), 88% of the country's refined petroleum products were derived from domestic refineries and the remaining 12% were imported in 2006. Of this total refined product supply, about 10% was exported, 10% consumed by maritime shipping and 80% consumed within SA's borders. In 2010 South Africa's refining capacity for petrol, diesel and kerosene (jet fuel plus illuminating paraffin) fell short of demand by an amount of 2,324 million litres or 11% of capacity (see Table 3-2).[84] In 2008 PetroSA announced that it was planning to construct a new 400,000 barrel per day refinery at Coega in the Eastern Cape, which it hoped would come on stream by about 2014 (Pringle, 2008). In February 2010 the Board of PetroSA approved the progression of the project to Front-End Engineering studies, conditional on Ministerial approval (PetroSA, 2010). Indications were that PetroSA was intending to source the crude oil from Venezuela.

[84] There appears to be inconsistency between the data in Table 3-1 and Table 3-2, since 703 000 bpd is equivalent to 40.8 million litres per annum (mlpa), assuming the bpd refining capacity is averaged over 365 days, or 29.1 mlpa assuming refining occurs five days per week. In the 2010 financial year, PetroSA produced at just 45% of its nameplate capacity.

Table 3-2: Refining capacity shortfall, 2010

2010	Millions of litres		
	Refining capacity	Demand	Surplus/ shorfall
Petrol	9,866	11,311	-1,445
Diesel	7,984	9,109	-1,125
Kerosene	2,976	2,730	246
Total	20,826	23,150	-2,324

Source: SAPIA (2010)

Distribution of oil products

As Table 3-1 shows, a large proportion (66%) of South Africa's crude oil refining capacity is located on the coast in Durban, Cape Town and Mossel Bay. Hence refined fuels have to be transported to inland areas, especially to Gauteng, where the largest share of oil products is consumed. This is done via a 12-inch fuel pipeline from Durban to Gauteng, as well as by rail and road. In addition, crude oil is transported to the inland Natref refinery in a pipeline operated by Transnet Pipelines. Following the recommendations of the DME's (2007) *Energy Security Master Plan – Liquid Fuels*, Transnet Pipelines began construction of a new multiproduct pipeline between Durban and Gauteng in 2009. The project was initially due for completion in 2010 but as of late 2011 it was still under construction. Refiners and wholesalers transport petroleum products from refineries to approximately 200 depots, and from these to roughly 4,600 service stations and 100,000 direct consumers (most of whom are farmers) (GCIS, 2011: 181). According to the DME (2007: 20-21), the logistical infrastructure for petroleum products was under severe pressure by 2007. Major constraints were evident in fuel offloading infrastructure at harbours, on oil companies' storage and distribution infrastructure, on inland petroleum pipelines and rail infrastructure, and in fuel storage capacity at the country's airports. These constraints represent significant vulnerabilities in terms of short-term supply shortfalls and their potential economic and social impact.

Oil and refined fuel stocks

South Africa maintains a strategic petroleum reserve at Saldanha Bay in the Western Cape. The facility has a maximum capacity of 45 million barrels, which translates into about 140 days' worth of crude oil imports (DME, 2007a). Information on the actual volume of oil in storage is not publicly available. In December 2005 South African oil refineries underwent modifications in order to comply with cleaner fuel regulations, and shortages of refined product developed in certain areas, which brought about economic losses and inconveniences. In view of this, the DME (2007a) recommended that the oil industry be required to maintain 28 days' worth of commercial petroleum product stocks.

3.1.3 Demand for oil

This subsection presents historical data describing the consumption of petroleum products in total, disaggregated by product type, sector and geographical region, and on a per capita basis.

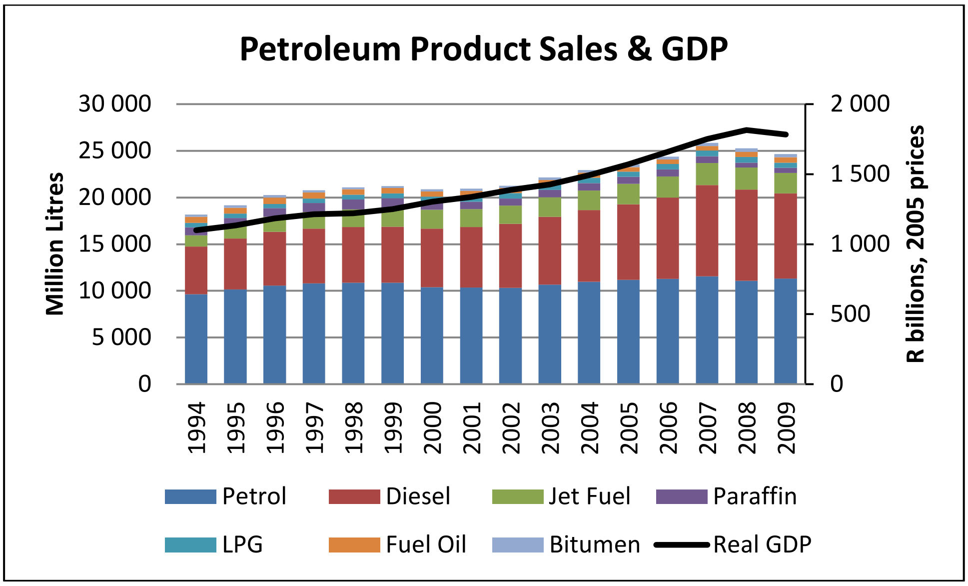
Consumption by petroleum product type

Total annual sales of petroleum products grew largely in line with the economy (real GDP) in the period 1994 to 2009 (see Figure 3-9). It should be noted that as yet, biofuels do not contribute any significant portion of all liquid fuels; their use is confined to very small-scale operators.[85] The same

[85] South Africa was the world's ninth largest producer of ethanol in 2006, accounting for 0.8% of the world total; however, none of this ethanol was used for automotive fuel. As of early 2011, no large-scale biodiesel

applies to liquid petroleum gas (LPG) in motor vehicles. LPG sales in the figures below relate mainly to household use for cooking and heating.

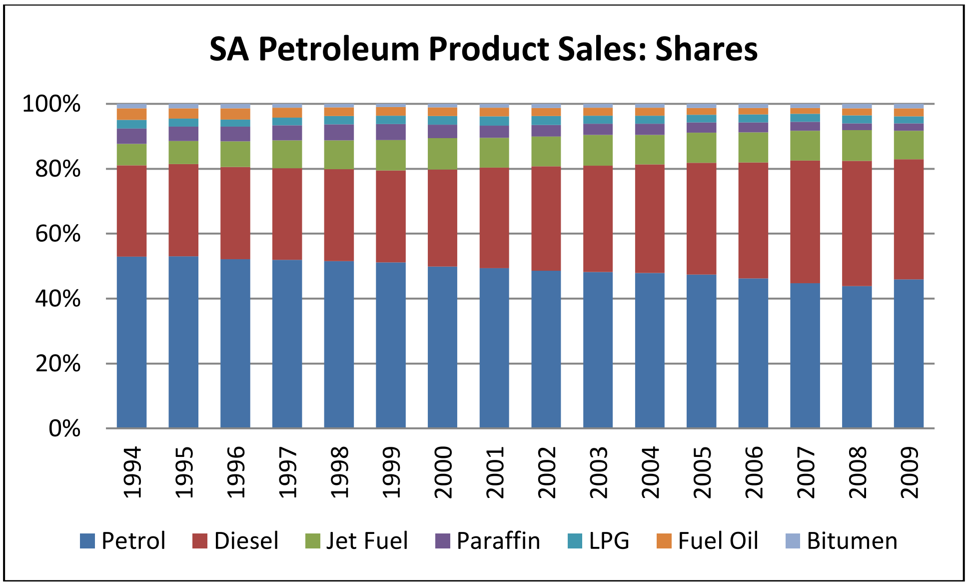
Figure 3-9: Annual total petroleum product sales, 1994-2009



Source: SAPIA (2009) and SARB (2011)

Figure 3-10 shows the percentage shares of fuel sales by fuel type. Petrol's share, while still the largest, declined monotonically over the period 1994 to 2008 (but increased slightly in 2009). This trend is mainly due to strong growth in diesel sales until 2008 (followed by a marked decline in 2009). The share of jet fuel also increased over the period. Paraffin sales have declined in relative terms while the proportions of other petroleum products have remained fairly constant.

Figure 3-10: Annual percentage shares of petroleum product sales by product type, 1994-2009



Source: SAPIA (2009)

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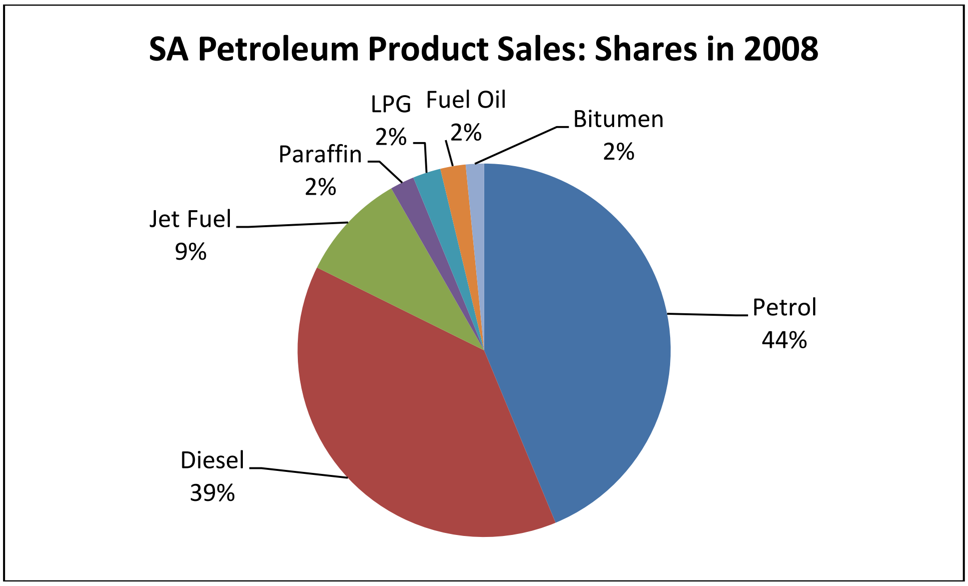
was being produced; very small-scale production of biodiesel from waste vegetable oil occurred in some parts of the country), and Jatropha plants were being cultivated in KwaZulu-Natal.

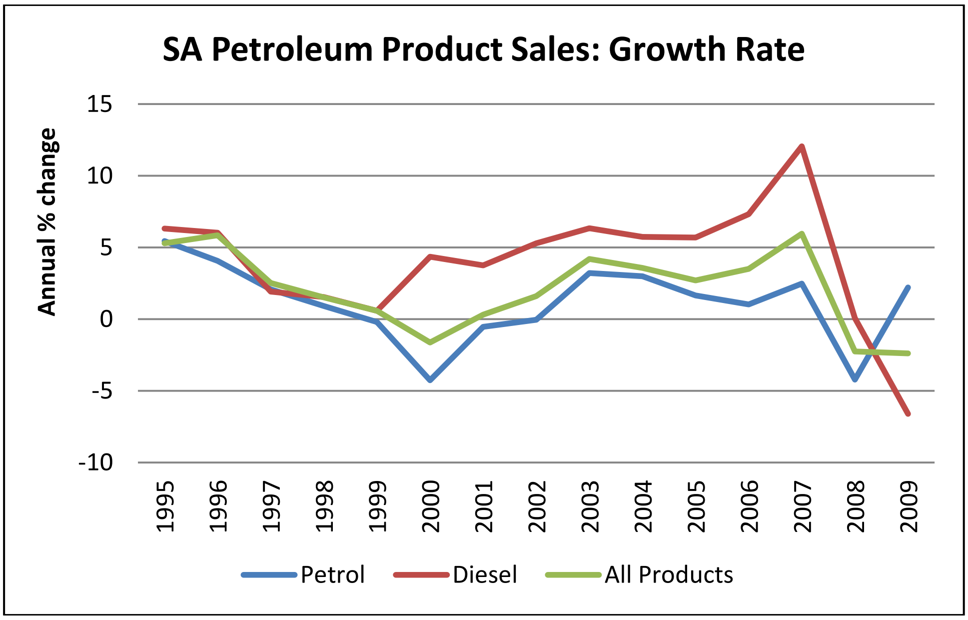
The dominance of road transport fuels out of total fuel sales is clearly evident in Figure 3-11 below. Petrol and diesel together make up more than 80% of petroleum product sales. The relative shares partly reflect demand and partly the proportions of a barrel of oil that can be refined into the various petroleum products.

Figure 3-11: Percentage shares of petroleum product sales by product type, 2008



Source: SAPIA (2009)

Figure 3-12: Annual growth in petroleum product sales, 1995-2009



Source: Own calculations based on SAPIA (2009)

Growth of diesel sales outstripped that of petrol sales by a considerable margin between 2000 and 2008, with 2007 recording spectacular growth of 12% (see Figure 3-12). The average growth rate for sales of all liquid petroleum fuels was 2.8% for the period 1995 to 2007. In that period the average annual growth rate for diesel was 5.1%, and for petrol, 1.4%. However, these growth rates fell steeply during 2008 as a result of sharply rising fuel prices (crude oil traded at $100 per barrel on average for the year) as well as tighter economic conditions (i.e. rising costs of living and higher interest rates). The recession in 2009 significantly dampened demand for diesel (consumption fell by 6.6%), although petrol demand grew by 2.2%.

Geographical patterns of consumption

Table 3-3 shows the provincial breakdown of petroleum product consumption in 2007. Gauteng consumed the largest share (36%) of petrol, followed by the Western Cape (16%) and Kwazulu-Natal (16%). Consumption of diesel followed a similar pattern: Gauteng again consumed the largest share (23%), although its dominance was much more muted than in the case of petrol. The Western Cape (17%) and Kwazulu-Natal (17%) also accounted for sizable shares. The relative shares of diesel consumption were determined in large part by freight volumes, but also depended on incomes and population densities. Paraffin consumption was highest in Gauteng and Kwazulu-Natal, but also significant in poorer provinces such as Eastern Cape and Mpumalanga. LPG was used mainly in three provinces, namely Mpumalanga, KwaZulu-Natal and Western Cape.

Table 3-3: Provincial shares of petroleum product consumption, 2007

Province	Petrol	Diesel	Paraffin	LPG	Total
Eastern Cape	7.3	6.5	18.6	1.2	7.1
Free State	5.9	8.7	4.7	1.1	6.9
Gauteng	36.3	23.3	20.1	2.6	29.3
Mpumalanga	7.9	12.5	16.6	28.5	10.7
Kwazulu-Natal	15.5	17.3	18.9	29.4	16.7
Northern Cape	1.7	4.0	1.3	0.5	2.6
Limpopo	4.5	4.6	2.1	0.7	4.4
North West	5.5	6.6	4.4	0.0	5.8
Western Cape	15.5	16.5	13.3	36.0	16.4
Total	100	100	100	100	100

Source: Own calculations based on SAPIA (2009)

The shares of petrol and diesel consumption are related to the provincial distribution (percentage shares) of car ownership, population and income (see Table 3-4). Car ownership is concentrated in the two wealthiest provinces, namely Gauteng and Western Cape. KwaZulu-Natal features mainly because of its large share of the population.

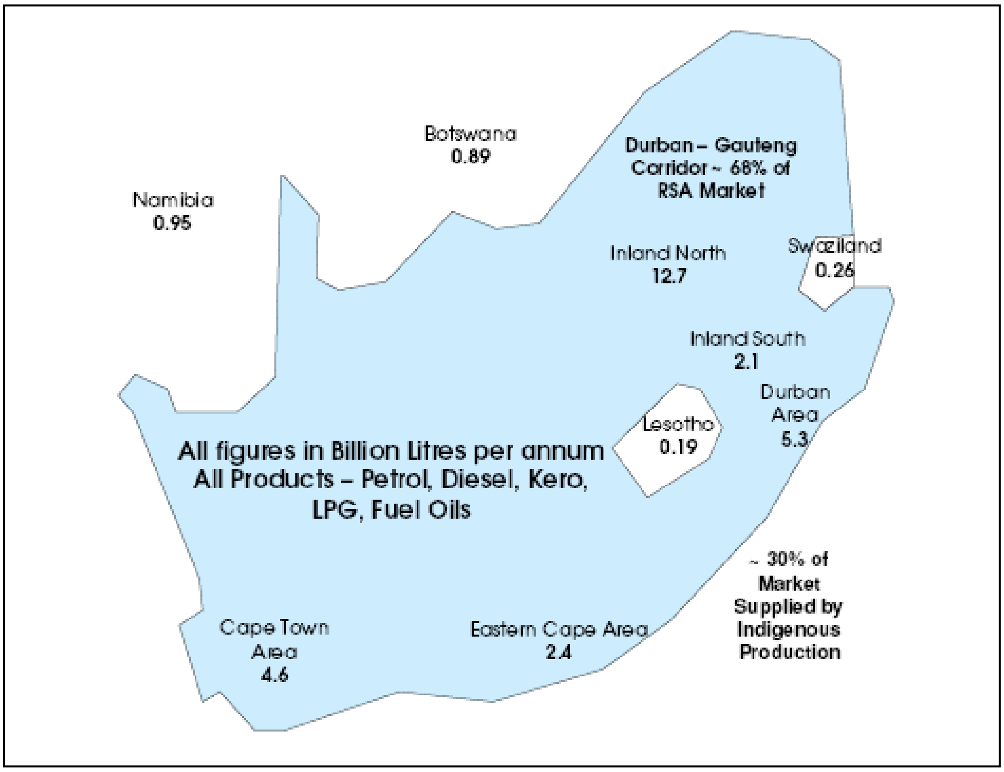
Table 3-4: Provincial distribution of vehicles, fuel consumption and population, 2008

Province	Vehicle registrations %	Petrol consumption %	Diesel consumption %	Population %	Av. household income R/annum
Eastern Cape	6.9	7.3	6.5	14.5	47,930
Free State	5.3	5.9	8.7	6.2	60,700
Gauteng	38.6	36.3	23.3	20.2	111,079
Mpumalanga	5.9	7.9	12.5	7.4	54,562
Kwazulu-Natal	14.2	15.5	17.3	21.0	58,551
Northern Cape	2.1	1.7	4.0	2.4	49,697
Limpopo	4.7	4.5	4.6	11.3	36,386
North West	5.4	5.5	6.6	7.0	56,310
Western Cape	16.9	15.5	16.5	10.0	135,029
Total	100.0	100.0	100.0	100.0	74,589

Source: Own calculations based on eNatis (2008), SAPIA (2009), StatsSA (2008)

Geographically, fuel consumption is concentrated in certain transport corridors. The DME (2007a) reports that 68% of all petroleum fuels (including jet fuel and heavy fuel oils) are consumed on the Johannesburg-Durban corridor, which effectively includes the Gauteng and Durban metros. A further 17% is consumed in the Cape Town area and 9% in the Eastern Cape (see Figure 3-13).

Figure 3-13: Geographical demand for petroleum fuels



Source: DME (2007a)

Sectoral patterns of consumption

Table 3-5 displays petrol and diesel sales by customer type. Petrol sales are overwhelmingly at the general retail level. Unfortunately the disaggregation does not fall into private versus public transport. For instance, the 'retail' category includes fuel sold by garages and general dealers, whether to private motorists or to minibus taxi operators. The agricultural sector (co-ops and farmers) consumes nearly 10% of diesel fuel and mining nearly 8%. The proportion of diesel fuel utilised for freight can be approximated by stripping out all sectors apart from retail and road

Table 3-5: Percentage sales of petrol and diesel by customer type (sector), 2007

Sector	Petrol	Diesel	Total
Agriculture	1.0%	9.5%	4.9%
Fishing	0.0%	1.3%	0.6%
Mining	0.1%	7.8%	3.6%
Construction	0.0%	2.5%	1.1%
Government	0.2%	0.7%	0.4%
Public Transport	0.0%	1.7%	0.8%
Retail	98.6%	67.4%	84.3%
Road haulage + Transnet	0.1%	9.2%	4.3%
Total	100%	100%	100%

Source: Own calculations based on SAPIA (2009) haulage plus Transnet's freight, and assuming that about 10% of the remainder is sold to private motorists.[86] This yields an estimate that 70% of diesel is used for freight transport.

3.1.4 Summary of energy vulnerabilities: systemic interdependencies

There are several interdependencies among the different primary energy sources and energy carriers in South Africa. In the first place, the production, refining and distribution of fossil fuels (coal, oil and gas) rely on energy carriers such as electricity and diesel. For example, the machinery and equipment used for mining coal consumes diesel and electricity. Domestic refining of imported crude oil, and therefore the supply of petroleum products like petrol and diesel, also depends on electricity supply. So too does domestic production of synthetic fuels by Sasol and PetroSA (Sasol produces only a portion of its own electricity needs on-site). In addition, electricity is required for pumping oil through the Durban-Gauteng pipeline (to the Natref refinery) and at the point of distribution in fuel service stations. Similarly, the domestic production of synthetic gas by Sasol and LPG by the refineries utilises electricity. The generation of electricity in turn depends on fossil fuels both directly (in terms of feedstock, mostly coal) and indirectly. Coal supplies have to be transported from mines to power stations, either by rail or by road, and this depends on diesel to fuel the trains and trucks. As coal deposits located close to coal-fired power stations are progressively depleted, so the distances and costs of transporting coal to power plants increases. In addition, a small portion of South Africa's electricity is generated in open cycle gas turbines, which utilise petroleum fuels. (These turbines are significant in that they are used to generate electricity to meet peak demand, which is important for stabilising the national grid.) Nuclear power is derived from uranium, which first needs to be mined, requiring diesel fuel and electricity. The uranium then needs to be enriched, which again consumes electricity. Although South Africa mines and exports uranium, it does not presently enrich its own uranium and therefore imports enriched material from abroad. Diesel fuel is used to transport enriched uranium to the Koeberg nuclear power plant from the Cape Town harbour. Finally, production of solar and wind power, although currently negligible in scale, nevertheless relies on oil for manufacturing, transport, installation and maintenance. These interdependencies compound the vulnerabilities of South Africa's energy system and economy to cumulative oil supply constraints or price shocks and hence present a set of long-term risks.

3.2 Transport

This section begins with an overview of South Africa's transport system. It then details the energy and oil dependence of the transport system, before identifying key strengths and vulnerabilities in relation to oil price and supply shocks. The final subsection summarises the discussion.

3.2.1 Overview of the transport system[87]

The transport system is characterised by infrastructure, passenger travel and freight movement. Each of these facets is considered in turn, according to various transport modes, namely road, rail, air, sea and pipelines (in the case of freight).

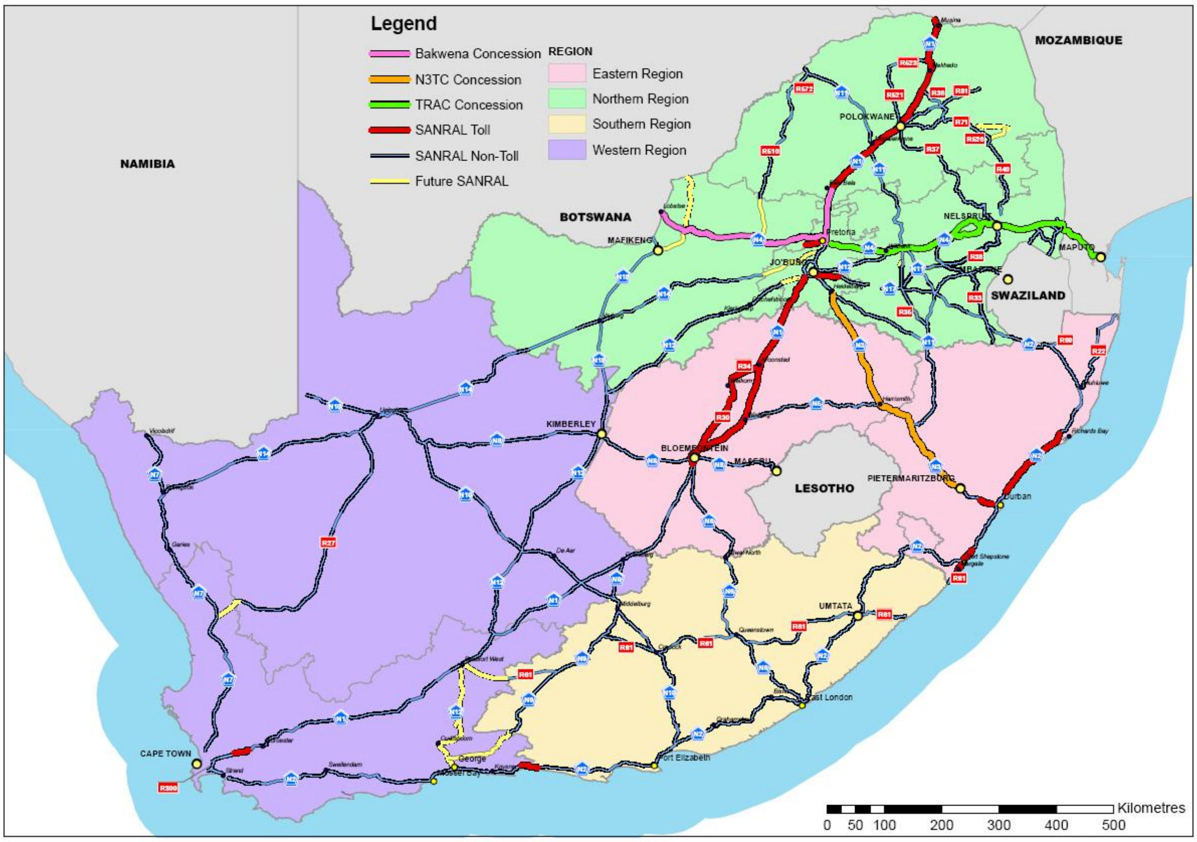
[86] According to NAAMSA (2007), 10% of private passenger vehicles are diesel and the remainder petrol driven. Since total petrol and diesel consumption volumes are similar, it is assumed that on average diesel cars consume roughly the same volume as petrol cars.

[87] This section draws substantially on ASPO-SA et al. (2008a).

Transport infrastructure

South Africa has a transport infrastructure that is the envy of many developing countries. An extensive road network, comprising both paved and (to a much greater extent) unpaved roads, covers much of the country (see Figure 3-14). The South African National Roads Agency Limited (SANRAL) administers 16,750 kilometres of paved national roads (GCIS, 2009: 537). In addition the country has some 170,000 kilometres of urban roads, most of which are paved (DoT, 2002). A rail network of 20,000 kilometres connects all of the major urban settlements in the country. Approximately 80,000 wagons and 2,300 locomotives operate on this network (ASPO-SA et al., 2008a: 24). The South African Rail Commuter Corporation (SARCC) operates commuter railways in the six major metropolitan areas. There are no light rail systems in South Africa's cities. South Africa has in excess of 20 commercial airports, although many of these are small and provide limited services (ASPO-SA et al., 2008a: 24). At least 50 airlines operate in South Africa, six of which offer domestic flights. The majority of international flights land at the O.R. Tambo International Airport (ORTIA) in Johannesburg, although airports in Cape Town and Durban also offer some international flights. South Africa has a coastline of 2,954 kilometres, on which there are 18 notable ports including eight multi-purpose commercial ports (ASPO-SA et al., 2008a: 29). These ports are connected to the rail and road networks and serve as entry and exit points for internationally traded goods. A national pipeline network spans KwaZulu-Natal, Free State, North West, Mpumalanga and Gauteng provinces, while the Western Cape has a distinct pipeline system (ASPO-SA et al., 2008a: 31). These pipelines transport a variety of products, including crude oil, natural gas and refined fuels such as aviation fuel, diesel and petrol. The major pipelines transport fuels from eThekwini (formerly Durban) to refineries in Gauteng and the Free State. Sasol imports gas via a pipeline from Mozambique.

Figure 3-14: South Africa's national road network



Source: DoT (2008)

Passenger travel

Despite the country's extensive transport infrastructure, approximately one half of South African citizens rely for their mobility on non-motorised transport, mainly walking and (to a lesser extent) cycling (DoT, 2005). The remaining half of the population makes use primarily of road-based motorised transport, including private motor vehicles and minibus taxis. According to the National Household Travel Survey (NHTS), South Africa had some 10 million commuters in 2003 (DoT, 2005). The major reasons for travel overall were education (41% of household members), shopping (30%), visiting (29%) and work (27%), although the main purpose varied according to settlement type and province. As seen in Table 3-6, the country's commuters are overwhelmingly dependent on road transport, including minibus taxis (22% of commuters), cars (15%), buses (6%) and other taxis (3.7%). Just 2.3% of commuters reported use of trains. Passengers in general have a low regard for public bus and rail transport systems as a result of perceptions of long distances between dwellings, stations and bus stops (ASPO-SA et al., 2008a: 9). Table 3-6 also shows that the usage of various transport modes varies by province, with private car usage being highest in the Western Cape (30% of household members) and Gauteng (25%). The reliance on motorised transport is substantially higher in metropolitan and urban areas compared to rural areas for almost all transport modes. Water-based passenger transport (along the coast) is negligible.

Table 3-6: Travel modes used by household members in a typical week

Province	Percentage of all people							
	Train	Bus	Metered taxi	Minibus taxi	Sedan taxi	Bakkie taxi	Car	Other
Western Cape	7.6	4.6	1.2	19.6	0.8	1.2	29.9	35.1
Eastern Cape	0.7	3.3	0.5	15.9	1.2	4.9	8.6	64.9
Northern Cape	0.3	2.2	0.4	12.7	0.4	0.9	16.1	67
Free State	0.2	3.3	0.9	22.5	1.5	0.6	12.6	58.4
KwaZulu-Natal	1.1	8.7	1.6	20.5	0.9	2.8	11.2	53.2
North West	1.1	6.7	1	22.7	0.4	0.7	11.9	55.5
Gauteng	5.7	3.7	1.6	31.8	0.7	1.1	25	30.4
Mpumalanga	0.2	8.1	1	19.7	1	1.1	11.8	57.1
Limpopo	0.1	5.6	0.6	17.7	0.3	0.7	7.7	67.3
RSA	**2.3**	**5.5**	**1.1**	**21.7**	**0.8**	**1.9**	**15.3**	**51.4**
Metropolitan	5.9	6.3	1.8	29.3	0.8	1.2	24.5	30.2
Urban	1	3.9	0.9	24.4	1.4	1.2	19.8	47.4
Rural	0.3	5.7	0.7	14	0.5	2.9	5	70.9

Source: DoT (2005)

Table 3-7 displays statistics on vehicle registrations by vehicle type and province. As of 31 December 2009, there were approximately 8.5 million self-propelled registered vehicles on South Africa's roads, including 5.4 million motor cars, 283,000 minibus taxis, 45,000 buses, almost 2 million light trucks and over 320,000 heavy trucks. Gauteng province accounted for the largest share (39%) of self-propelled vehicle registrations, followed by the Western Cape (17%) and KwaZulu-Natal (14%).

Table 3-7: Vehicle ownership per vehicle type and province, 31 December 2009

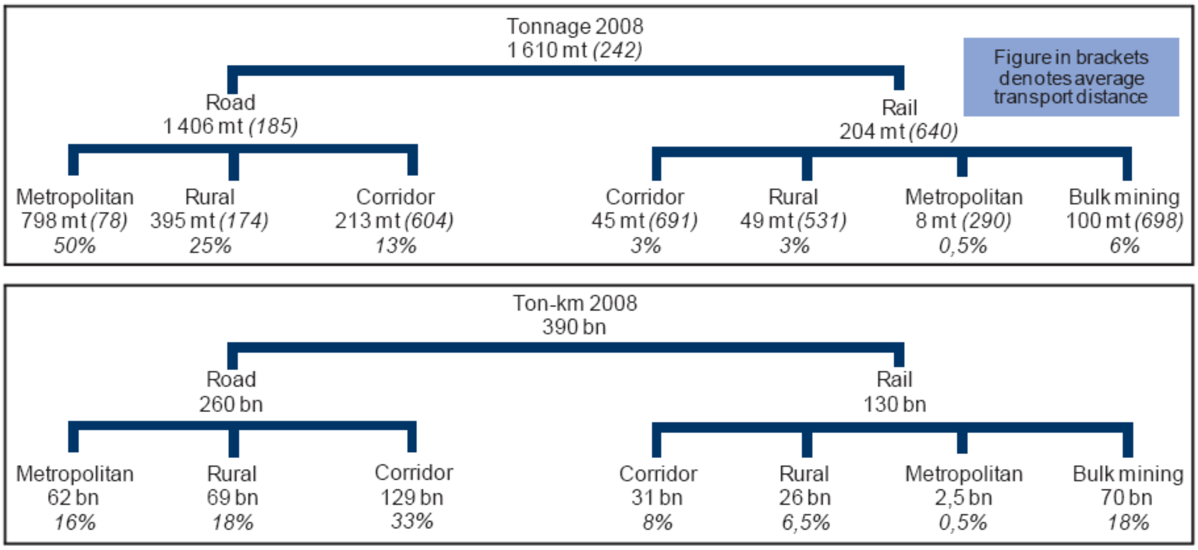
Vehicle class	GP	KZ	WC	EC	FS	MP	NW	L	NC	Total	% of total
Motor cars	2,256,780	754,048	969,006	346,880	253,701	282,341	255,514	200,662	92,161	5,411,093	63.04%
Minibuses	110,845	43,394	35,458	20,715	12,035	19,781	18,090	18,781	3,842	282,941	3.30%
Buses	14,916	6,958	5,107	3,714	2,025	4,406	3,118	3,846	1,127	45,217	0.53%
Motorcycles	141,423	33,526	74,669	24,281	23,266	22,925	20,681	12,637	8,992	362,400	4.22%
Light trucks	626,637	281,554	271,920	161,633	110,215	151,718	128,660	153,258	60,697	1,946,292	22.68%
Heavy trucks	121,769	50,441	34,586	24,470	19,227	24,978	17,976	19,504	8,653	321,604	3.75%
Other	34,081	30,020	30,916	12,694	37,413	23,351	24,531	13,368	7,258	213,632	2.49%
Total	**3,306,451**	**1,199,941**	**1,421,662**	**594,387**	**457,882**	**529,500**	**468,570**	**422,056**	**182,730**	**8,583,179**	**100.0%**
% of total	38.52%	13.98%	16.56%	6.93%	5.33%	6.17%	5.46%	4.92%	2.13%	100.0%	

Source: eNatis (2010)

Freight movement

Freight transport is also heavily road-based. Slightly more than 1.6 billion tons were moved in 2008: 1.4 billion tons (87%) by road and 204 million tons (13%) by rail, of which approximately half was on the two bulk mining corridors (see Figure 3-15). In tonnage terms, half of all freight is moved on metropolitan roads, and another quarter on rural roads. However, average distances are much shorter on roads (185 kms) than rail (640 kms). As a result, road freight accounts for 67% of ton-kilometres and rail for the remaining 33%. Mining products, such as coal and iron ore, account for almost half of all freight tonnage, manufacturing for another 45% and agricultural products for just 6% (GCIS, 2007: 578). Since the mid 1990s, rail freight volumes on corridors have declined while road freight volumes have grown steadily. Logistics costs in 2008 amounted to R339 billion or 14.7% of GDP, half of which were transport costs (CSIR, 2010: 5). Relatively small volumes of freight are transported by air, mainly to and from ORTIA and Cape Town International Airport. South Africa lacks any significant navigable rivers and hence does not make use of water-borne freight transport.

Figure 3-15: Modal distribution of road and rail freight in South Africa, 2008



Source: CSIR (2010)

Table 3-8 shows the trends in freight movement between 2003 and 2008. Road tonnage grew significantly (on average 7.7% per annum) while average distances declined slightly (-1.5%); overall, road ton-kilometres grew every year (7.2% average). Rail tonnage remained almost constant (average 0.4% growth), while average distances declined markedly between 2004 and 2005 and thereafter stabilised; ton-kilometres grew marginally (average 1.0%). In total, freight tonnage grew by an annual average 6.6%; average distances declined slightly (-0.4%) and ton-kilometres grew by 4.9% on average.

Table 3-8: Freight transport in South Africa, 2003-2008

Mode	Description	Units	2003	2004	2005	2006	2007	2008
Road	Tonnage	million tons	973	1037	1210	1291	1373	1406
	Average distance	kilometres	200	195	184	178	178	185
	Ton-kms	billion ton-kms	184	202	223	230	245	260
Rail	Tonnage	million tons	200	202	206	202	205	204
	Average distance	kilometres	800	800	626	633	629	640
	Ton-kms	billion ton-kms	124	127	129	128	129	130
Total	Tonnage	million tons	1173	1239	1416	1493	1578	1610
	Average distance	kilometres	270	270	189	240	237	242
	Ton-kms	billion ton-kms	308	329	352	358	374	390

Source: CSIR (various years)

3.2.2 Oil dependence of the transport system

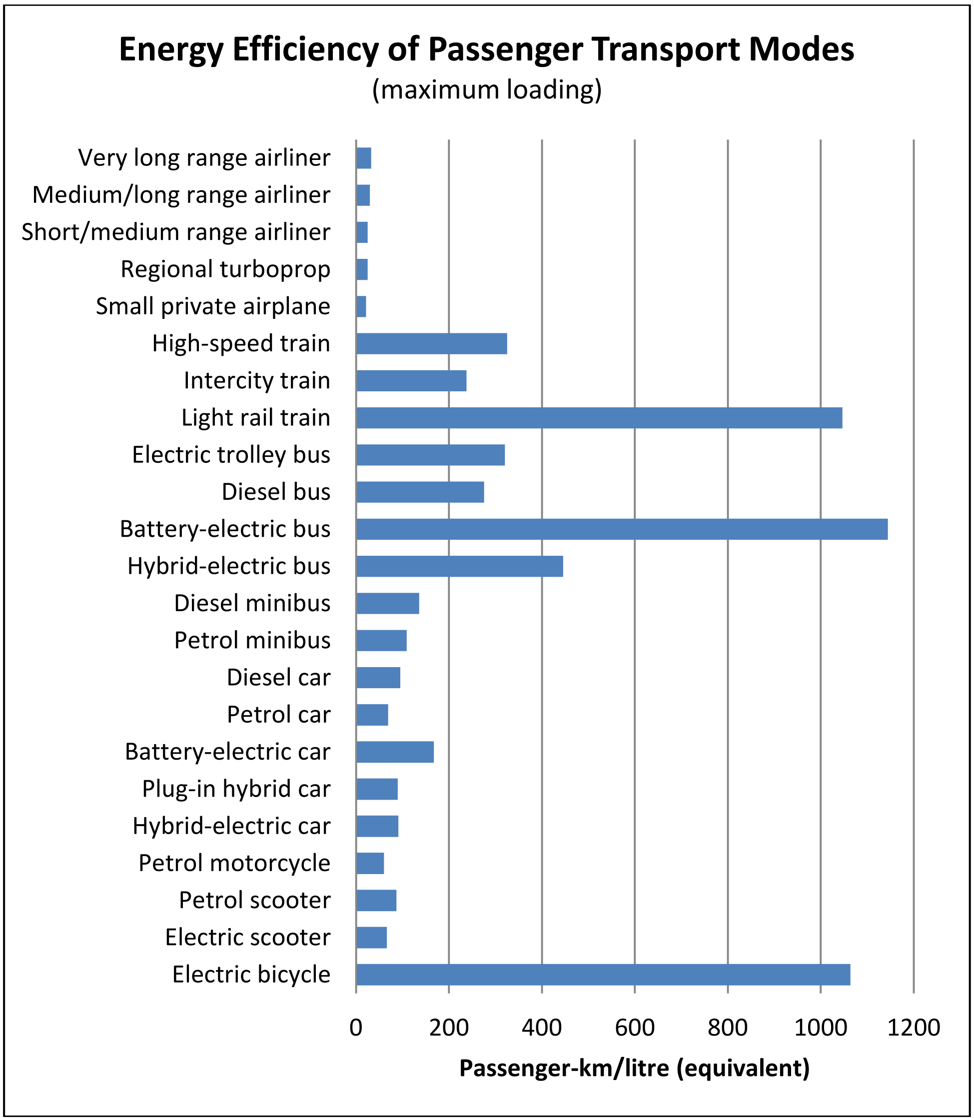
As seen in Section 3.1 (Figure 3-4), the transport sector utilised 77% of all petroleum energy, 2% of all electricity, and 25% of total final energy consumed in South Africa in 2007. Within the transport sector itself, 98% of the energy consumed is derived from petroleum products, and only 2% from electricity (these shares have hardly changed since 1990). Clearly, the transport sector is overwhelmingly dependent on liquid petroleum fuels, i.e. petrol, diesel and jet fuel. Table 3-9 shows the consumption of energy disaggregated by energy carrier and by transport mode. Road transport dominates energy consumption with nearly 89% of petroleum fuels and 87% of all energy. Aviation (including international and domestic air transport) accounted for 11% of petroleum consumption within the transport sector in 2006. Rail used predominantly electricity (94% of electricity consumed by the transport sector) plus a small amount of diesel, but only 2% of total energy consumed by transport.

Table 3-9: Energy consumption by the transport sector, 2006

Transport Sector	Petroleum		Electricity		Total	
	TJ	%	TJ	%	TJ	%
International civil aviation	35,178	4.9	-	-	35,178	4.8
Domestic air transport	43,510	6.1	180	1.4	43,690	6.0
Road	632,489	88.6	71	0.6	632,560	87.1
Rail	2,892	0.4	11,810	94.3	14,702	2.0
Pipeline transport	-	-	284	2.3	284	0.04
Internal navigation	-	-	181	1.4	181	0.02
Non-specified	-	-	1	0.0	1	0.00
Total	714,069	100.0	12,527	100.0	726,596	100.0

Source: DME (2006)

Figure 3-16: Energy efficiency of various passenger transport modes with maximum loading



Sources:

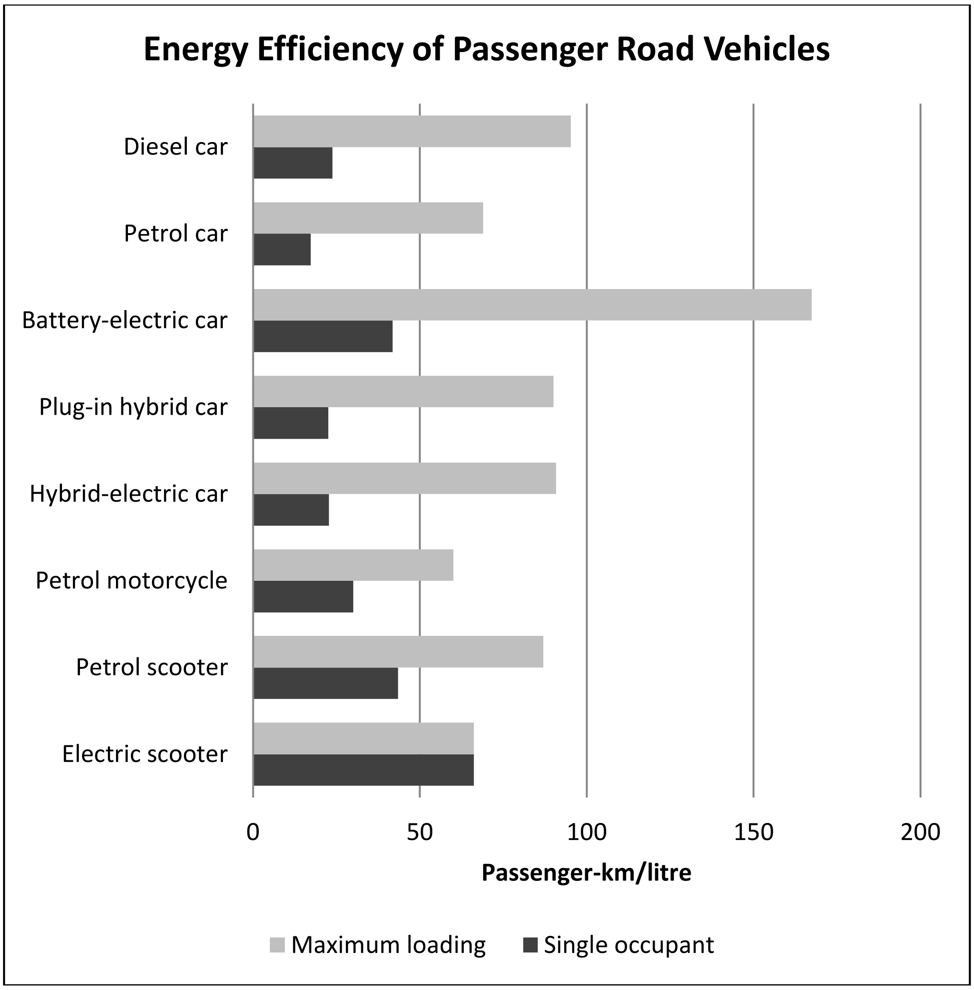
- Airplanes: Schiller et al. (2010)
- Trains & trolley bus: Schiller et al. (2010)
- Diesel bus; hybrid-electric bus: Thomas Built Buses (2011)
- Battery-electric bus: Xinhua News (2008)
- Petrol & diesel minibus: Toyota (2011)
- Diesel car: Volkswagen (2011)
- Battery-electric car: Independent News (2011)
- Plug-in-hybrid: United States Government (2011)
- Petrol motorcycle; hybrid-electric car; petrol car: Honda (2011)
- Electric scooter; petrol scooter: Scooti (2011)

Notes: For details of vehicle models, see Table 5-7 in Chapter 5. Energy efficiency of an electric bicycle is 1064 km/litre equivalent.

Energy efficiency of various transport modes

Statistics on the relative energy efficiency (in kilometres per litre of petrol or equivalent electrical energy) of different transport modes (e.g. motorcycles, private cars, minibuses, buses and trains) are presented graphically in Figure 3-16 and Figure 3-17, based on information provided by manufacturers and suppliers. At maximum loadings, the highest energy efficiency is attained by battery-electric buses, light rail, and electric bicycles, followed by other buses, trains, minibuses, cars, scooters and motorcycles. With single occupants, electric and petrol scooters and battery-electric cars are amongst the most efficient modes. Clearly, efficiencies are much higher when motorised vehicles are fully loaded. Thus policies which encourage higher vehicle occupancy rates can make a considerable difference to energy consumption. Diesel cars are up to 30% more fuel efficient than petrol cars of comparable size (Vanderschuren et al., 2009). Larger buses are more efficient than minibuses. There is very little difference in efficiency between diesel and electric trains (Hughes, 1993). At maximum loading the difference between buses and trains is very small. Notably, non-motorised transport (cycling and walking) is more energy efficient than any form of motorised transport except electric bicycles, although NMT is clearly limited in terms of distances that can be travelled. Air transport is clearly the least efficient mode of transport, especially for small airplanes that fly shorter distances.

Figure 3-17: Energy efficiency of road vehicles: maximum loading versus single occupant



Sources: Same as previous figure

3.2.3 Strengths and vulnerabilities of the transport system

The major vulnerabilities inherent in South Africa's transport system include infrastructural, modal (passenger and freight), geographical, social and institutional dimensions.

Transport infrastructure in South Africa, although extensive relative to many other developing countries, suffers from several problems. A major weakness of the road network is the deficit in road maintenance in many areas, with an estimated backlog of R75 billion in April 2010 (Davenport, 2010). Some four fifths of the country's roads were older than the 20-year lifespan for which they were designed (Davenport, 2010). According to the CSIR (2010: 5), "The percentage of bad and very bad roads in the secondary road network of South Africa increased from 8% in 1998 to 20% in 2008." Road maintenance costs are vulnerable to oil price shocks, since the bitumen used for surfacing paved roads is derived from crude oil.

Although the rail network has significant spare capacity for moving freight, it has been neglected in terms of maintenance and upgrading (ASPO-SA, 2008a: 50-51). Much of the nation's rolling stock is very old and needs to be replaced (Situma, 2007). According to the Director-General of the DoT, George Mahlalela (2010), "most of our commuter rail system has reached the end of its lifespan." In addition, the rail lines are narrow gauge, which limits their efficient carrying capacity. Furthermore, there has been an attrition of skills in the rail sector. The well-developed port infrastructure could serve the economy well if more freight is shifted from road to sea. However, since manufacturing production is concentrated in Gauteng, there is limited scope for such modal transfer, especially considering the lack of inter-modal facilities (ASPO-SA, 2008a). Many of the country's airports were upgraded or expanded in preparation for the FIFA Soccer World Cup in 2010, but this expenditure will be of doubtful use for the future when air travel is likely to be severely constrained internationally and domestically by rising fuel costs and declining disposable incomes. Public transport in several major cities also received a significant boost as part of the preparations for the Soccer World Cup. In particular, construction was begun on Bus Rapid Transit (BRT) systems in Johannesburg and Cape Town. However, provision of infrastructure to facilitate non-motorised transport in cities, such as walk-ways and bicycle paths, is sorely lacking.

The mobility of the half of South Africa's population that relies on motorised transport is highly vulnerable to oil price shocks and shortages, given the overwhelming reliance on liquid petroleum-fuelled vehicles. Poorer transport users tend to spend a much higher proportion of their incomes on transport and therefore are more vulnerable to rising fuel and transport costs than their wealthier counterparts. Owners of private vehicles and users of minibus taxis alike are vulnerable to physical fuel supply shortages. While air travel will be particularly vulnerable to rising fuel prices (since fuel accounts for a relatively high proportion of total costs), business travellers can adapt to some extent by telecommuting. Many of those travelling by air for other purposes (e.g. tourism) are likely to have to shift mode and/or reduce their travel distances. Respondents to the National Household Travel Survey (NTHS) reported a number of concerns, the chief one being lack of access to public transport (50% of households), while 75%, 40% and 75% reported no access to rail services, buses and cars, respectively (DoT, 2002). Other concerns identified by households included safety (33%), affordability (20%) and security. Thirty percent of households spent more than 20% of their income on public transport (including taxis) in 2003; since then, petrol and diesel prices have more than trebled. According to ASPO-SA et al. (2008a: 9), "The public transport system is underutilised, severely under-developed and undercapitalized in relation to commuter needs."

The heavy reliance of freight on road transport presents a major challenge to the economy, both in terms of future fuel supply constraints and the impact of rising costs. Lane (2009) catalogues a range of vulnerabilities that characterise freight transport in South Africa, including inadequate technology, equipment and facilities; outdated infrastructure; lack of inter-modal facilities; capacity bottlenecks; monopoly ownership of certain infrastructure; skills shortages; and a lack of information. "The cost, efficiency and capacity of the national logistics system" was highlighted in the Accelerated and Shared Growth Initiative for South Africa (AsgiSA) as a "binding constraint" on the country's economic performance (The Presidency, 2006a: 5). The National Freight Logistics Strategy (DoT, 2005: ii; original italics) identifies several specific weaknesses:

> "*The freight system in South Africa is fraught with inefficiencies at system and firm levels. There are infrastructure shortfalls and mismatches; the institutional structure of the freight sector is inappropriate, and there is a lack of integrated planning. Information gaps and asymmetries abound; the skills base is deficient, and the regulatory frameworks are incapable of resolving problems in the industry*."

Vulnerabilities can also be identified on a geographical basis. Most obviously, there are substantial distances between major metropolitan areas and towns. The bulk of liquid fuels are consumed in metropolitan areas, due to the high concentration of vehicles found here and the phenomenon of urban sprawl. Residents of townships and informal settlements are highly vulnerable because of their dependence on minibus taxis, their susceptibility to poverty, and the large distances from places of work. Areas in the hinterland that have no rail access are also highly vulnerable, with a danger that both people and assets could become stranded. Many parts of the country are accessible only by roads (ASPO-SA et al., 2008a: 56). Both industry and population are concentrated in the interior of the country, far from ports (and at a much higher altitude), which means that two long-distance corridors (Gauteng-Durban and Gauteng-Cape Town) carry large freight volumes (Lane, 2009). Finally, South Africa is far from most of its trading partner countries, which makes international trade especially vulnerable to rising transport costs.

The social dimension of vulnerability is related to the geographical and infrastructural dimensions. Of particular concern is the minibus taxi industry, which has demonstrated considerable potential for episodes of extreme violence, including intimidation and even killing of commuters who choose to use trains and buses (Economist, 1998). Another group who would be adversely affected by fuel shortages and price rises are truckers. Even advanced countries such as Britain and France have found that striking or protesting truck drivers can bring segments of their economies to a standstill in a short space of time (Strahan, 2007: 13-16). In addition, low-income metropolitan and urban areas could become flashpoints for social protests as economic pressures and constraints on mobility intensify.

A final set of vulnerabilities concerns institutional factors (SACN, 2009). First, the lack of skills in the country that are required for adequate transport service delivery has resulted in "enormous planning and implementation backlogs, and an inability to spend allocated capital and operation budgets for improved public transport services" (SACN, 2009: 7). Second, the lack of integration between local, provincial and national authorities has hindered transport planning and implementation. Third, reforms of public transport systems have in some instances been met with resistance from labour unions. These institutional failures have contributed to the increase in transport costs.

3.2.4 Summary of transport vulnerabilities

Mainly as a consequence of poverty, about half the South Africa's population relies mostly on non-motorised transport. The other half are almost entirely reliant on road-based motorised transport, mostly in the form of minibus taxis and private cars. Freight is also transported predominantly by road. Thus South Africa's transport system is extremely dependent on petroleum-based liquid fuels. Although extensive by developing country standards, the road and rail networks suffer from inadequate maintenance. The rail network is underutilised, but new locomotives and wagons would have to be imported. Most changes to bulk transport infrastructure, such as the development of new railways, are by their nature both costly and time-consuming, which means that short-term impacts of oil shocks could be severe. South Africa is spatially challenged in several respects, including the wide distribution of metropolitan areas as well as the configuration of urban and metro settlement patterns. Spatial realities and the reliance on road transport interact with social issues (such as poverty) to create various potential flash-points, such as the minibus taxi industry. An effective transport system is essential to the functioning of the economy, which relies on the movement of both people and goods. After transport, the next most petroleum-dependent sector in South Africa is agriculture, which is considered in the following section.

3.3 Agriculture

Agriculture, which is classified as one of the primary economic sectors, is a quantitatively small but qualitatively important sector of the economy. It represents the base layer of the economy in that the population and labour force must have food in order to carry out economic activities. Economic and social stability depend on a healthy, functioning system of agricultural production and food distribution. Section 3.4.1 provides an overview of the agricultural system in South Africa, while Section 3.4.2 describes its dependence on oil. Section 3.4.3 explores the strengths and vulnerabilities of agriculture in relation to oil shocks, with a special emphasis on national food security. The final subsection summarises the discussion.

3.3.1 Overview of agriculture

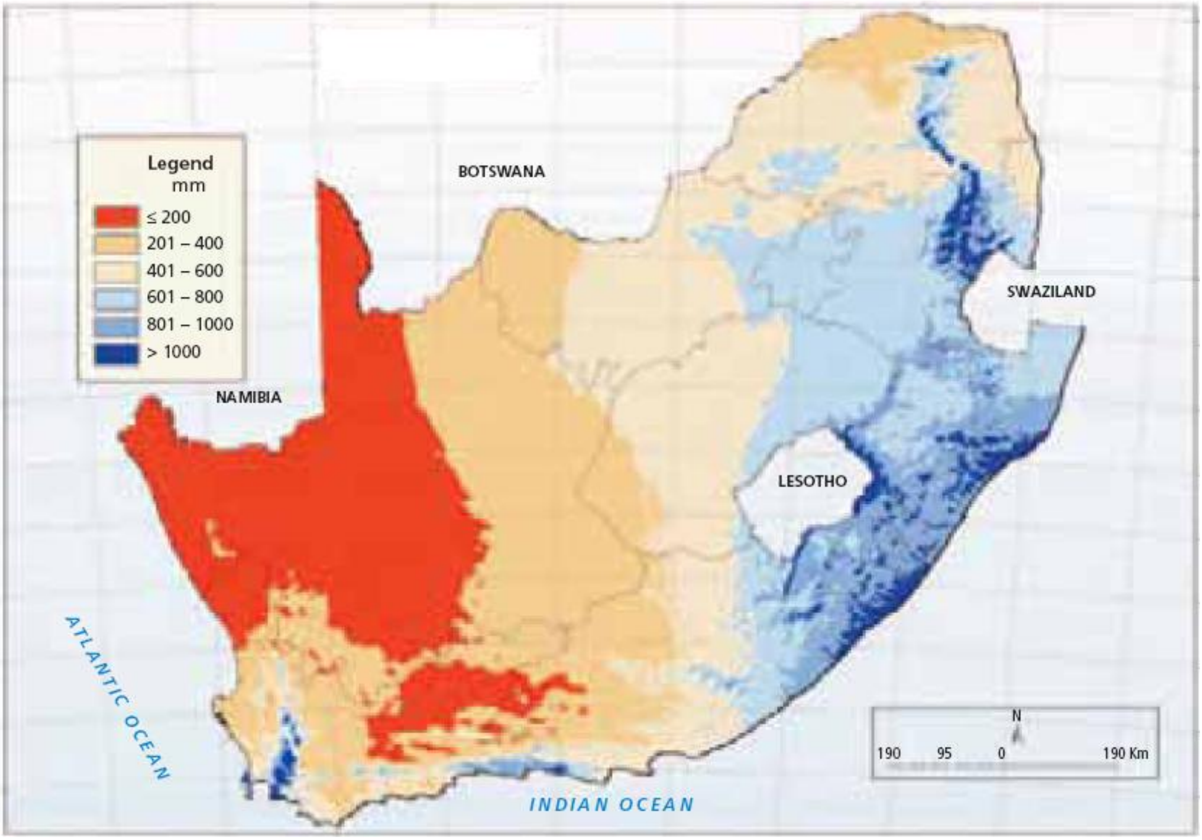
South Africa has a total land area of 127 million hectares, of which just over 100 million hectares (82%) is classified as farmland (National Department of Agriculture (NDA), 2009a). The vast majority of this farmland (84 million hectares or 69% of the total land area) is suitable for grazing only. Approximately 16.7 million hectares (14%) of the country's land area receives sufficient rainfall to be potentially arable, although only about a fifth of this land is of high quality (GCIS, 2009: 47). Water scarcity is a limiting factor for agriculture, and only about 1.35 million hectares (1.5% of agricultural land and less than 10% of arable land) is under irrigation (NDA, 2009a). Nonetheless, irrigation uses approximately 50% of the country's run-off water (GCIS, 2009: 47).

South Africa's agricultural economy is made up of two parts: an industrialised commercial sector, and a largely rural subsistence or smallholder sector (GCIS, 2009: 47). Commercial farmers account for at least 95% of total marketed agricultural produce (Food and Agriculture Organisation (FAO), 2005: 2). The commercial agriculture sector produces a wide range of commodities, including livestock products (meat and dairy products), field crops (grains such as maize, wheat and sorghum; sugar; oil seeds; and cotton) and horticultural produce (fruits and vegetables). These three major categories contributed R 53.1 billion (44%), R 39.9 billion (33%) and R 27.1 billion (23%), respectively, to a total value of commercial agricultural production of R120 billion in 2007/08 (NDA, 2009a). Maize occupies half of all the land under crops (FAO, 2005: 13), is the most important food crop by volume of output, and is the staple food for the majority of South Africans.

Subsistence farming occurs predominantly in the rural, former 'homeland' areas of South Africa (Pauw, 2007: 196) and contributes less than 5% of total agricultural output (FAO, 2005: 2). Maize cultivated by the subsistence sector amounted to about 4% of national maize production in 2008 (NDA, 2009b: 11). Subsistence farming involves a small share of the South African population relative to other sub-Saharan African countries, where it remains a major contributor to livelihoods (Baiphethi & Jacobs, 2009: 462). Nevertheless, there are approximately four million South Africans involved in subsistence farming, mostly to secure an "extra source of food" (Aliber & Hart, 2009: 439).

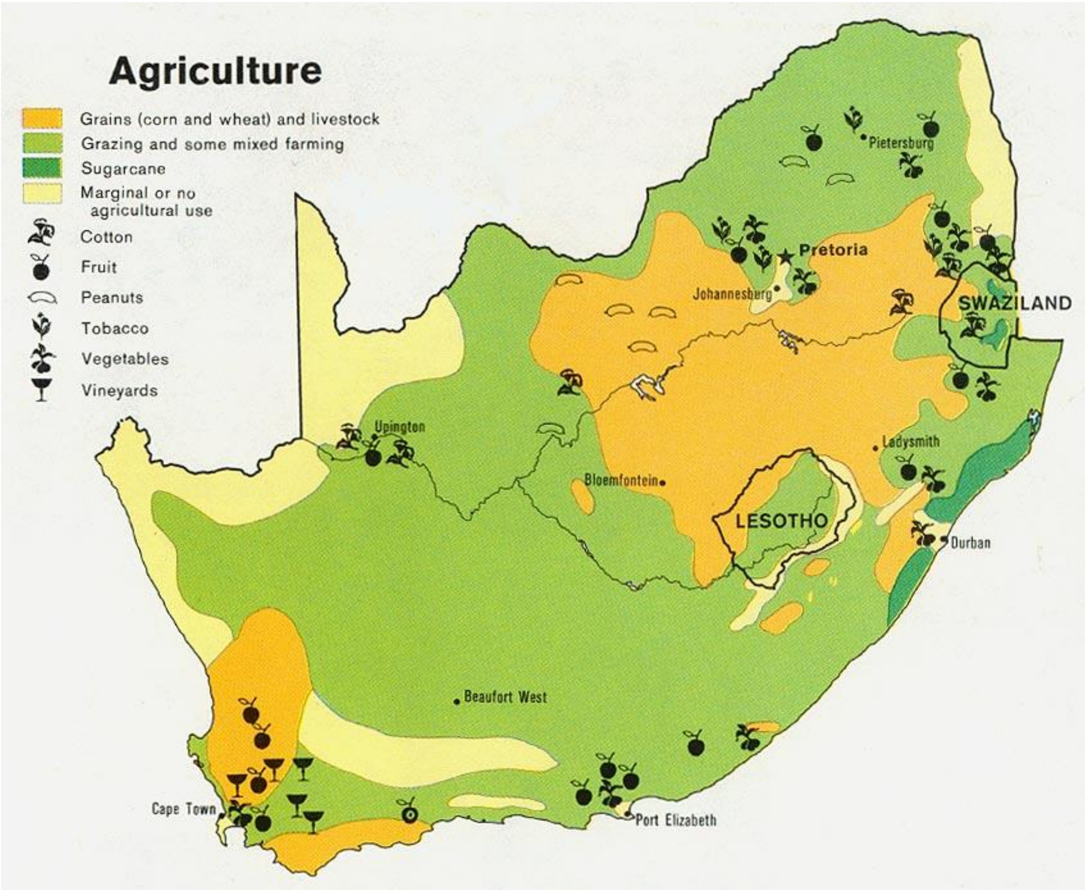
Production of most agricultural products is geographically restricted according to favourable growing conditions such as rainfall, temperatures and soil types. For the most part, the western half of the country is arid, with average annual rainfall of less than 500 millimetres (see Figure 3-18), and is used mainly as rangeland for extensive livestock production (O'Farrel et al., 2009). The major exception is the south-western Cape, whose winter rainfall supports the production of wheat, while irrigation is used for horticultural production during the summer months. The Eastern half of the country has a higher average annual rainfall, generally above 500 mm (see Figure 3-18), and supports a greater diversity of agricultural commodities. The majority of the country's maize is grown in the Highveld "maize quadrangle" in North West, Free State and Mpumalanga provinces, while some wheat is cultivated in the eastern Free State (NDA, 2009b: 17). Sugar cane production is concentrated along the coast in KwaZulu-Natal. Figure 3-19 shows the geographical distribution of major agricultural activities in the country.

Figure 3-18: Average annual rainfall in South Africa



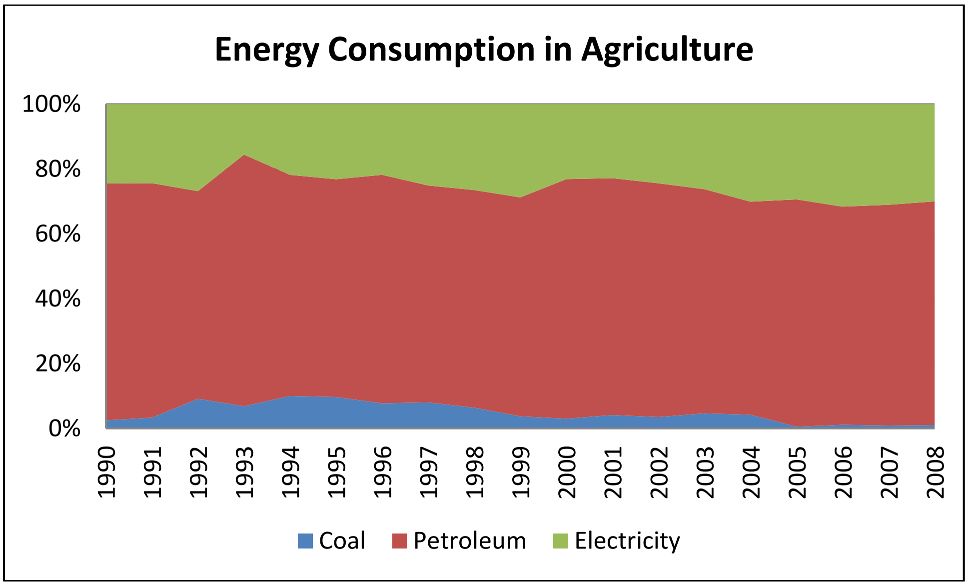
Source: FAO (2005)

Figure 3-19: Map of agricultural production in South Africa



Source: University of Texas (2010)

Figure 3-20: Energy consumption in agriculture, 1990-2008



Source: IEA (2011a)

3.3.2 Oil dependence of agriculture

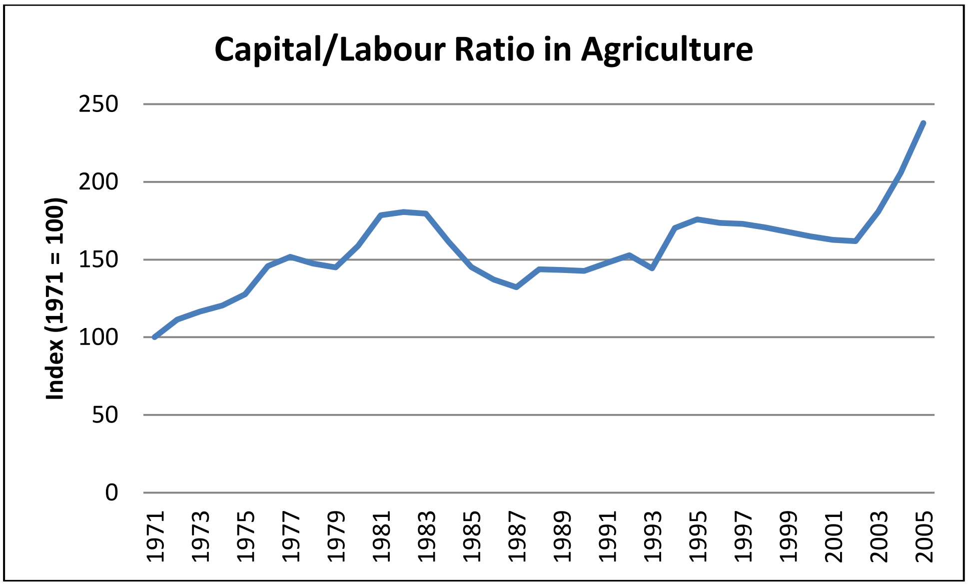
The agriculture, forestry and fishing sector accounted for 3% of total final energy consumption in 2008 (see Figure 3-4 above), which was commensurate with its 2.9% contribution to gross domestic product. As seen in Figure 3-20 above, the relative contributions of coal, petroleum and electricity to total energy consumption in agriculture have not changed substantially over the past two decades, although the already small share of coal has diminished further. In 2008, approximately two thirds (69%) of the energy used by the agricultural sector was in the form of liquid petroleum fuels, while electricity contributed 30% and coal just 1%. Energy and oil intensity varies according to the type of farming practiced, namely industrialised commercial, organic or subsistence farming.

Commercial agriculture

The industrialised, commercial agricultural system in South Africa is highly dependent on fossil fuel energy at every stage of the value chain, from primary production on farms, to processing in factories, to wholesale and retail distribution. At the production stage, this energy intensity results primarily from the extensive use of liquid petroleum fuels – especially diesel – to power farm vehicles and machinery such as tractors, planters and harvesters. Electricity is also consumed to power irrigation systems and other machinery, including refrigerators.

The relative capital intensity (as measured by the capital/labour ratio) of commercial agriculture has increased considerably over the past several decades as farmers have progressively replaced human labour with machinery (see Figure 3-21; Institute for Natural Resources, 2008: 67). Townsend and Thirtle (1997) provide evidence that technical change in agriculture has been biased towards machinery rather than labour. The level of regular farm employment fell by a third between 1990 and 2002 (Sparrow et al., 2008: 53).

Figure 3-21: Capital-labour ratio in agriculture, 1971-2005

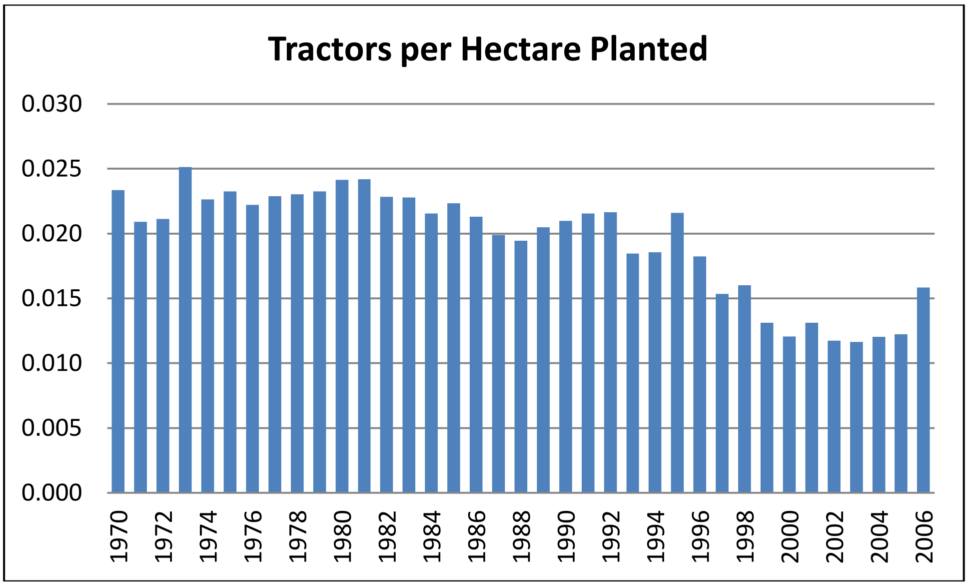


Source: Author's calculations based on NDA (2009a) and SARB (2011)

Note: The employment series from NDA (2009a) had several missing values, which were replaced with linearly interpolated figures.

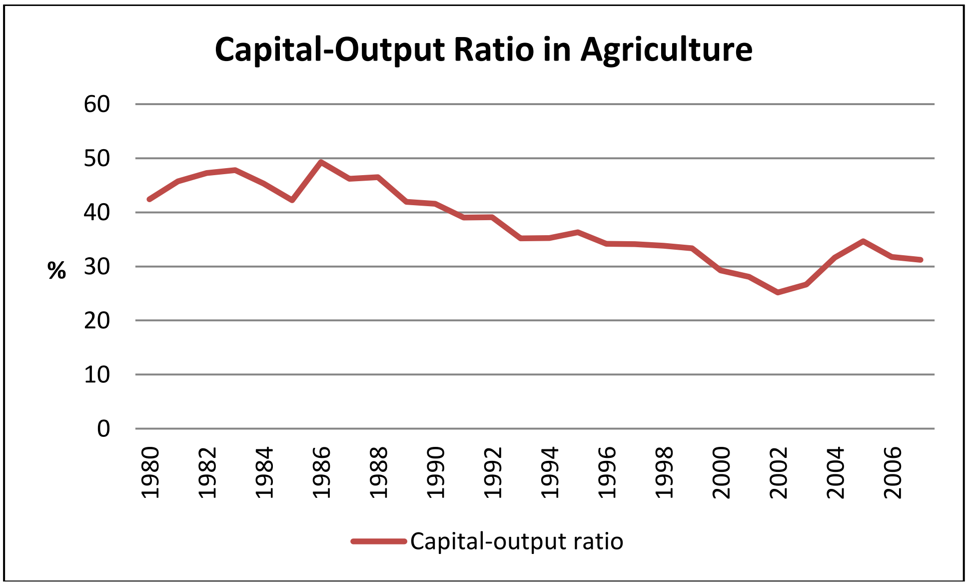
Somewhat surprisingly, however, the number of tractors in use per hectare planted to major field crops declined markedly from an average of approximately 0.022 in the 1970s and 1980s to an average of 0.013 since 2000 (see Figure 3-22). Similarly, the capital-output ratio in agriculture (measured by the ratio of the value of machinery, implements, motor vehicles and tractors to the gross value of output) has declined since the 1980s (see Figure 3-23).

Figure 3-22: Tractors in use per hectare planted to major field crops, 1970-2006



Source: FAO (2009), NDA (2009a) and own calculations

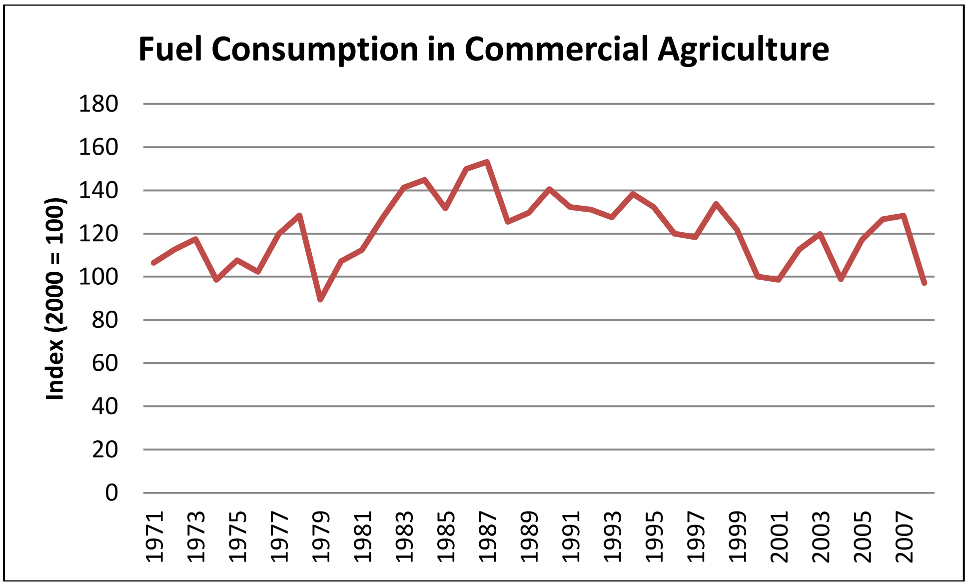
Figure 3-23: Capital-output ratio in agriculture, 1980-2007



Source: Own calculations based on NDA (2009a)

Nevertheless, the volume of fuel (diesel, petrol and lubricating oils) purchased by commercial farmers remained relatively constant between 1971 and 2008 (see Figure 3-24). These trends could in part reflect the consolidation of smaller farms into larger units; between 1993 and 2002, the number of farming units declined significantly in all but one of the nine provinces (NDA, 2009a). The declining capital-output ratio (i.e. rising capital productivity) may also reflect the declining area of land planted to major field crops over the same period, which resulted from the deregulation of the agricultural sector and the withdrawal of state subsidies (FAO, 2005). Farmers reduced their plantings on marginal lands, and hence average yields tended to rise.

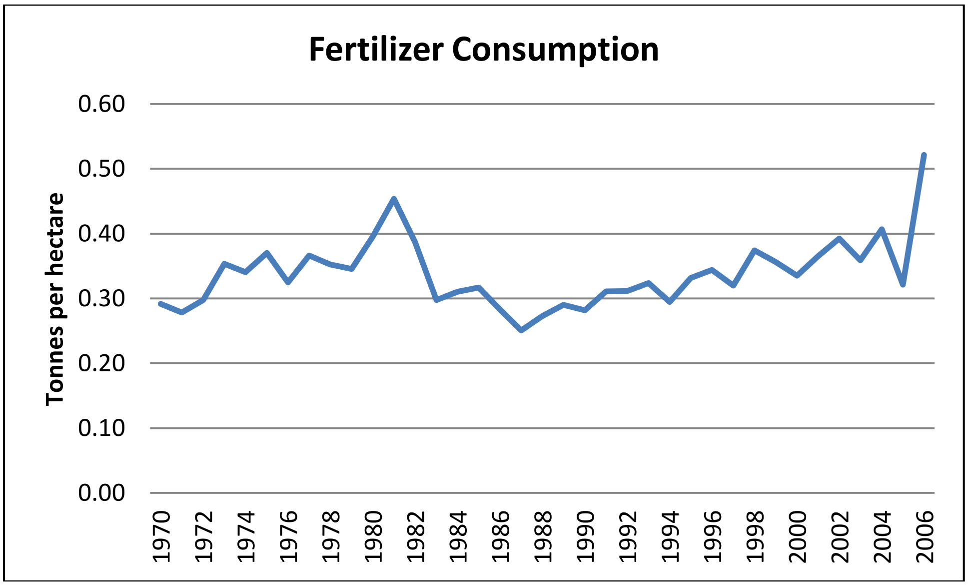
Figure 3-24: Fuel consumption in commercial agriculture, 1971-2008



Source: Own calculations based on NDA (2009a)

Note: This index was derived by dividing the nominal expenditure on fuel by the fuel price index.

Figure 3-25: Fertiliser consumption in South Africa, 1970-2006



Source: Fertilizer Society of South Africa (FSSA, 2009) and FAO (2009)

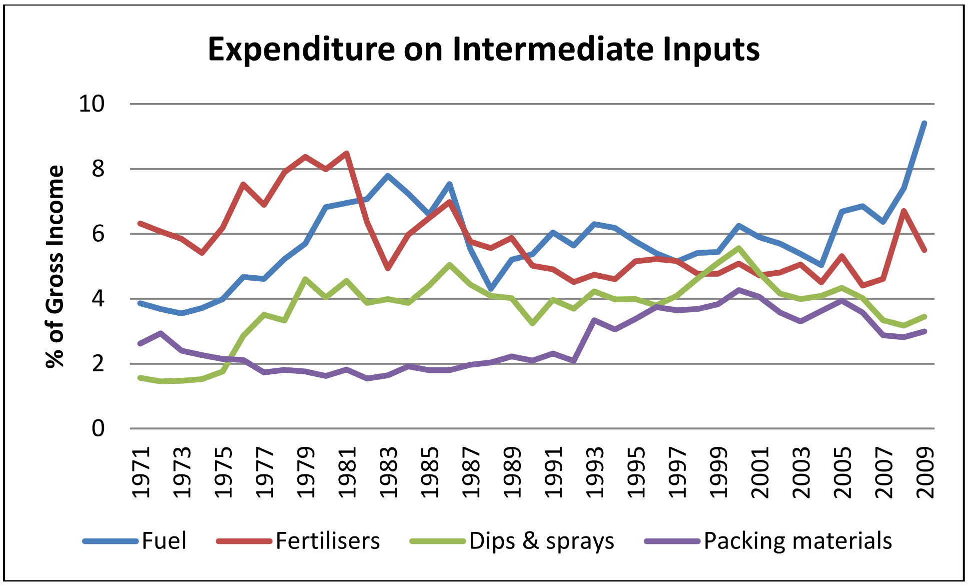
In addition to the direct use of petroleum fuels, commercial agriculture consumes significant quantities of energy indirectly in the form of fertilisers and pesticides, whose manufacture involves the use of natural gas (or gasified coal) and oil, respectively. Total fertiliser consumption in South

Africa grew steadily from the early 1950s to reach a peak in 1982 at more than 3 million tons, and has subsequently declined significantly to approximately 2 million tons (Fertilizer Society of South Africa, 2009). The decline is largely the result of deregulation of the fertiliser market, which involved import tariffs being scrapped and government subsidies being withdrawn (van der Linde & Pitse, 2006: 5). The fall in consumption of fertilisers also reflects a reduction in the area of land under cultivation, a trend itself mostly driven by the policy liberalisation (FAO, 2005). The consumption of fertilisers per hectare planted to major field crops in fact shows a slightly rising trend since the late 1980s after declining in the early 1980s (Figure 3-25).

The majority of crops in South Africa are grown with fertilisers: 100% of fruits and vegetables; 95% of maize; 100% of wheat; 85% of sunflower; 40% of soya beans; 95% of sugar cane; 90% of lucerne; and 30% of other field crops (FAO, 2005: 25). Horticulture accounts for 20% of fertiliser consumption, maize for 41%, wheat for 7% and sugar cane for 18% (FAO, 2005: 25). Organic fertilisers (derived from manures) contribute just three to four per cent of fertilisers consumed (FAO, 2005: 21).

Intermediate input costs as a proportion of gross income in the agricultural sector have generally risen since the 1970s, with the exception of fertiliser costs (see Figure 3-26). Most noticeable is the rising trend in the proportionate cost of fuel, from a low of 4.3% in 1988 to a high of 9.4% in the year ending June 2009. This trend was mainly driven by the rising price of crude oil, since the volume of fuel consumed was on a declining trend from the mid-1980s (see Figure 3-24 above). Total input costs rose from an average of 33% of gross income in the 1970s to 54% in the 2000s, indicating the deteriorating profitability of farming over the long term.

Figure 3-26: Input costs as a percentage of gross income in agriculture, 1971-2009



Source: DAFF (2010)

Note: Figures are for the year ending in June.

Beyond the production stage, energy is also consumed for the transport, processing and distribution of agricultural commodities and food products. First, agricultural produce has to be transported from farms to industrial centres for processing and/or packaging. Owing to the geographical dispersal of farms, the predominant mode of freight transport from farms to urban centres is by road and therefore relies on petroleum fuels (mostly diesel). Second, the processing of raw agricultural commodities into food products in factories requires energy, mostly in the form of electricity, which is largely generated from coal. Much of the packaging used for food products consists in plastics that are derived from oil or coal (the latter produced in South Africa by Sasol). Third, processed food products are transported to distribution centres and thence to retail outlets, primarily the large supermarket chain stores. In the final stage, most consumers rely on motorised travel to shops to purchase their food. As a result of the geographical specificity of agricultural production mentioned earlier (see Figure 3-19), some food products travel great distances within the country to arrive on supermarket shelves.

Although energy intensity figures for commercial agriculture in South Africa are not readily available, comparative figures for the United States, whose commercial agriculture is also heavily mechanised, may serve as an example. It is estimated that 10 calories of fossil energy inputs are required to produce one calorie of food in the United States (Pfeiffer, 2006: 21). In South Africa it appears as if the intensive use of fossil fuels has enabled a substitution of capital for labour and helped to increase yields for field crops since the 1970s.

Organic agriculture

By reducing or avoiding the use of chemical fertilisers and pesticides that are derived from fossil fuels, organic farming is up to fifty per cent less energy intensive than conventional agriculture (Pfeiffer, 2006: 68). Organic farming has grown fairly rapidly in recent years, but this has been from a very small base and the sector comprises a miniscule proportion of commercial farms in South Africa (Niemeyer & Lombard, 2003: 1). Organic farms, most of which are horticultural, also tend to be smaller than conventional farms (Niemeyer & Lombard, 2003: 5). Conventional farms become more energy efficient than organic farms at larger scales (Pfeiffer, 2006: 68). Small organic farms may be less reliant than larger-scale farms on fossil fuel powered machinery. However, commercial organic farming, like conventional farming, depends on oil-based transport to deliver produce to factories and markets.

Subsistence agriculture

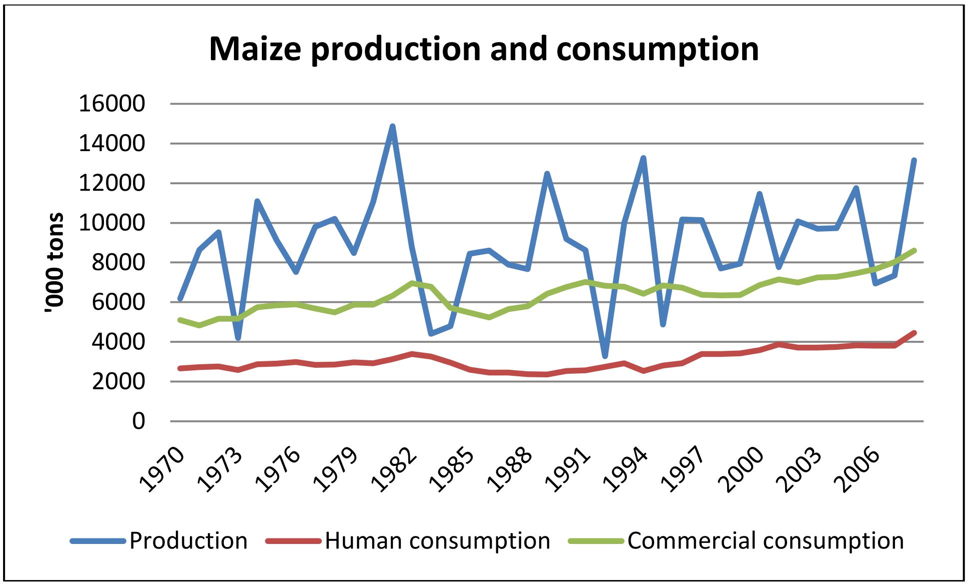
Traditional subsistence farming is generally much less dependent on oil than commercial farming, for several reasons. First, subsistence production is small-scale and labour intensive rather than large-scale and capital intensive (mechanised), and therefore uses little or no petroleum fuel directly. Second, traditional farming has at least until recently been mostly organic, i.e. farmers do not use chemical fertilisers and pesticides derived from fossil fuels (Modi, 2003: 676). Nevertheless, some subsistence farmers may rely to an extent on purchases of fertilisers, seeds and other inputs whose prices may be affected by oil prices. Third, most smallholder produce is consumed locally rather than being transported to distant markets.

3.3.3 Strengths and vulnerabilities of agriculture: national food security

The dependence of agriculture on oil has significant implications for food security. According to the Food and Agricultural Organisation (FAO, 1996, in Hendriks & Msaki, 2009: 184), "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life." Food security can be analysed on different scales of aggregation. The remainder of this subsection considers food security at the national level, while household level food security is discussed in Section 3.5. At the national level, food security has two determinants: (1) the capacity of the country to be self-sufficient in food production; and (2) the ability of the country to afford food imports where necessary or desirable.

As of 2008, South Africa had the capacity to be self-sufficient in most agricultural products, i.e. domestic production exceeded consumption (GCIS, 2009). In most years, South Africa produces a surplus over domestic consumption of the main staple crop, maize (NDA, 2009a; see Figure 3-27). Historical exceptions to this have largely been the result of droughts. The country is also self-sufficient in sorghum production. However, South Africa does rely on imports for some significant agricultural products. Major agricultural net imports in 2008 included rice, wheat, poultry and vegetable oils (NDA, 2009c: 10). Approximately one third to one half of the country's wheat requirement is imported, although this is partly because imports are cheaper than domestic production on marginal lands and there is no import tariff protection. All of the rice consumed domestically is imported, but rice is generally consumed by the wealthy minority and does not represent a broad staple food.

Figure 3-27: Maize production and consumption in South Africa, 1970-2008



Source: NDA (2009a)

Note: Commercial consumption refers to maize used as animal feed.

The primary agricultural export products are wine, a large variety of fruits and fruit juices, sugar and wool (NDA, 2009a). These products have a relatively high weight to value ratio, which means that export volumes are vulnerable to rising transport costs. Agricultural imports, mostly of processed foods, grew more rapidly than exports in the early 2000s so that by 2008 South Africa had become a net food importer in value terms for the first time (NDA, 2009b: 8). The balance between exports and imports is influenced by a variety of factors, including the rand exchange rate, international commodity prices, comparative production costs, and global and local weather conditions.

Continued national food self-sufficiency clearly depends on access to affordable, quality inputs for agricultural production. Key inputs include fertilisers, pesticides, machinery, farming skills, water and soil. South Africa has vulnerabilities in each of these areas.

An indigenous fertiliser industry sprang up in the early 20th century and was developed extensively with government support in the form of subsidies and trade protection from the 1950s to the early 1980s (FAO, 2005: 19). This led to the extensive and unsustainable use of fertilisers on marginal lands. Subsequently, however, government subsidies and tariff protection were gradually withdrawn so that by the 2000s the industry was totally deregulated and integrated with the world economy. As a consequence, the domestic fertiliser industry was rationalised and after being a net exporter until the late 1990s, South Africa became a net importer of fertilisers in the 2000s (FAO, 2005: 19). As of

2004, South Africa imported 100% of its potassium salts (potash), about 63% of nitrogen and less than 10% of phosphates (FAO, 2005: 20). Phosphate rock reserves are concentrated in only a few countries and South Africa is in the fortunate position of possessing the world's fourth largest reserves (4 gigatonnes, or 6% of the world total) after Morocco/Western Sahara, China and the USA (Gilbert, 2009).[88] Domestic producers of fertilisers include Sasol Limited, Omnia and Yara SA (van der Linde and Pitse, 2006: 3). Sasol Nitrates, a division of Sasol Limited, supplies the majority of ammonia consumed domestically and also produces ammonium sulphate, using coal as feedstock. Foskor supplies the local market with phosphoric acid and is also a significant exporter of the product. Domestic fertiliser prices are influenced heavily by prevailing international prices, the rand-dollar exchange rate and freight costs (FAO, 2005: 28) and are therefore susceptible to rising oil prices both directly (through higher transport costs) and indirectly (through the impact of oil prices on the exchange rate and international prices). Fertilisers are mostly delivered to farms by road and rarely by rail (FAO, 2005: 30), further entrenching dependence on oil.

The second key input category is machinery and equipment. The majority of farming equipment, such as tractors and harvesters, is imported[89] and therefore farmers face the risk of rising international prices and/or a depreciating exchange rate.

The third major agricultural input is farming skills. As seen in Table 3-12, the agriculture, forestry and fishing sector accounted for just 7.1% of total formal employment in 2008, which implies that the vast majority of the South African population do not currently have farming skills. The proportion of the South African population with farming skills has declined in recent decades, for several reasons. First, as mentioned earlier, the number of commercial farms (and therefore farmers) has declined, indicating a loss of high-level skills in the sector. Second, basic farming skills have been lost as farm employment levels have declined and people have migrated from rural to urban areas. The number of farm employees and domestic servants on farms declined from approximately 1.3 million in the mid-1980s to under a million by 1994 and approximately 630,000 by 2005 (DAFF, 2010). Third, there has been a loss of knowledge of traditional, organic African farming techniques as a consequence of the so-called 'Green Revolution' (Thamaga-Chitja & Hendriks, 2008: 320) as well as the process of urbanisation.

The scarcity of water resources is potentially a major threat to future agricultural production. Large areas of the country, especially the western half, are arid to begin with and also prone to drought (O'Farrell et al., 2009: 34). According to Laker (2005: 1), "It is estimated that a maximum of 1.5 million ha [of arable land] can be irrigated" at present. Climate change is expected to exacerbate the water scarcity situation, with more erratic rainfall patterns in the eastern half of the country, a general drying in the west, and an increase in the prevalence of droughts overall (O'Farrell et al., 2009: 34). In addition, higher average temperatures may reduce the yields of certain crops, notably maize. The drier western parts of the 'Highveld' where most maize is grown is likely to experience higher variability of yields and/or lower mean yields (Walker & Schulze, 2008: 114).

A further vulnerability is the poor quality of South Africa's soils, which are generally shallow and sandy (Laker, 2005) and mostly low in organic content and essential minerals (FAO, 2005: 5-6). Further problems include a high degree of vulnerability to various types of soil degradation, including water and wind erosion, soil compaction and crusting, acidification (partly the result of coal mining), nutrient leaching and pollution (mainly from mines and industry) (Laker, 2005; FAO,

[88] Global phosphorus production from mined phosphate rock reserves could reach a peak and begin to decline around 2033. This has major implications for modern agriculture, which is totally dependent on this source of phosphorus (Cordell, Drangert & White, 2009).
[89] According to Fofana et al. (2008: 63), the import penetration ratio for agricultural machinery was 56% in 2000.

2005). The intensive use of chemical fertilisers and pesticides has degraded the fertility of arable land over time (Kelly, 2009: 103). Another form of land degradation, which is irreversible, derives from the conversion of arable land to industrial, residential and mining uses (Laker, 2005).

The second important determinant of national food security is South Africa's capacity to import food products. This depends on international food prices as well as the strength of the domestic economy, in particular the balance of payments and the level of the exchange rate. As indicated in Section 3.4, these aspects of the macro-economy are likely to come under pressure from any future oil price shocks. At the same time, the prices of agricultural commodities on international markets are related to oil prices both directly because of rising input and transport costs, and also indirectly because of the incentives to produce biofuels from food crops or using arable land that could have supported food production (FAO, 2008: 10). The oil price spike between 2006 and 2008 was accompanied by spikes in the prices of many basic agricultural commodities such as maize, wheat and rice. These price spikes were exacerbated by steps taken by governments in some countries to lower domestic food prices and safeguard food security by imposing limitations or outright bans on the export of certain staple commodities (FAO, 2008: 11). A repeated confluence of these factors in the future could constrain South Africa's ability to import agricultural products and make it increasingly important for the country to be able to feed its own population and thereby maintain social wellbeing and stability.

3.3.4 Summary of agricultural vulnerabilities

Commercial agricultural production, which dominates the agricultural sector in South Africa, is highly oil-intensive, especially in respect of important field crops such as maize and wheat. The distribution of food products to consumers relies heavily on road-based transport and therefore on liquid petroleum fuels. Furthermore, the country became a net importer of fertilisers in 2008, and imports all of its potash requirements. The scale of organic agriculture as of 2009 was extremely limited, as were the knowledge and skills required for this form of farming, which by its nature is relatively resilient to oil shocks. Subsistence farming is limited to a small percentage of the country's population, and most subsistence farmers have access to low quality land and water, suffer from poverty and rely on supplementary sources of income and food. Continued national self-sufficiency in the production of most agricultural commodities is by no means certain in a future context of rising oil prices and increasing fuel scarcity. The risks are compounded by additional vulnerabilities such as water scarcity and droughts, climate change, low and declining soil quality, and an attrition of farming skills and knowledge.

Having considered the energy, transport and agriculture sectors, the following section broadens the scope to analyse oil-related dependencies and vulnerabilities in the macro-economy as a whole.

3.4 Macro-economy

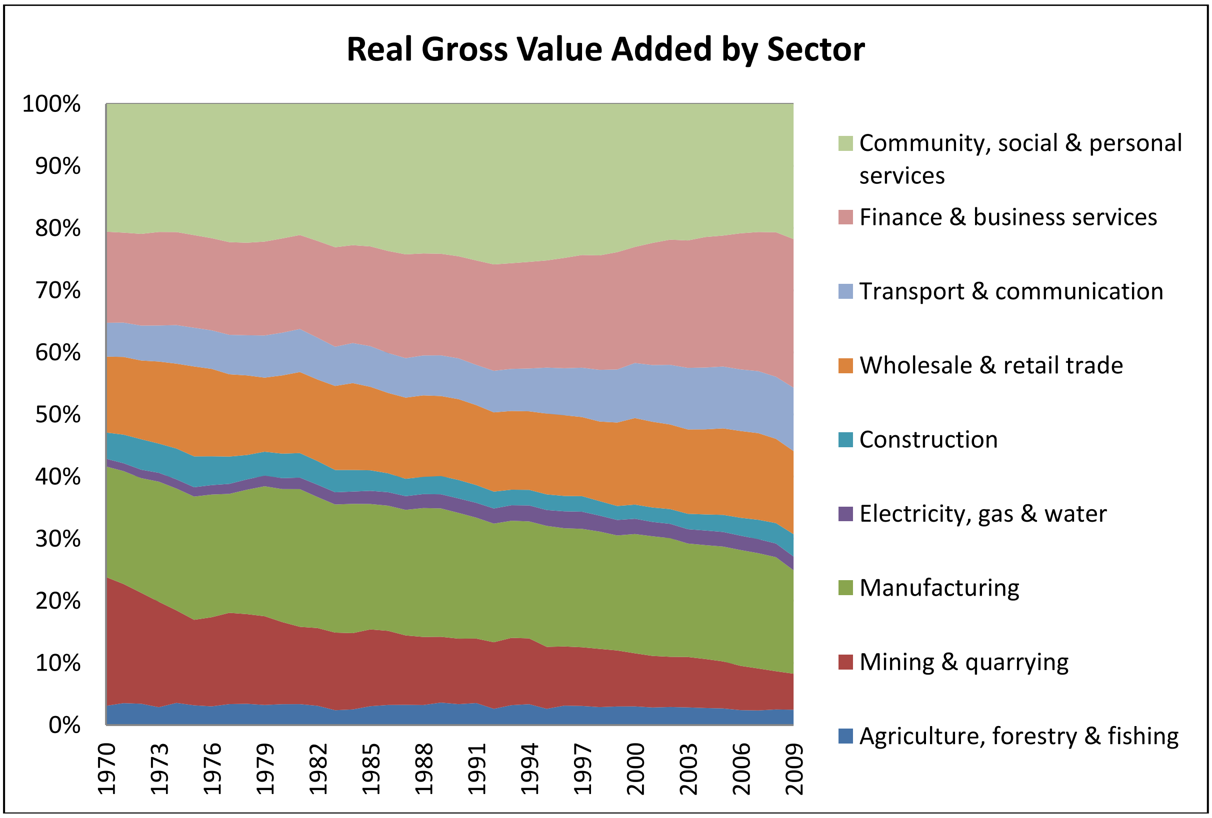
This section begins with a brief overview of the structure of South Africa's macro-economy. It then details the economy's energy intensity and oil dependency. The third subsection analyses the main macroeconomic strengths and vulnerabilities to oil shocks, including the international sector (balance of payments and exchange rates) and domestic variables such as inflation and interest rates, fiscal deficits and debt, and employment and unemployment. The fourth subsection provides a brief synopsis.

3.4.1 Structural composition of the macro-economy

The evolution of the broad structure of the South African economy between 1970 and 2009 is represented in Figure 3-28, which shows the relative contributions to gross value added (GVA) by the nine one-digit economic sectors. The most significant shift has been the decline in the relative importance of mining, from over 20% of GVA in 1970 to less than 6% in 2009. The shares of agriculture and construction contracted slightly over the period, while the largest gains were in transport (almost doubling in relative size from 5.4% in 1970 to 10.2% in 2009), utilities (1.2% to 2.2%) and financial services (15% to 24%). Other sectoral shares have not changed notably.

Table 3-10 reports the percentage shares of gross value added by sector in 2009. The tertiary sectors together contributed 69.3% of GVA, secondary sectors 22.4% and primary sectors just 8.3%. The largest sector was finance, real estate and business services (23.9%). Agriculture was the second smallest sector with just 2.5% of GVA. Overall, the economy is reasonably well diversified across the range of sectors. This diversity is partly a legacy of South Africa's isolationist past in the apartheid era, and is likely to boost the economy's resilience to the anticipated impacts of higher oil prices (as will be discussed more fully in Chapter 5).

Figure 3-28: Sectoral shares of real gross value added, 1970-2009



Source: SARB (2011)

Table 3-10: Sectoral shares of gross value added and formal sector employment, 2009

Sector	Gross value added (%) 2009	Employment (%) 2009Q2
Primary	*8.3*	*10.2*
Agriculture, forestry & fishing	2.5	7.1
Mining & quarrying	5.8	3.1
Secondary	*22.4*	*25.8*
Manufacturing	16.6	16.6
Electricity, gas & water	2.2	0.9
Construction	3.6	8.3
Tertiary	*69.3*	*64.1*
Wholesale & retail trade	13.4	19.6
Transport, storage & communication	10.2	5.3
Finance, real estate & business services	23.9	15.8
Community, social & personal services	21.8	23.4
Total	*100.0*	*100.0*

Source: SARB (2011); StatsSA (2009b)

Table 3-10 also contains the percentage breakdown of formal employment by sector in the second quarter of 2009. The community, social and personal services (23%), trade (20%) and manufacturing (17%) sectors have the largest shares of employment. The agriculture, forestry and fishing sector is relatively labour intensive since its share of formal sector employment (7.1%) is considerably greater than its share of gross value added (2.5%). The construction sector is also relatively labour intensive, with 8.3% of formal employment compared with 3.6% of GVA. The non-agricultural formal sector accounted for 70% of total employment in 2009Q2, while the remainder of total employment was comprised of agriculture (5%), private households (9%) and the non-agricultural informal sector (16%) (StatsSA, 2009b). Employment in the agriculture, mining and manufacturing sectors shrank between 1994 and 2004 (The Presidency, 2009: 97).

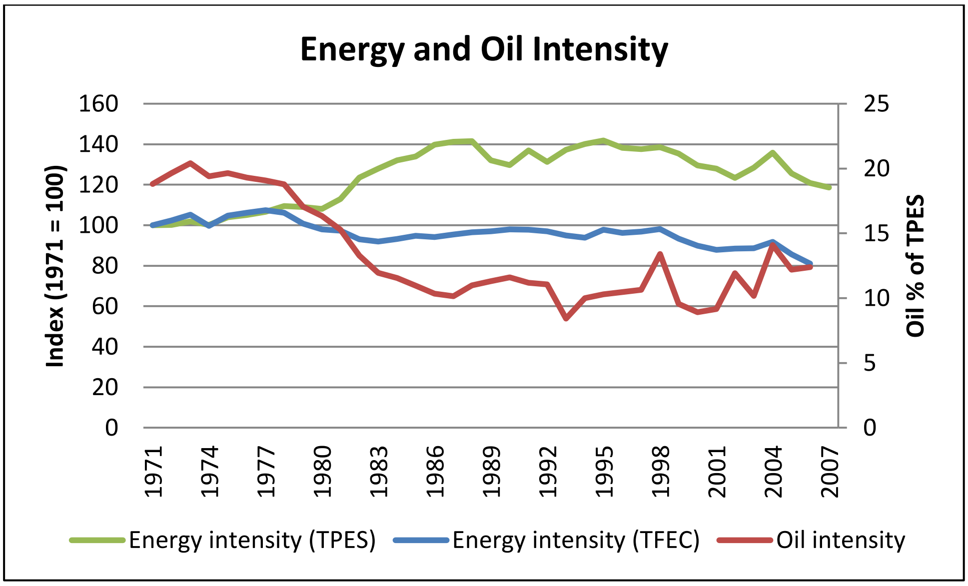
The South African government has articulated a conception of a "Second Economy", existing alongside the formal (first) economy and reflecting endemic "structural inequalities, disadvantage and marginalisation" in society (The Presidency, 2008: 40). The Second Economy includes both informal sector activity, and the unemployed and underemployed components of the labour force. Between 1994 and 2004, a growing number of work-seekers were trapped in the Second Economy by a lack of appropriate skills that were needed in the rapidly growing sectors such as finance (The Presidency, 2008: 98). According to The Presidency (2008: 98), "Persistently high concentration in the economy and the dominance of larger firms at the expense of SMEs [small and medium enterprises], reinforce the trends towards capital intensity at the core of the economy." Capital intensity, in turn, is closely related to energy intensity, which is the subject of the following subsection.

3.4.2 Oil dependence of the macro-economy

In the context of internationally determined oil prices, the vulnerability of an oil-importing country to oil shocks can be broken down into three dimensions (Nkomo, 2006: 10): oil import dependence (the proportion of domestic oil consumption that is imported); oil resource dependence (the ratio of oil to total energy use); and the energy intensity of the economy (the ratio of energy use to real gross domestic product). Developing countries tend to have higher vulnerability than do developed economies, especially where mining and manufacturing are relatively important sectors, as is the case in South Africa.

The South African economy is characterised by high *energy intensity*, especially in its mining and manufacturing sectors. Only ten countries in the world had higher primary energy intensities in 2008 (EIA, 2010). This is mainly attributable to the country's abundant coal reserves, which historically have been exploited to generate amongst the cheapest electricity in the world. South Africa's energy intensity, measured as the ratio of total primary energy supply to real GDP, rose by 40% between the 1970s and 1980s, but since the mid-1990s has declined by approximately 20% (see Figure 3-29). However, when measured by the ratio of total final energy consumption to real GDP, energy intensity has gradually fallen by a cumulative 20% since the late 1970s. This partly reflected a change in the composition of the economy away from mining and manufacturing to services, which are less energy intensive, but to some extent was a result of improvements in energy efficiency.

Figure 3-29: South Africa's energy intensity and oil resource intensity, 1971-2007

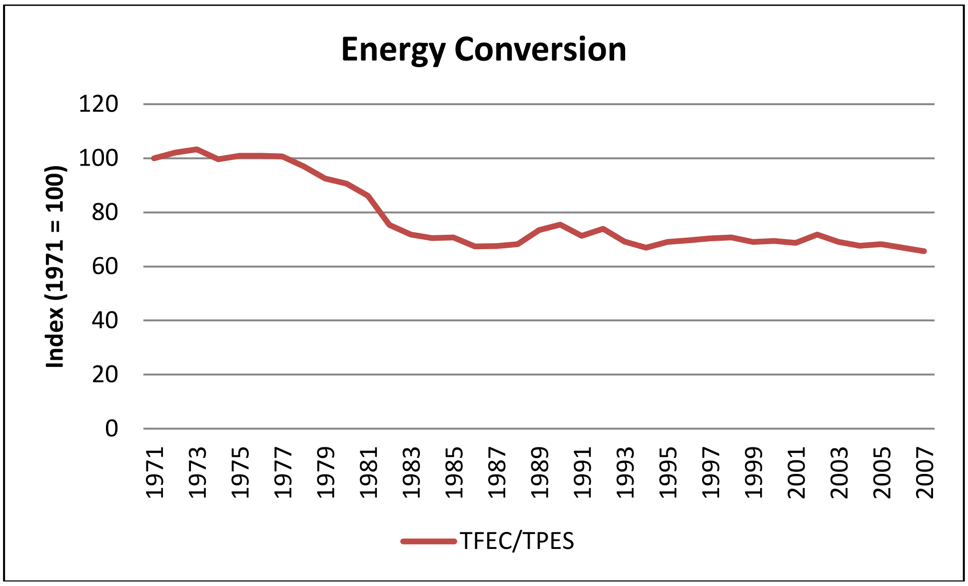


Source: IEA (2011a), SARB (2011) and author's calculations

Note: The energy intensity indexes are derived from the ratios of total primary energy supply (TPES) and total final energy consumption (TFEC) real GDP, respectively; oil intensity is the percentage share of oil in total primary energy supply (TPES).

The discrepancy between the two measures of energy intensity highlights the fact that South Africa's energy sector has over the past four decades become less efficient at converting primary energy sources into final, usable energy carriers, by a factor of one third (see Figure 3-30). This trend was driven mainly by the substitution of domestically produced synthetic liquid fuels derived from coal for imported oil (the steepest drop in the index around 1979 coincides with the construction of the third Sasol CTL plant as well as the impact of the second oil price shock). In other words, a lower quality energy source (coal) has been substituted for a higher quality source (oil). This trend is likely to continue as the economy becomes even more reliant on domestic energy sources after the global oil peak, and as the grade of coal reserves progressively declines.

Figure 3-30: Energy conversion from primary supply to final consumption, 1971-2007



Source: Own calculations based on IEA (2011a)

South Africa's *oil resource dependence* is low relative to many other developing countries, partly as a result of the heavy use of domestic coal reserves. According to IEA figures, oil in 2007 constituted approximately 12.6 percent of South Africa's primary energy supply (which includes energy used to produce final, usable energy), down from around 20 percent in the early 1970s (see Figure 3-29 above).[90] Again, this decrease was mainly attributable to the construction of another CTL plant in 1979. In 2006 nearly 80% of all (i.e. domestically produced and imported) oil-based liquid fuels were consumed by the transport sector, compared with about two-thirds in 1976 (Dagut, 1978: 32). The area of the economy most directly susceptible to oil shocks is therefore the transport sector.

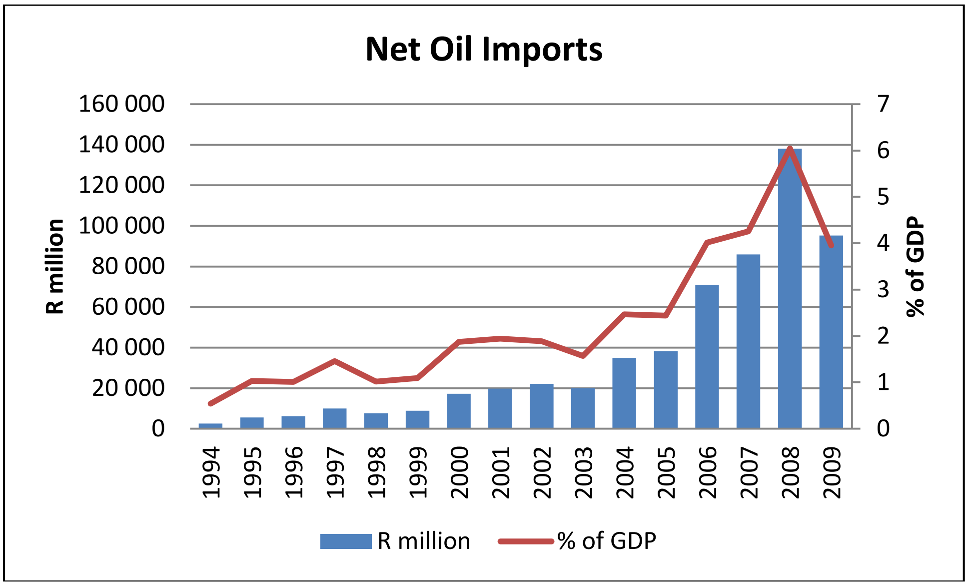
Because South Africa's domestic oil reserves are very limited, the country has a very high degree of *oil import dependence*: about 95 percent of crude oil requirements are imported. However, thanks to a strong domestic liquid fuels industry (Sasol's coal-to-liquids and PetroSA's gas-to-liquids facilities), only 70 percent of the country's *liquid fuel* requirements are met by imported oil. On the other hand, the synthetic liquid fuels produced by Sasol and PetroSA are currently priced on an import parity basis. If this does not change, then consumers are just as vulnerable to oil *price* shocks, even though there is a partial buffer for oil *supply* shocks.

The nominal value of South Africa's crude and refined oil imports rose fairly rapidly between 2004 and 2008 (see Figure 3-31), thanks to a combination of rising consumption (driven by economic growth and an expanding population) as well as a steadily rising oil price.[91] In 2008 the country spent nearly R138 billion, or 6% of GDP, on oil imports, which represented the single largest import item on the balance of payments. In 2009, as a result of the recession and lower oil price, oil imports fell to R95 billion (4% of GDP). In comparison, net coal exports in 2009 amounted to R33 billion (1.4% of GDP).

[90] In contrast, the DME's (2006) energy balances for 2006 record oil's share of TPES as 20%. It is unclear why there is a discrepancy between the two data sources, but the DME energy balances are very volatile over time and are therefore probably unreliable.

[91] Unfortunately, oil import data for earlier years are unobtainable as they were classified information under the Apartheid regime; therefore comparisons with the 1970s oil price shocks are not possible.

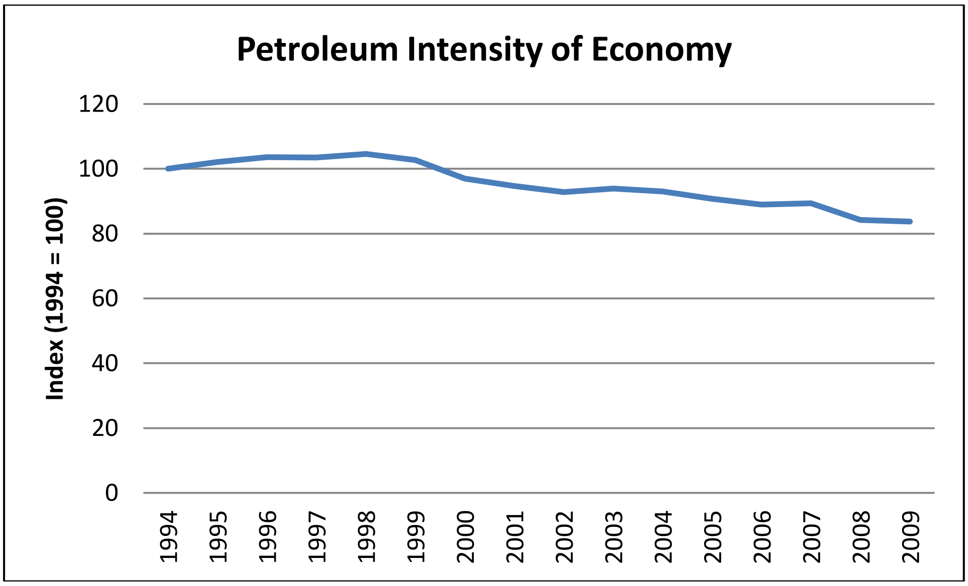
Figure 3-31: Net crude and refined oil imports, 1994-2009



Source: DTI (2010) and SARB (2011)

A final measure of the oil dependence of the South African macro-economy is provided by the ratio of petroleum product consumption to real GDP. Figure 3-32 shows that this measure of petroleum dependency increased slightly from 1994 (by 4.5%) to reach a peak in 1998, after which it declined nearly monotonically by an average of 2% per annum and a cumulative 20 percentage points by 2009. This is an illustration of *relative resource decoupling* (Fischer-Kowalski & Swilling, 2011):[92] although absolute consumption of petroleum products rose between 1998 and 2009, consumption relative to real GDP fell considerably.

Figure 3-32: Petroleum intensity of the economy, 1994-2009



Source: Author's calculations based on SAPIA (2009) and SARB (2011)

[92] Fischer-Kowalski and Swilling (2011: 4) define *resource decoupling* as "reducing the rate of use of (primary) resources per unit of economic activity."

This relative decoupling can partly be explained by the growth in the financial services sector (which has very low petroleum intensity), which has increased its share of the economy (gross value added) from 17.2% in 1994 to 23.9% in 2009. Nevertheless, this decoupling achievement bodes well for the potential to reduce future petroleum consumption while attenuating negative impacts on economic activity.

Table 3-11 shows the petroleum and chemical intensity of South African industries in 2008, as calculated from the final use table of the national accounts (StatsSA, 2010). Measured in terms of the share of petroleum expenditures in input costs, the sectors most dependent on petroleum and chemicals are agriculture (34%), mining (about 20% on average) and transport (21%). The figure of 31% for communications appears to be anomalous.

Table 3-11: Petroleum intensity of South African sectors, 2008

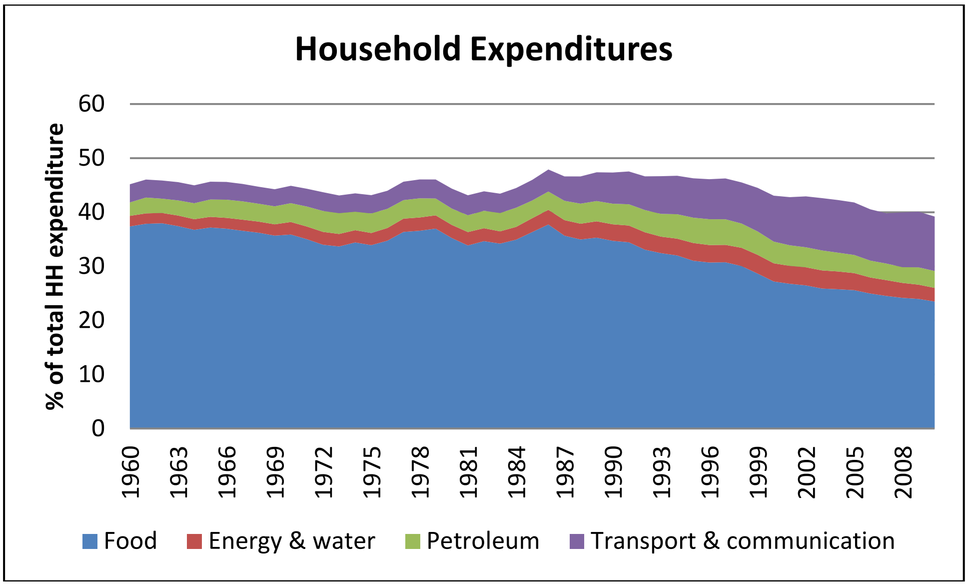
Industry	Petroleum input cost share (%)	Industry	Petroleum input cost share (%)
Agriculture	33.8	Electricity	4.4
Mining - Coal	13.0	Water	6.2
Mining - Gold	25.4	Construction	13.3
Other mining	21.0	Trade	9.7
Food, beverages, tobacco	6.9	Hotels, restaurants	3.2
Textiles, leather	10.2	Transport	21.4
Footwear	15.5	Communication	30.7
Petroleum, chemicals	36.2	Financial, insurance	0.3
Glass, non-metallic	5.6	Real estate	7.1
Metal, machinery, equipment	8.4	Other business	6.5
Electrical	11.5	General government	8.1
Radio, TV, optical instruments	5.3	Health	8.3
Motor vehicles, transport	7.8	Other services, Non-profit	6.3
Furniture, other	10.3	**Total (weighted)**	**13.4**

Source: StatsSA (2010)

Figure 3-33 displays the evolution of various categories of household spending as a percentage of total household expenditure. The share of food, beverages and tobacco in total spending has diminished since the late 1980s, while proportional spending on energy and water and on fuel has remained fairly constant; relative spending on transport and communication has grown substantially. In 2010, petroleum products accounted for just 3.1% of total spending (almost R55 billion), having peaked in 1996 at 4.8%.

In summary: South Africa's primary energy intensity has risen since the 1970s, but the ratio of final energy consumption to real GDP has declined; oil resource dependence has fallen substantially since the 1970s, thanks mainly to the commissioning of Sasol III in 1979, although dependence on oil imports in absolute terms has risen gradually since then; since 2004 expenditure on oil imports has risen considerably as a percentage of GDP, in line with the rising price of crude oil and rising oil imports; petroleum consumption relative to real GDP declined by 20 percent between 1998 and 2009, indicating relative decoupling; the transport sector has become more petroleum dependent over time as passengers and freight have moved from (partly electric) rail to road-based transport. The following section examines other aspects of the South African macro-economy that make it more or less susceptible to negative impacts from oil shocks.

Figure 3-33: Household expenditure on various items, 1960-2010



Source: SARB (2011)

3.4.3 Strengths and vulnerabilities of the macro-economy

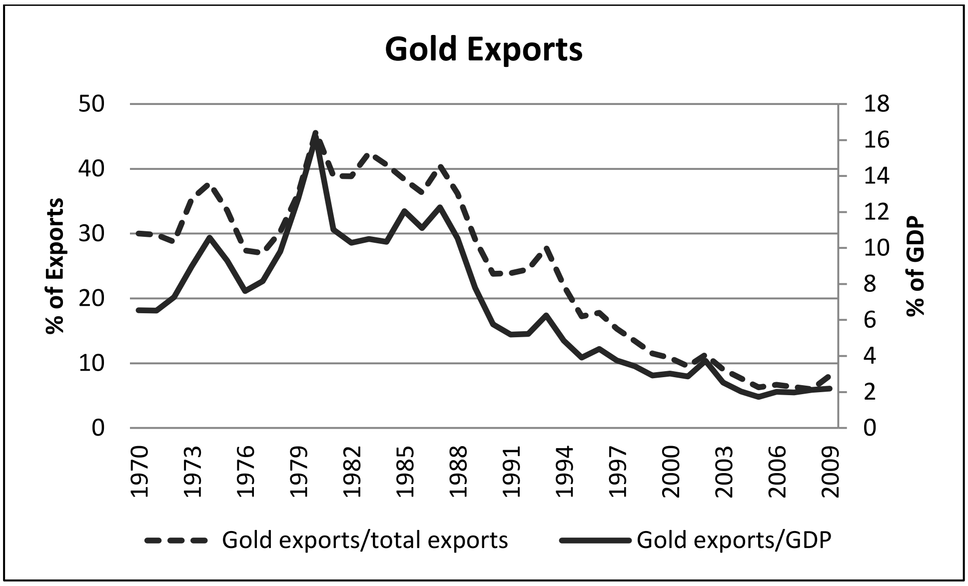
Oil shocks emanate from outside the domestic economy, and therefore impact on the balance of payments and exchange rate in the first instance. However, these shocks quickly filter through to the domestic economy and thus a range of other macroeconomic variables indicate the country's vulnerabilities to oil shocks.

Balance of payments and exchange rate

The immediate effect of an increase in the international oil price is a rise in the oil import bill, which reduces the trade and current account balances. This pressure on the balance of payments must either be offset by rising exports, or increased financial inflows, or else the exchange rate will depreciate.

Gold exports provided a major buffer against the effects of oil price shocks in the 1970s. The positive impact of the first two oil shocks on the ratios of net gold exports to GDP and to total exports is clearly evident in Figure 3-34. However, there has been a long-term decline in output of gold from South African mines since the early 1980s, mainly as a result of depletion of ores, such that by 2008 gold exports accounted for just 6% of total exports and 2% of GDP. By the 2000s, platinum had replaced gold as the country's major export commodity. However, the demand for platinum is much more pro-cyclical than that for gold, since a substantial portion of platinum demand is linked to the production of motor vehicles (for use in catalytic converters). Thus while gold and other mineral exports can still be expected to provide some level of shock absorption for future oil price hikes, it was substantially attenuated by 2008 relative to the 1970s.

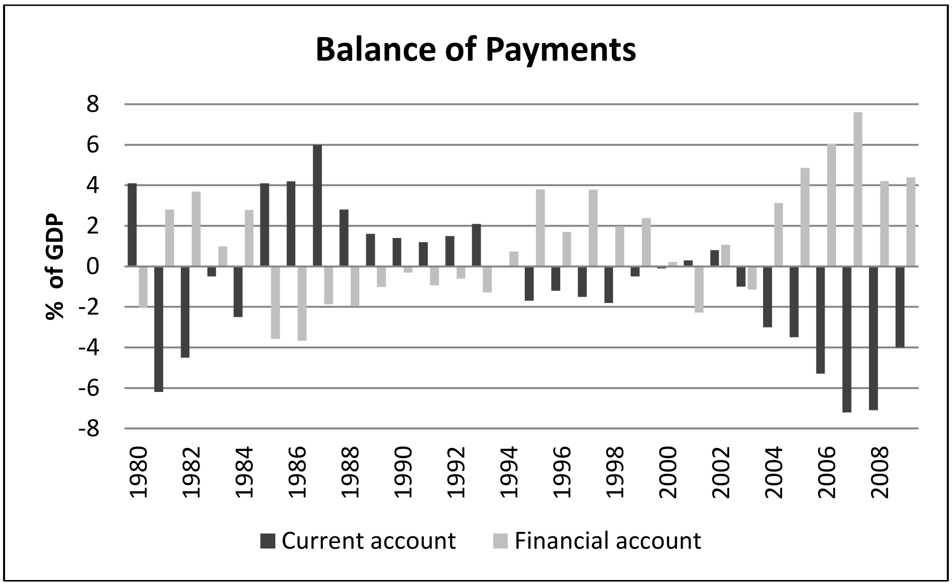
Figure 3-34: Ratios of net gold exports to total exports and GDP, 1970-2009



Source: SARB (2011) and author's calculations.

A significant weakness of the South African economy in the mid to late 2000s was the large size of its current account deficit. As can be seen in Figure 3-35, South Africa's current account balance had been in surplus in the early 1990s and early 2000s, but deteriorated markedly from about 2003. It reached a record large deficit of 7.4% of GDP in 2008. This was at least in part attributable to the sizeable increase in expenditure on crude oil imports during this period (see Figure 3-31 above). It also reflected a general boom in imports, driven partly by debt-based consumer spending. On the other hand, Figure 3-35 shows that the financial account of the balance of payments was in healthy surplus between 2004 and 2007 (although somewhat reduced in 2008), and therefore provided the foreign exchange required to support the large trade imbalance. Thus despite the weakening current account, the ratio of imports of goods and services covered by reserves rose from 7.9 weeks in 2003 to 14.6 weeks on average in 2008.

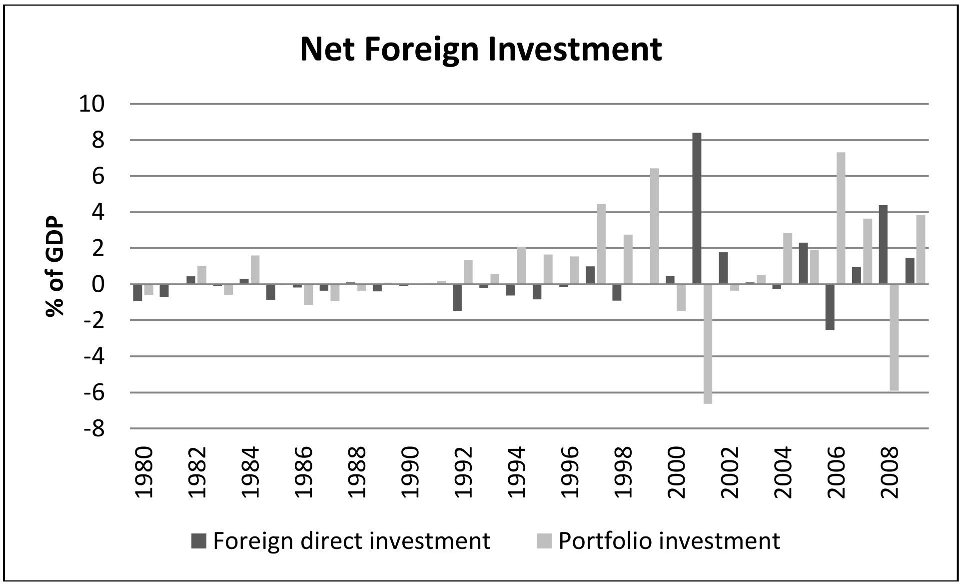
Figure 3-35: Balance of payments as a percentage of GDP, 1980 to 2009



Source: SARB (2011)

However, the majority of the capital inflows in this period were portfolio investment (in local bonds and equities) rather than foreign direct investment (see Figure 3-36). Such short-term inflows are vulnerable to sudden capital flight and therefore pose a currency risk. This was amply demonstrated in the final quarter of 2008, when a large portfolio withdrawal occurred.

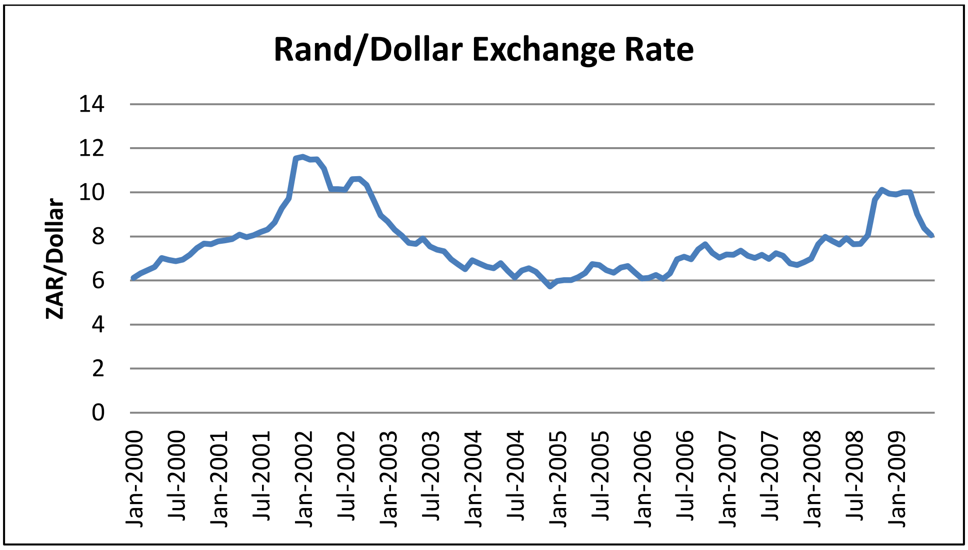
Figure 3-36: Foreign direct and portfolio investment as a percentage of GDP, 1980 to 2009



Source: SARB (2011)

Thanks to the combination of the large current account deficit and the substantial portfolio investment outflow towards the end of 2008, the rand exchange rate experienced a marked depreciation relative to the dollar and other major currencies (see Figure 3-37). However, the rand recovered in the first half of 2009 and as of June of that year, the current account deficit had not yet precipitated a full-blown currency crisis (as had occurred for instance in certain other countries with large deficits, such as Iceland).

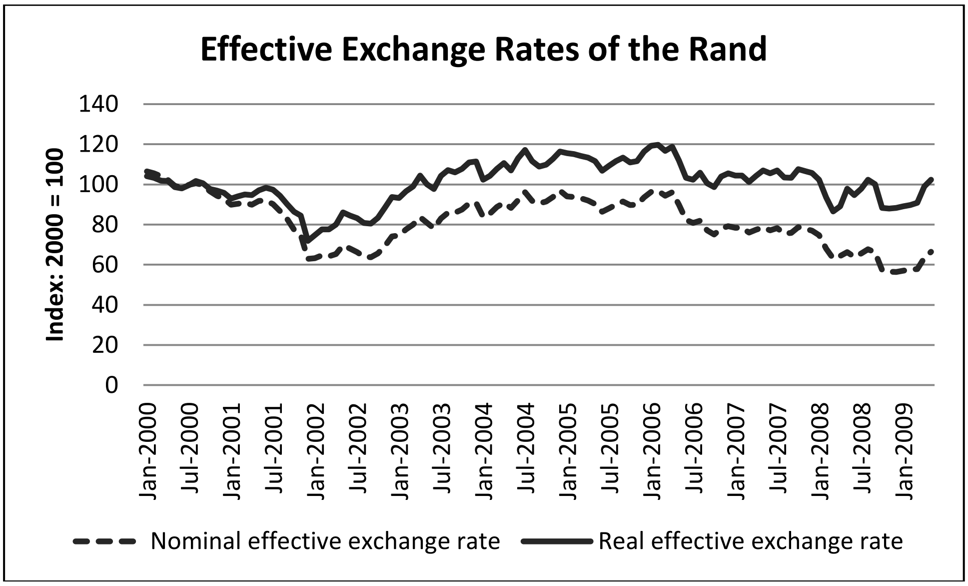
Figure 3-37: Rand/US dollar exchange rate, 2000-2009



Source: SARB (2011)

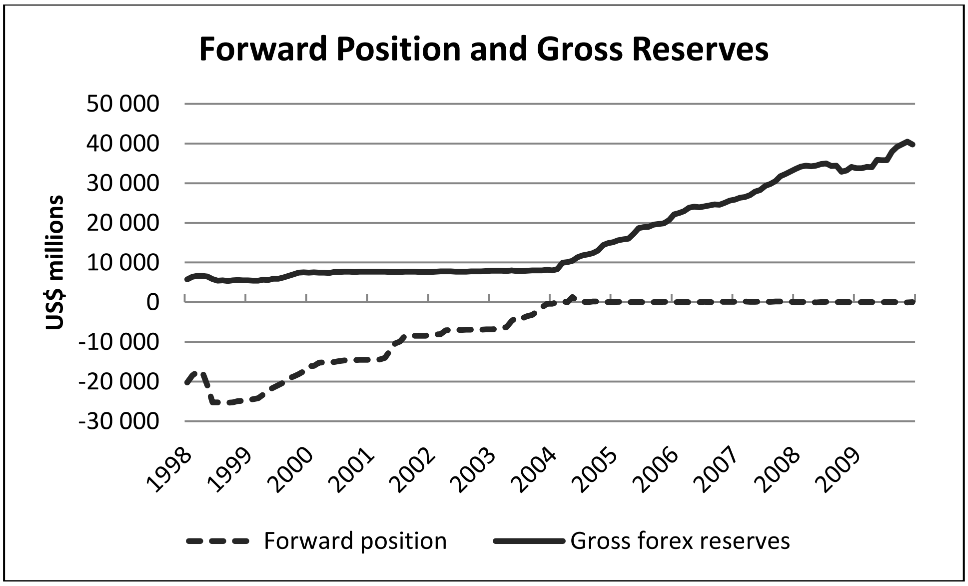
As can be seen in Figure 3-38, the real effective exchange rate of the rand (i.e. the value of the rand relative to a basket of currencies of South Africa's major trading partners, and adjusted for inflation rate differentials) was approximately the same in 2009 as it was at the beginning of the decade. However, the rapid depreciation experienced in 2001-2002 illustrates the currency's vulnerability to speculative attacks. The AsgiSA framework identified the "volatility and level of the currency" as one of six "binding constraints" on the economy's performance (The Presidency, 2006a: 4).

Figure 3-38: Nominal and real effective exchange rates of the rand, 2000-2009



Source: SARB (2011)

Figure 3-39: Forward position and gross reserves, 1998-2009



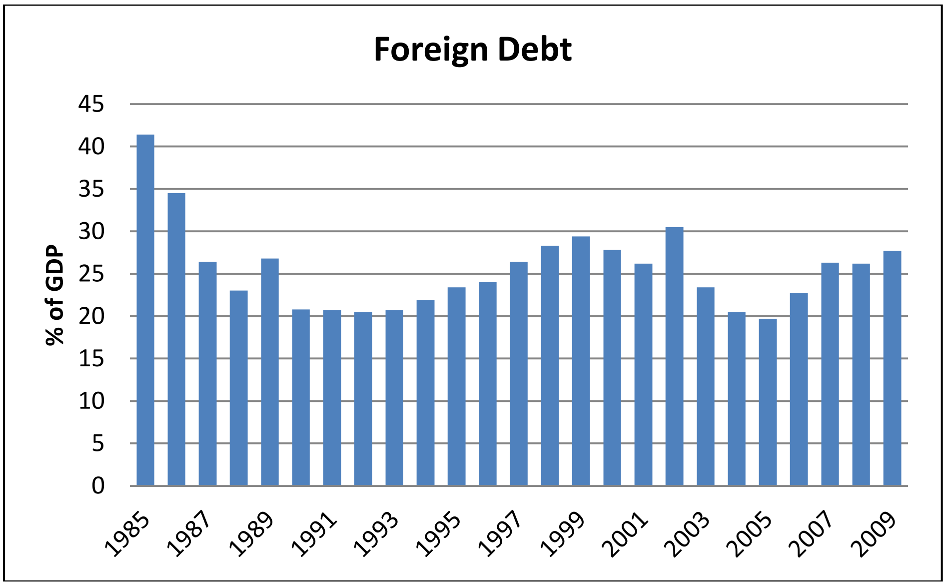
Source: SARB (2011)

South Africa's foreign exchange reserve position improved substantially after the year 2000. As shown in Figure 3-39, the SARB managed effectively to close its forward position by 2004 after it had reached a record high of $25 billion in the wake of the emerging market crisis in 1998, when the Reserve Bank attempted to defend the rand by buying US dollars forward. Gross gold and foreign exchange reserves increased from less than $10 billion prior to 2004 to nearly $40 billion by the end of 2009. Nevertheless, the 1998 experience clearly demonstrated that any policy by the SARB of attempting to "lean against the wind" (i.e. defend the rand in currency markets) can be very costly as well as ultimately ineffective. This is primarily due to the highly liquid nature of South Africa's financial markets coupled with its very small size in the global economy.

South Africa's total foreign debt was a moderate 28% of GDP by 2009, which equalled the average for the period 1985 to 2009 and was comparatively low by international standards (see Figure 3-40). On its own, this level of debt did not present a particularly large macroeconomic vulnerability at this time.

All in all, as of 2009 the large current account deficit still presented a significant risk in terms of potential currency volatility, depreciation and speculative attacks on the rand, especially considering the likelihood of further oil price spikes. Exchange rate volatility can negatively impact on investment by creating uncertainty for businesses, while a weaker exchange rate raises the rate of import price inflation.

Figure 3-40: Ratio of total foreign debt to gross domestic product, 1985-2009

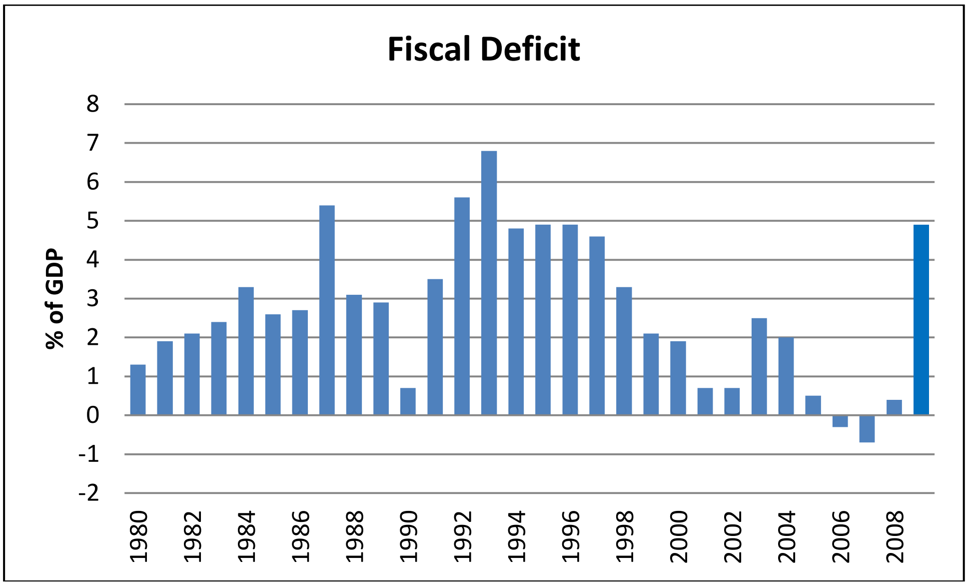


Source: SARB (2011)

Fiscal deficit and debt

The government's fiscal position and debt are important determinants of the country's resilience to macroeconomic shocks. After reaching a high of over 6% of GDP in 1993, the fiscal deficit declined over the 1990s and 2000s as a result of a deliberate policy of fiscal prudence. The government managed to run modest fiscal surpluses in 2006 (0.3%) and 2007 (0.7%), partly thanks to relatively robust economic growth and also to improvements in the efficacy of the tax collection system. The National Treasury was therefore much better placed than previously to respond to the recession in 2009, which saw both falling tax receipts as well as the need for additional government expenditure. However, the recession led to a sharp rise in the fiscal deficit in 2009 to 4.9% of GDP (see Figure 3-41).

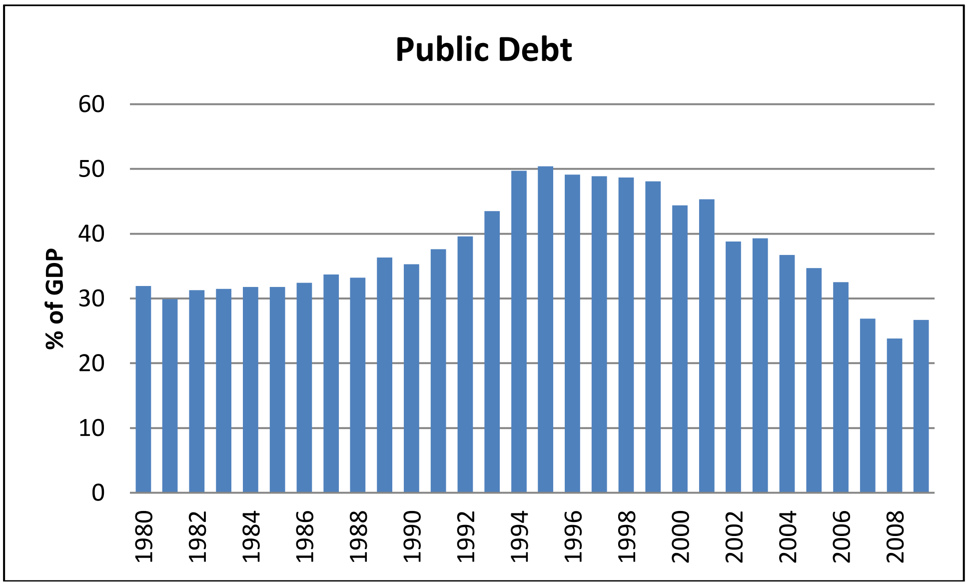
Figure 3-41: Fiscal deficit as a percentage of GDP, 1980-2009



Source: SARB (2011)

As a result of the prudent fiscal management illustrated above, South Africa's public debt declined markedly from dangerously high levels in the early 1990s (touching 50% of GDP in 1995) to a low of 24% in 2008. This minimised the risk of the country falling into a 'debt trap', where borrowing to repay interest on existing debt becomes unsustainable. By 2009, therefore, the South African government had some room to move in terms of raising its level of public borrowing in response to the recession (see Figure 3-42).

Figure 3-42: Public debt as a percentage of GDP, 1980-2009

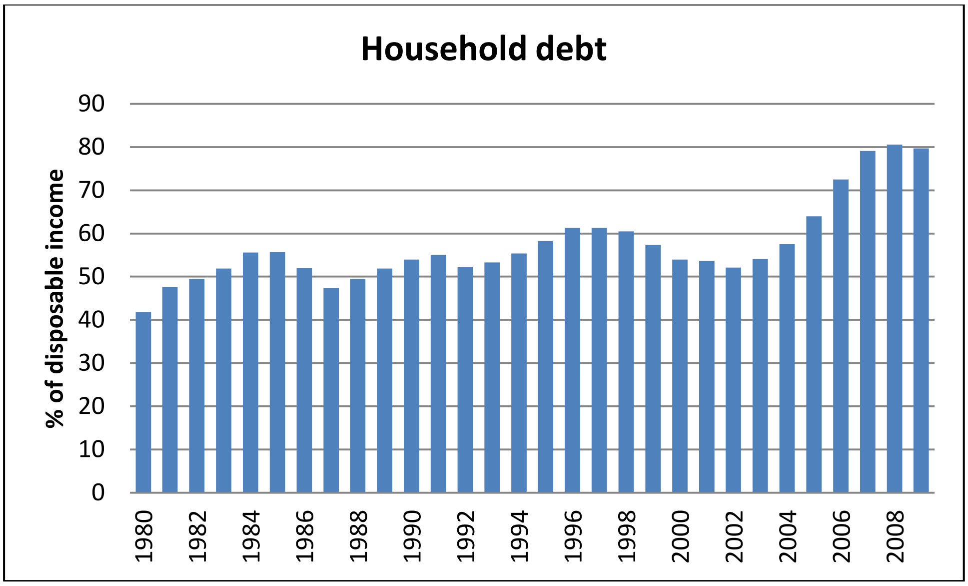


Source: SARB (2011)

On the other hand, the historically high level of indebtedness of South African consumers represents a significant macroeconomic vulnerability. The average ratio of household debt to disposable income for the period 1980 to 2009 was 57%, but rose considerably from 50% in 2002 to a record high of 80% in 2008 (see Figure 3-43). This high level of indebtedness exposed consumers to shocks such as higher costs of living, higher interests rates and falling real incomes, all of which were experienced in 2008, thus contributing to the recession. Nevertheless, banking reforms introduced during the mid-

2000s, such as the National Credit Act, did help to curtail excessively risky lending and limit the damage caused by the Global Financial Crisis of 2008-09.

Figure 3-43: Ratio of household debt to disposable income, 1980-2009

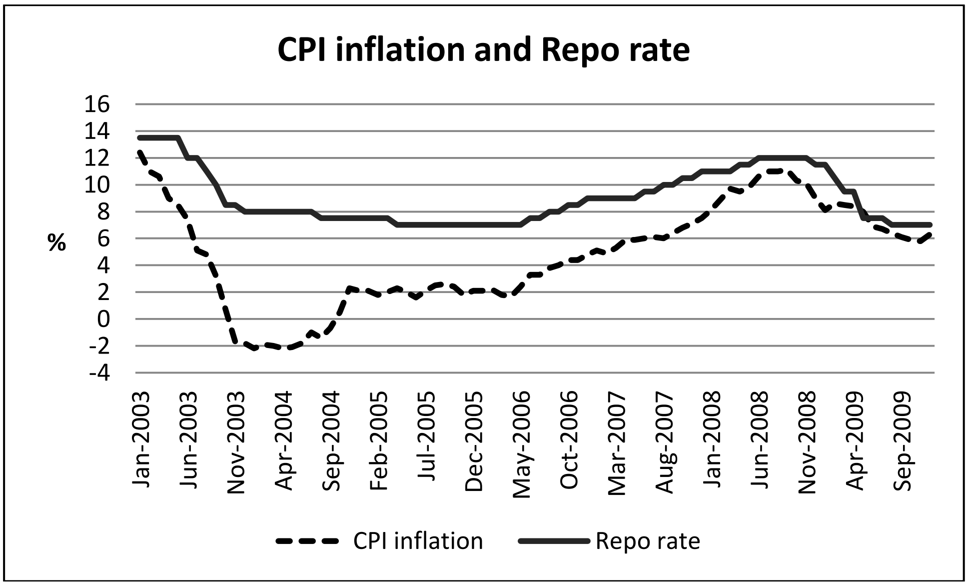


Source: SARB (2011)

Inflation and interest rates

The rate of consumer price inflation reached historical lows of -2% in 2004, but after that followed a rising trend until peaking at 11% in 2008 (see Figure 3-44). By the end of 2009 the inflation rate had fallen to 6.3%, but this was still outside the South African Reserve Bank's inflation target range of 3-6%. The SARB raised its key repo lending rate 10 times in half-percent increments between June 2006 and June 2008, but subsequently cut the rate by 5 percentage points to reach 7% in 2009, in response to the falling inflation rate and the economic recession. The spread between the repo rate and headline inflation narrowed to zero by early 2009. The inflation rate remains a key macroeconomic risk, especially considering how heavily it is influenced by the crude oil price and the exchange rate.

Figure 3-44: CPI inflation rate and repo rate, 2003-2009



Source: SARB (2011)

Employment and unemployment

The high rate of unemployment in South Africa represents one of the major macroeconomic vulnerabilities. The working age population (15-64 years) of South Africa as of June 2009 was estimated at 31.08 million (StatsSA, 2009b). The labour force (i.e. the economically active population) was 17.495 million, which comprised those employed (13.369 million) and the unemployed (4.125 million). The balance of the working age population constituted those not economically active (13.585 million), which included 1.517 million discouraged work seekers (i.e. those who have given up searching for jobs). Table 3-12 shows the employment figures by major sector in the second quarter of 2009. The formal, non-agricultural sector accounted for 70% of jobs, while the non-agricultural informal sector contributed 16%. Agriculture accounts for just 5% of employment, while 9% of jobs were in private households.

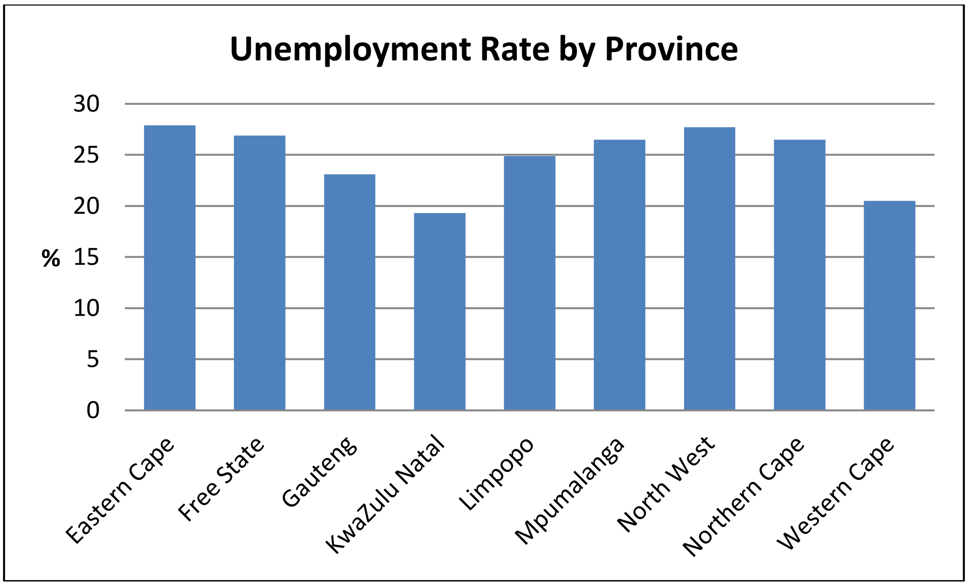
Table 3-12: Employment by sector, 2009Q2

Employment by sector	Thousand	%
Formal sector (non-agricultural)	9,356	70.0
Informal sector (non-agricultural)	2,109	15.8
Agriculture	710	5.3
Private households	1,194	8.9
Total	**13,369**	**100**

Source: StatsSA (2009b)

The official unemployment rate stood at 23.6% in the second quarter of 2009 (StatsSA, 2009b). For females the unemployment rate was 25.7%, whilst for males it was 21.8%. The unemployment rate varied considerably among population groups: Black/African 27.9%; Coloured 19.5%; Indian/Asian 11.3%; and White 4.6%. The so-called broad rate of unemployment, which includes discouraged workers (i.e. those who wanted to work but did not actively search for jobs in the week preceding to the survey), was 29.7%. The unemployment rate by province in June 2009 is depicted in Figure 3-45. The highest rates occurred in the Eastern Cape (27.9%) and North West (27.7%), while the lowest rates were recorded in KwaZulu Natal (19.3%) and the Western Cape (20.5%).

Figure 3-45: Unemployment rate by province, 2009Q2



Source: StatsSA (2009b)

A high rate of unemployment has been a structural feature of the South African economy for at least two decades. At least two factors have contributed to this. First, the apartheid education system was deliberately designed to withhold quality education from the majority of black South Africans. Since 1994, however, the education system has continued to be dysfunctional in many respects (The Presidency, 2008). As a result, South Africa suffers from a severe skills deficit. A "[s]hortage of suitably skilled labour amplified by the impact of apartheid spatial patterns on the cost of labour" was identified as one of six "binding constraints" on the economy in the AsgiSA programme (The Presidency, 2006a: 5). Second, certain sectors that have historically been a major source of employment have in recent years been shedding jobs, partly as a result of capital intensification and technological progress. The latter process has been driven partly by the need for South African firms to be internationally competitive. Examples are mining (where the production of certain minerals, notably gold, have been on a declining trend), manufacturing and agriculture (The Presidency, 2008: 97).

3.4.4 Summary of macroeconomic vulnerabilities

The South African macro-economy is reasonably well diversified across the full range of major sectors, which will help it to adapt to the impact of oil price shocks. However, the relative size of the primary and secondary sectors diminished over the 1990s and 2000s, such that services accounted for around two thirds of both gross value added and employment in 2009. Primary sectors are likely to be increasingly important when the costs of international freight transport are pushed up by higher oil prices after the global oil peak.

The economy is characterised by high energy intensity, relatively low oil intensity, and relatively high oil import dependence. In times of high oil prices, oil imports become the single largest expenditure item on the balance of payments and place a large burden on an already very large current account deficit, which poses a risk to the exchange value of the currency. In addition, because South Africa's financial markets are relatively open and highly liquid, the country is exposed to large short-term financial inflows and outflows and hence currency volatility. While in the 1970s gold played a major role in offsetting the impact of oil price shocks on the balance of payments, the share of gold in exports and GDP has fallen steadily since then.

Although by 2009 the levels of foreign and domestic public debt were manageable, household debt as a percentage of disposable income was at an all-time high and posed a serious risk to the robustness of consumer expenditure. Another major weakness in the economy was the persistently high rate of structural unemployment. By 2009 both inflation and interest rates were at historically reasonably low levels, but historical experience has shown how sensitive they are to exogenous shocks such as oil price spikes and exchange rate depreciation.

The macro-economy is clearly a complex system whose key variables are highly interconnected. An exogenous disturbance to a particular variable, either positive or negative, sets in motion ripple effects across a range of other variables and in some instances triggers positive feedback loops which intensify the impacts. These interactions will be explored in greater detail in Chapter 5, which deals with impacts of oil supply and price shocks.

3.5 Society

This section provides an overview of several important features of contemporary South African society that are relevant to understanding potential social vulnerabilities to oil supply and price shocks. Section 3.5.1 presents data on various measures of the extent of poverty and inequality. Section 3.5.2 discusses food security at the household level. Section 3.5.3 highlights some key features of human settlement patterns. Section 3.5.3 discusses the issue of social cohesion and several factors that may undermine it. The concluding subsection highlights systemic linkages among these various social vulnerabilities.

3.5.1 Poverty and inequality

Poverty renders people more vulnerable to economic shocks, including rising transport and food costs. Furthermore, a society characterised by a high degree of inequality can be expected to experience greater social stresses and tensions in times of economic adversity. Poverty and inequality can be defined and measured in various ways, such as household income and expenditure, asset ownership, and access to social services. These are discussed in turn.

South Africa has no official income poverty line. However, The Presidency's (2008) report *Towards a Fifteen Year Review* sets two benchmark poverty lines, at R322 per month and R174 per month (both in 2000 rands). The *poverty headcount rate* is the proportion of individuals living in households with an income less than the poverty line. In 2005, 48% of households earned less than R322 per month; 93% of these people were African. As shown in Table 3-13, poverty rates varied greatly by population group; at the upper poverty line, the poverty rate was highest for Africans (56%) and lowest for whites (0.4%). The *poverty gap* is defined as the gap between the average income of poor people and the poverty line. Poverty rates were higher amongst women and those living in rural areas.

Table 3-13: Headcount poverty rate and poverty gap ratio, 2005

	Headcount rate		Poverty gap ratio	
Poverty line	**R322/month**	**R174/month**	**R322/month**	**R174/month**
African	56.3%	27.2%	24.4%	8.6%
Coloured	34.2%	12.3%	13.0%	3.9%
Indian/Asian	8.4%	1.6%	2.2%	1.1%
White	0.4%	0.1%	0.1%	0.0%
Total	**48%**	**22.7%**	**20.6%**	**7.2%**

Source: The Presidency (2008)

Social grants, in the form of the Child Support Grant, the Old-Age Grant and the Disability Grant, reached 12.4 million recipients as of March 2008 and helped considerably to reduce the poverty rate from earlier years (The Presidency, 2008: 468). State expenditure on social security was projected to be on the order of R73 billion in 2009/10, representing 3.1% of GDP. However, these grants placed a large burden on the state's fiscal balance and might prove to be unsustainable in a context of an oil shock-induced economic contraction.

Despite the extensive social grants programme, household income and expenditure are highly unequally distributed in South Africa, as shown in Table 3-14. The top 10% of earners derived more than half of total household income in 2005, while the poorest 50% of the population earned just 10% of income. Average income in urban areas was more than three times that in rural areas in

2005. Another indicator of the extent of inequality is the Gini coefficient, which stood at 0.679 in 2008 (The Presidency, 2009).[93] This was amongst the highest national rates of inequality in the world (United Nations Development Programme, 2009).

An additional aspect of poverty is asset poverty. One important dimension of asset poverty in South Africa is the lack of adequate housing. Despite the government's considerable progress in providing housing for poorer citizens over the past fifteen years, there remains a very large backlog in access to formal housing, with nearly 30% of households lacking formal dwellings in 2007 (The Presidency, 2008: 28).[94] The two principal drivers of growth in demand for housing have been population growth and a rapid expansion in the number of households, by 3.5 million, between 1996 and 2007 (The Presidency, 2008: 28). A second, related aspect of asset poverty is the highly unequal ownership of land, which reflects the legacy of Apartheid as well as the slow pace of land reform since the democratic transition.[95] Where land transfers have taken place, they have too often not been followed up by adequate support for new farmers, and this has had negative impacts on agricultural productivity (The Presidency, 2008: 29).

Table 3-14: Household income and expenditure, 2005

	Income		Expenditure
Income group	**R/annum**	**% of total**	**R/annum**
Decile 1	4,312	0.2	11,381
Decile 2	9,587	1.2	13,982
Decile 3	13,297	2.2	16,784
Decile 4	17,626	2.9	20,547
Decile 5	22,974	3.5	22,819
Decile 6	30,522	4.7	28,374
Decile 7	43,572	6.4	35,654
Decile 8	69,495	10.3	55,055
Decile 9	128,785	17.8	108,024
Decile 10	405,617	51.0	248,823
Total	74,589	100.0	56,152
Rural	30,859		25,576
Urban	98,011		72,529

Source: StatsSA (2008)

A further indicator of poverty and inequality is access to basic social services. Access to electricity, water and sanitation improved significantly since the advent of democracy in South Africa mainly as a result of targeted government programmes (see Table 3-15). Nevertheless, as of 2007 many households still lacked access to electricity, especially for heating and cooking; 30% had no on-site access to tap water; and 40% had no flush toilet. Lack of such basic facilities renders people more vulnerable to economic and social shocks.

[93] The Gini coefficient ranges between 0 (complete equality) and 1 (complete inequality).

[94] "The combined effect of government and private-sector housing saw the proportion of households in traditional dwellings decline from 18,2% to 11,7% between 1996 and 2007 and those in formal dwellings increase from 64,4% to 70,5%." (The Presidency, 2008: 28)

[95] According to The Presidency (2008: 29), "The Government set a target of transferring 30% of white-owned agricultural land through restitution, redistribution and tenure reform by 2014, which amounts to 24,9 million hectares. The total transferred by 2008 amounted to 4,8 million hectares, indicating that the land reform programme would have to be stepped up considerably to meet the 2014 target."

Table 3-15: Household access to key social services, 2001 and 2007

Households	2001	2007
Using electricity		
for lighting	70%	80%
for heating	51%	67%
for cooking	49%	59%
Water		
Tap in dwelling or on site	61%	70%
Sanitation		
Flush toilet	52%	60%

Source: The Presidency (2008)

Poorer households are in general more vulnerable to increases in energy, transport and food prices. Table 3-16 shows annual expenditures on household energy, transport and food in rands and as a percentage of total expenditure (exclusive of taxes) for the 10 income deciles in 2005/6. Food is the largest expenditure item for poorer households, although energy and transport costs are also significant.

Table 3-16: Annual household expenditure on energy, transport and food, 2005/6

Income Group	Energy R	Energy %	Transport R	Transport %	Food R	Food %	Total R
Decile 1	606	5.3	910	8.0	3,735	32.8	11,381
Decile 2	809	5.8	1,143	8.1	4,638	33.2	13,982
Decile 3	924	5.5	1,315	7.8	5,190	30.9	16,784
Decile 4	1,012	4.9	1,770	8.7	6,108	29.7	20,547
Decile 5	1,062	4.7	2,121	9.3	6,600	28.9	22,819
Decile 6	1,082	3.8	2,778	9.8	7,392	26.1	28,374
Decile 7	1,185	3.3	4,029	11.3	7,904	22.2	35,654
Decile 8	1,544	2.8	5,567	10.1	9,225	16.8	55,055
Decile 9	2,311	2.1	10,349	9.6	11,990	11.1	108,024
Decile 10	3,179	1.3	17,384	7.0	18,267	7.3	248,823
Total	1,371	2.4	4,737	8.4	8,105	14.4	56,152
Rural	1,167	4.6	2,276	8.9	6,334	24.8	25,576
Urban	1,481	2.0	6,055	8.3	9,054	12.5	72,529

Source: StatsSA (2008)

Notes:

- *Energy includes electricity, gas, liquid and solid fuels used in homes.*
- *Transport includes operation costs including fuel (5.0% of the CPI basket) plus transport services (3.4% of the CPI basket).*
- *Food includes foodstuffs plus non-alcoholic beverages.*

3.5.2 Household food security

Food security is a vital condition for human well-being and social stability. National food security (e.g. self-sufficiency in the majority of agricultural commodities, including the main staple, maize) is no guarantee of food security for individual citizens of the country (Leroy et al, 2001: 6). According to Maxwell (1996, cited by Hendriks, 2005: 103), there were at least 250 definitions of food security as of 1996, including "food supply, access, adequacy, utilisation, safety and, in some cases, cultural acceptability of food for all people at all times." Leroy et al. (2001: 5) highlight nutritional sufficiency and security of access, both in general and at critical times, as being important aspects of food security. These various dimension of food security at the household level may perhaps be distilled to two basic dimensions: the physical availability and the economic affordability of nutritious foodstuffs. Food insecurity is defined as "the lack of food security that, at the extreme, is experienced as hunger" (Hendriks, 2005: 103).

The incidence of food insecurity in South Africa is not known with any degree of certainty owing to a lack of nationally representative surveys of food security (Hendriks, 2005: 109). Nevertheless, the available evidence indicates that in the region of 59% to 73% of households experience food insecurity, approximately 16% have an inadequate energy intake, about 30% experience hunger, and approximately 22% of the population could be stunted and 3.7% afflicted by wasting (Hendriks, 2005: 115).

While the determinants of food insecurity are numerous and complex, two basic drivers can be identified, reflecting the principal dimensions referred to above. These are: (1) inadequate income (i.e. poverty) in relation to the cost of food products; and (2) a lack of access to land, water and other productive inputs required for own food production. These drivers help to identify the groups within the population that are most vulnerable to food insecurity.

Food insecurity is a major issue in many countries with a high level of income poverty, including South Africa. Poorer income groups spend a higher proportion of their monthly budget on food relative to wealthier groups and are therefore relatively more vulnerable to rising food prices (Hendriks & Msaki, 2009: 185). The majority of poor people living in urban areas do not have the opportunity to grow some of their own food as they lack access to adequate land and water.[96] The process of urbanisation thus results in more people relying on wage incomes for food purchases.

Somewhat ironically, however, hunger and malnutrition are more common in agricultural areas, especially amongst smallholder farmers, agricultural workers and the landless (Hendriks & Msaki, 2009: 185). This is essentially because the incidence of poverty is higher in rural areas (Pauw, 2007). While some of the rural poor do have opportunities to meet some of their nutritional requirements through own food production, households engaged in subsistence farming are by no means assured of food security. This is primarily because the majority of small-scale farmers in South Africa are confined to areas with relatively low agricultural potential, for example in terms of soil quality and rainfall (Thamaga-Chitja & Hendriks, 2008: 321), and many are vulnerable to droughts (Mekuria & Moletsane, 1996, in Hendriks, 2005: 112). Pauw (2007: 210) found a 90% poverty rate among black subsistence farmers in 2000, implying a very limited ability to supplement own production with purchased food products. Instead they relied heavily on government transfers and remittance payments to supplement their incomes (Pauw, 2007: 196). According to Vink and van Rooyen (2009: 14), "the number of South African households with access to land for farming purposes declined from 1.8 million in 2002 to 1.4 million in 2006 (or a decline of 21%)." The proportion of all South

[96] In a survey conducted in three large cities, only 5% of poor urban households reported growing their own food (Frayne, Battersby-Lennard, Fincham & Haysom, 2009).

African households with access to land fell from 15.3% in 2002 to 10.7% in 2006 (Vink & van Rooyen, 2009: 14).

A further group of households especially vulnerable to food insecurity are those with members living with HIV/AIDS (Hendriks, 2005: 116). This is because HIV/AIDS limits suffers' abilities to sustain livelihoods and earn sufficient income to purchase food, and/or hinders their ability to produce their own food, and simultaneously increases expenditure on health care (Piot & Pinstrup-Andersen, 2002, cited by Hendriks, 2005: 117). Poor nutrition in turn exposes a person to a greater risk of contracting HIV, thereby establishing a negative feedback loop (Gillespie et al., 2004, cited by Hendriks, 2005: 117).

Oil depletion and the associated risk of oil price shocks carries two major threats to household food security. The first is rising food prices, since food prices are linked to oil prices through input and transport costs. The second threat is of falling employment levels and incomes as a result of the negative macroeconomic consequences of oil shocks. These factors act together to reduce the food purchasing power of households (see Hendriks, 2005: 116).

The South African government provides some level of support to bolster food security for certain vulnerable sectors of society. This support comes in the form of general social grants (discussed in Section 3.5.1 above) as well as specific agricultural assistance such as the distribution of seed starter packs, training in food cultivation, and school-feeding programmes (GCIS, 2009).

3.5.3 Settlement patterns

Human settlement patterns play an important role in South African society's dependence on liquid fuel based transport and therefore in its vulnerability to oil supply disruptions and price shocks. The two predominant features of the country's settlement patterns are inequality and inefficiency, and the two aspects are closely linked for historical reasons. Inefficiency in the spatial configuration of settlements relates largely to the phenomenon of urban sprawl, which occurs in virtually all cities and metropolitan areas around the country.[97] These two features are examined in terms of their main characteristics and drivers, and the vulnerabilities they generate for society.

The inequality in South Africa's human settlement patterns stems in the first instance from the legacy of apartheid, under which residential areas were segregated and land ownership was restricted on the basis of race. The bulk of the African population was confined to overcrowded 'homelands' (constituting just 13% of South Africa's land area), while townships were created on the outskirts of cities and towns, often to provide a pool of cheap migrant labour for industries such as mining (NPC, 2011e). Despite some progress, residential segregation in urban areas persists after more than 15 years of democracy, partly as a result of persistent income and wealth inequality. Similarly, progress in land reform has been slow, with the result that rural land is still concentrated largely in the hands of white farmers. The mechanisation of agriculture and casualisation of farm labour displaced many people who used to live and work on farms into rural towns and cities.

The apartheid-based urban settlement patterns, with remotely located townships, laid an initial foundation for urban sprawl. This pattern was perpetuated by an ongoing process of urbanisation, which accelerated after the democratic transition. A major driver of urbanisation has been deep and persistent poverty in rural areas, which has led to streams of migrants searching for economic opportunities in cities, and especially in the major metropolitan areas (Turok et al., 2011). Many of

[97] Approximately 60% of South Africans live in urban areas (RSA, 2011: 21).

the migrants joined existing townships or formed new informal settlements on urban peripheries.[98] In addition, many of the new formal housing developments have also been located on the margins of cities and towns (Turok et al., 2011: 10). The key problem is that these settlements are located far from social and economic opportunities (DoH, 2005; The Presidency, 2007: iv; The Presidency, 2008: 99). The large distances impose high travel costs, which are particularly burdensome for residents who are generally poor to begin with (The Presidency, 2007: ii). Combined with the inadequacy of state-provided public transport facilities such as trains and buses, long travel distances have resulted in heavy reliance among residents on minibus taxis (DoT, 2005).

A second type of urban sprawl, which occurs mainly among middle- and upper-income socioeconomic neighbourhoods, "is characterised by spatially extensive settlements where building densities are low and consists of free standing houses on large parcels of land" (Yusuf & Allopi, 2004: 520). Often termed 'suburban sprawl', it includes residential suburbs as well as cluster housing developments that are far from the urban core. One feature of urban sprawl is declining (or low) population density. Figure 3-46 provides the example of Cape Town's growth between 1900 and 2000, during which time the average population density fell from 115 to 39 persons per hectare (Gasson, 2002).

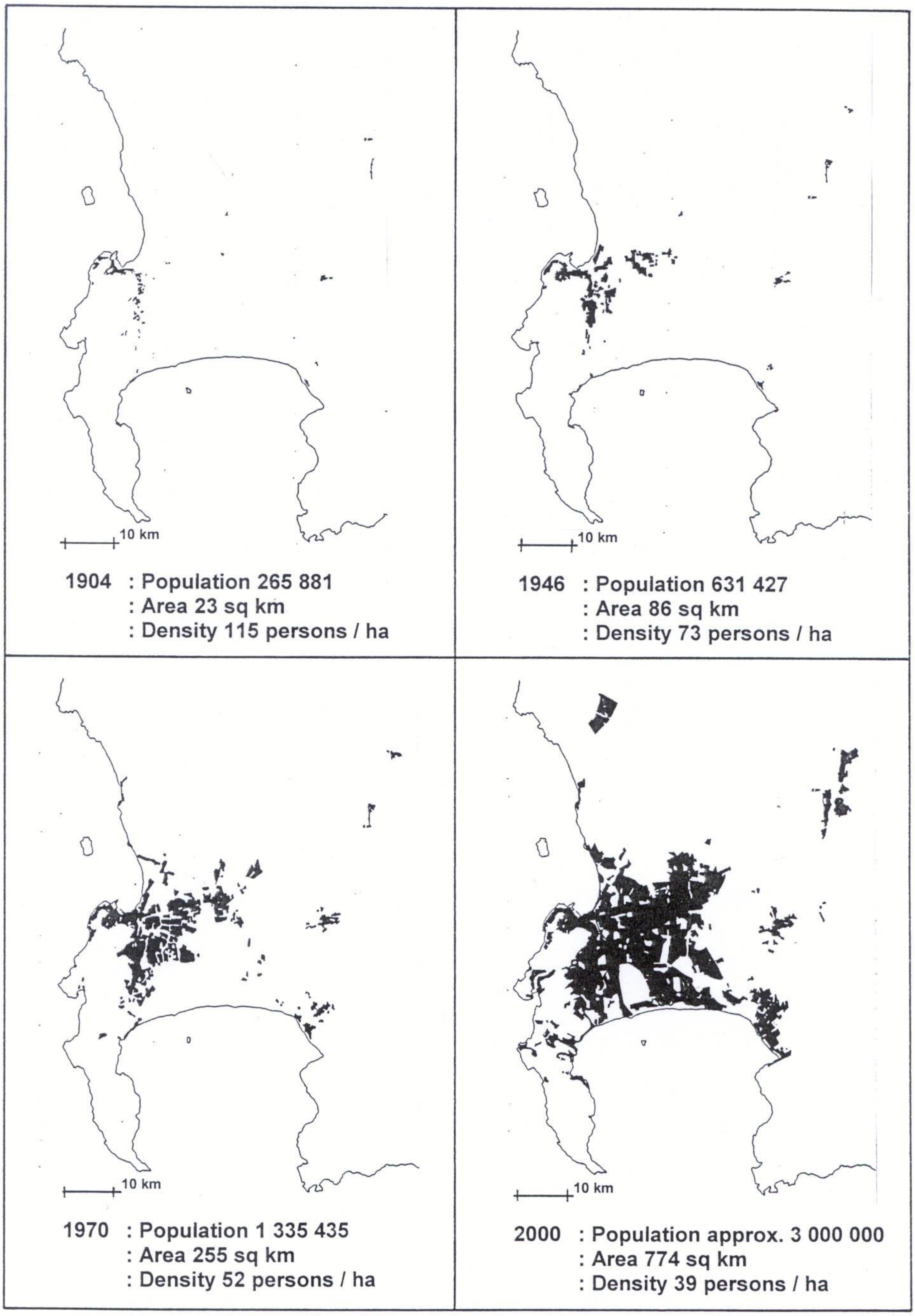
Suburban sprawl has been made possible by relatively cheap, private motorised transport. It is very much an oil-based pattern of development, in which citizens depend largely on private motor vehicles for transport to places of work, schools, and shops, and for socialising. Suburban sprawl has also been facilitated by local authorities' approach to urban planning, which for the most part has either allowed or encouraged this type of development, "based on an assumption that citizens have or will acquire cars" (Turok et al., 2011: 10). The consequence of this dependency on motorised transport is of course vulnerability to fuel price increases and fuel shortages.

One further aspect of historical and current settlement patterns deserves mention, which is its relation to arable land and food security. First, urban sprawl often results in the conversion of agricultural land to residential settlements on the outskirts of urban areas. This means that food has to be transported ever greater distances to reach consumers, implying higher transport costs and ultimately higher food prices as well. Second, many of the former 'homeland' areas created under apartheid suffered the effects of over-crowding and over-grazing (Huntley, Siegfried & Sunter, 1989). This contributed to a deterioration of the limited arable land, increasing rural food insecurity and the process of urbanisation.

In summary, two forms of urban sprawl characterise South Africa's cities. First, many lower-income citizens tend to reside in informal or formal settlements that are located on urban peripheries. They consequently rely heavily on public transport and/or non-motorised transport. Second, the majority of more affluent citizens reside in sprawling suburbs that are highly dependent on private motor vehicles. Both groups generally need to travel substantial distances to access economic and social opportunities and are therefore vulnerable to rising fuel and transport costs and fuel shortages. Nevertheless, rural areas are in some ways more dependent on motorised travel than urban areas, as distances to towns may be larger than distances typically travelled within cities, and there are less extensive or even nonexistent public transport services. In both urban and rural areas, the persistent inequality in spatial development patterns also contributes to vulnerabilities in social cohesion, which is discussed in the following section.

[98] In 2010, a quarter of South Africa's population lived in just 76 urban townships, and 40% of all households lived in townships; most township dwellers lived more than 20 kilometres from city centres and work opportunities (Karuri-Sebina, 2011).

Figure 3-46: Growth of Cape Town, 1900-2000



Source: Gasson (2002)

3.5.4 Social cohesion

The ability of a society to withstand social and economic shocks depends *inter alia* on the degree of social cohesion. Chipkin and Ngqulunga (2008) define social cohesion as "a situation where citizens of the state share feelings of solidarity with their compatriots, and act on the basis of these feelings." They further argue that the performance of state institutions plays a key role in determining the degree of social cohesion. Social cohesion in South Africa is affected by numerous other factors including the ethnic composition of the society, the political dispensation, inequality and poverty, migration and immigration, and rates of crime and violence.

South Africa's population is very diverse in terms of its ethnic and cultural composition, as reflected for example in the country's 11 official languages. The total South African population was estimated at 49.32 million in mid-2009 (see Table 3-17).[99] Females accounted for 52% of the population and males 48%. Africans constituted the largest population group, with 79.3% of the total population. Coloureds (9%), whites (9.1%) and Indian/Asians (2.6%) made up the remainder.

Table 3-17: Population estimates by population group and sex, 2009

	Male		**Female**		**Total**	
Population group	**Number**	**Percentage of total population**	**Number**	**Percentage of total population**	**Number**	**Percentage of total population**
African	18 901 000	79,2	20 235 200	79,5	39 136 200	79,3
Coloured	2 137 300	9,0	2 295 800	9,0	4 433 100	9,0
Indian/Asian	635 700	2,6	643 400	2,5	1 279 100	2,6
White	2 194 700	9,2	2 277 400	9,0	4 472 100	9,1
Total	**23 868 700**	**100,0**	**25 451 800**	**100,0**	**49 320 500**	**100,0**

Source: StatsSA (2009)

South Africa has enjoyed a stable democracy since 1994 with free and fair elections held every five years since then. The African National Congress has maintained power throughout this period with a strong majority in the National Assembly. There has been no widespread, serious political violence in the democratic era. Nevertheless, social tensions persist after more than fifteen years of democracy, reflecting in part the legacy of a conflict-ridden Apartheid past (Bradshaw, 2008) and also the persistence of income inequality and poverty (The Presidency, 2008: 29).

An uneven geographical distribution of real and perceived economic opportunities has contributed to substantial flows of migrants between the provinces in South Africa (StatsSA, 2009). It was estimated that approximately 390,000 people would migrate from the Eastern Cape and 200,000 people from Limpopo in the period 2006–2011 in net terms. The main net recipients of migrants were Gauteng and Western Cape, which were estimated to gain approximately 450,000 and 140,000 migrants, respectively, in the same period. Such migrant streams place significant pressure on the provision of social services and also intensify competition for jobs in the destination areas, which are principally the main metropolitan areas. One result has been an increasing prevalence of grass-roots social protests, particularly over the perceived lack of delivery of social services (Booysen, 2007). The percentage of survey respondents who considered the government to be performing well on the provision of basic services declined markedly from a post-2000 peak of 81% in 2004 to a low of 58% in 2009 (The Presidency, 2009: 78).

[99] All population data in this section are drawn from StatsSA (2009).

Such economic and social stresses have been further compounded in recent years by an increased rate of immigration from other African countries (The Presidency, 2008: 99).[100] Immigration has been driven both by push factors (such as political, social and economic upheavals in their home countries) as well as pull factors (e.g. the relative size and strength of South Africa's economy in the context of Southern Africa). This immigration placed extra strain on already over-stretched social services and aggravated social tensions, as evidenced by the so-called 'xenophobic' violence that erupted in many parts of the country in May 2008 (Laher, 2009; Sharp, 2008).

More generally, South African society is characterised by unacceptably high rates of crime**,** especially violent crimes such as murder, rape, assault and robbery (The Presidency, 2009: 59). Although the overall crime rate declined from 5,711 per 100,000 in 2000/01 to 4,310 in 2008/09, the incidence of violent crimes increased. The causes of crime are complex and multifarious, and include the high rate of unemployment, especially among young males, as well as the related high incidence of inequality and poverty. Although much of the violent crime occurs within poor and marginalised communities, especially in urban informal settlements, attacks on farm owners is another area of particular concern.

3.5.5 Summary of social vulnerabilities: systemic inter-linkages

The various vulnerabilities of South African society discussed above are interconnected and in many ways mutually reinforcing. The high levels of income poverty and inequality, together with backlogs in the provision of housing and social services, make a large proportion of the South African population especially vulnerable to economic shocks, including those potentially caused by oil shortages and price spikes. Part of this vulnerability takes the form of household food insecurity, which can engender social protests when severe. Poverty and inequality are also factors contributing to high rates of crime and violence, undermining social cohesion. Crime feeds back negatively on the economy and thereby helps to perpetuate poverty. By stimulating rural-urban migration and limiting the options for where people can afford to live, poverty also exacerbates urban sprawl in the form of informal settlements, townships and new low-cost housing developments being located far from urban centres. As a result, poorer people have to travel large distances to access social and economic opportunities, which renders many of them dependent on minibus taxis for mobility and hence vulnerable to rising fuel and transport costs. Urban sprawl can also contribute to food insecurity by increasing the distance food has to travel to reach consumers, which implies higher food prices. In addition, urbanisation and immigration from other African countries increase economic and social pressures in urban settlements and raise the risk of intensified social protests, 'xenophobic' violence, and crime, particularly when times are hard economically. Thus although the cultural and ethnic diversity of the South African population has many advantages, it can also create vulnerabilities in terms of social tensions.

[100] According to The Presidency (2008: 99), "[t]here is no adequate data on the scale of immigration and estimates vary wildly, but it is evident that the number of people from other countries in Africa has increased significantly."

3.6 Conclusions

South Africa's strengths and vulnerabilities vis-à-vis oil shocks in each of the five socioeconomic subsystems are summarised in Table 3-18. These subsystems are not isolated from one another, but are connected by many linkages and feedbacks, which in many ways intensify the dependencies on oil and magnify the vulnerabilities to oil shocks. These feedbacks are elaborated upon in the following paragraphs.

The transport and agriculture sectors in particular, and the macro-economy and society in general, are all dependent on flows of energy and oil. The subsystem that is most highly dependent on oil is transport, largely because it is dominated by road-based movement of both passengers and freight. Parts of the energy system are themselves dependent on transport in one form or another. A prime example is the use of railways and increasingly roads for hauling coal to thermal power stations. More generally, the installation of new infrastructure and the maintenance of existing energy generation and distribution systems depend heavily on road-based transport.

Transport in fact plays a crucial role in the entire socioeconomic system, as virtually all sectors of the economy depend on transport to some degree or other. This applies to the production chains of both primary and manufactured goods, to the distribution of final goods to consumers at the wholesale and retail levels, as well as to many services that require personal mobility of workers and/or consumers. Agricultural production is a case in point, since a large proportion of farm produce is moved by road to urban areas for domestic consumption and to ports for export. For both the economy and society, transport vulnerabilities are intimately related to human settlement patterns, which in South Africa have an entrenched dependence on internal combustion engine vehicles.

The health of the agricultural sector is clearly important for food security, although this also depends greatly on prevailing macroeconomic conditions that determine the affordability of imported foods at the national and household levels. Food security, in turn, is a vital component of social well-being and can have a large impact on social stability.

The state of the macro-economy also broadly influences the other subsystems. First, negative exogenous shocks to the macro-economy may limit the availability of funds for new energy and transport infrastructure or indeed for maintenance of existing systems. Second, macroeconomic variables such as interest and exchange rates also impact on the health of the agricultural sector via input costs and export demand. Third, rates of inflation, interest and unemployment have a major influence on social conditions such as the extent of poverty and inequality, and rates of migration and immigration, which in turn help to determine the degree of social cohesion. Finally, the degree of social cohesion feeds back to the macro-economy, for instance via crime levels and social unrest, which can be a hindrance to business confidence and investment.

Having identified the main oil dependencies, strengths and vulnerabilities in the South African socio-economy, the scene is set for an analysis of the potential impacts of oil price and supply shocks in Chapter 4.

Table 3-18: Summary of South Africa's key strengths and vulnerabilities

Subsystem	Strengths	Vulnerabilities
Energy	• relatively low oil dependence (12% of primary energy) • domestic synthetic fuels production (30% of liquid fuels) • electricity minimally dependent on imported oil • large coal & uranium reserves • abundant solar resources • substantial wind resources	• high oil import dependency (70% of petroleum fuels) • risk of dependence on Iran & Saudi Arabia for 52% of crude oil imports • import parity pricing for locally produced synthetic fuels • fuel distribution bottlenecks • insufficient strategic stocks • road dependence of coal deliveries
Transport	• extensive road network • rail network connects major urban centres • several major ports to facilitate cheaper transport and trade (for coastal settlements) • potential for greater bicycle use • development of integrated rapid transit systems in metropolitan areas	• extremely high dependence on petroleum fuels (98%) • very high reliance on roads for freight and passenger transport • inadequate public transport • large distances between major cities • large distance from trading partner countries • poor maintenance of road and rail networks • aged rail rolling stock • lack of domestic locomotive manufacturing capacity • violent elements in taxi industry
Agriculture	• self-sufficient in most commodities, including main staple maize (most years) • some subsistence agriculture • some underutilised land available	• high petroleum dependence • small percentage of land area is arable (13%) • generally poor soil quality • low rainfall & recurring droughts • highly oil-intensive farming • key input prices linked to oil • little organic agriculture • net food importer since 2008 • net importer of wheat and rice • attrition of farming skills • fuel shortages can be catastrophic
Macro-economy	• reasonably well diversified economy • relatively strong growth between 2004-2007 • relatively moderate inflation (5.5% in 2008) • government debt not excessive (but rising from 2009)	• high energy intensity of industry • large current account deficit • possibility of rapid capital flight • record household indebtedness • high rate of unemployment • skills shortages
Society	• successful political transition in 1994 • 15 years of stable democracy • strong constitution • improvements in access to social services • extensive social grants provide a safety net	• deep & widespread poverty • high degree of inequality • high degree of food insecurity • high prevalence of HIV/AIDS • high levels of crime • service delivery protests • migration and immigration

CHAPTER FOUR

4. Socioeconomic Impacts under Business-as-Usual

"The peaking of world oil production presents... the world with an unprecedented risk management problem. As peaking is approached, liquid fuel prices and price volatility will increase dramatically, and, without timely mitigation, the economic, social, and political costs will be unprecedented."

Hirsch, Bezdek & Wendling (2005: 4)

"Despite the complexity and level of development of a country's economy, lack of energy could lead to stagnation, slowing down or total collapse thereof."

SA Department of Minerals and Energy (2007: 11)

The looming decline in world oil production is an unprecedented event for modern economies, in that the availability and quality of the primary energy source will decline year after year. There is thus a large degree of uncertainty surrounding the impacts, which will depend on several factors, including: (1) the rates of decline of global oil production, world oil exports and the net energy surplus delivered by oil; (2) the trajectory of international oil prices; (3) behavioural responses on the part of oil producers (e.g. resource nationalism), oil consumers (e.g. predatory nationalism or conservation initiatives) and individuals (e.g. panic and hoarding versus conservation and cooperation); and (4) policy responses by all levels of government. Notwithstanding the uncertainties, plausible scenarios can be sketched on the basis of past experience, including episodes of local energy depletion and previous international oil shocks, together with reasoned argument. This chapter addresses the following primary question: what are the likely socioeconomic impacts of global oil depletion on South Africa under business-as-usual policies? More specifically, it investigates how international oil shocks are transmitted to the South African economy and what impacts international oil shocks had on South Africa in the past. It then considers the likely short term and long term impacts that the peak and decline in world oil production could have on South Africa's energy system, transport system and mobility, agricultural production and national food security, macro-economy and society.

The methodology used in this chapter consists of three elements. The first is historical analysis of oil shocks, using both quantitative data and qualitative information. Two dimensions of oil shocks are discussed, namely price shocks and quantity shocks (i.e., physical supply shortages). The second component is a review of empirical models that have attempted to estimate the economic impacts of oil price shocks. The third element is the construction of scenarios for the future impacts of oil depletion. These scenarios are based on the following assumptions:

- global oil production begins to decline by 2-5% per annum, but oil export supply declines slightly faster on account of rising domestic consumption in oil exporting countries;
- no prior programme of mitigation has been undertaken at either global or South African levels, and there is no co-ordinated international policy response;
- technical innovations cannot be scaled up sufficiently rapidly to offset the decline in oil;
- oil prices continue to follow a rising trend, but with significant volatility around that trend; and
- physical fuel supply disruptions and shortages are experienced from time to time.

The impact analysis involves several dimensions, namely: (1) *transmission channels:* direct via higher prices and limited supplies of imported oil, and indirect via global economic and political upheavals; (2) *geographic scales:* global, national and local; and (3) *time periods*: short term (0-2 years), medium term (2-10 years) and long term (10+ years). Furthermore, consideration is given to the likely *behavioural responses* to declining oil supplies and rising oil prices on the part of producers and consumers. As has already been discussed, the South African socio-economy is a complex system with a high degree of interactivity amongst the major subsystem components. This complexity, together with the high degree of uncertainty with regard to the global oil supply/demand dynamics, impacts and responses, means that precise quantitative predictions for national and local impacts are impossible. Therefore a qualitative approach is more appropriate in general. Furthermore, the domestic economy will respond to the impact of oil depletion as a system; it is therefore not possible to completely isolate impacts in, say, agriculture from those in transport. For tractability, however, the potential impacts are arranged according to the five subsystems, namely energy, transport, agriculture, macro-economy and society.

The chapter is organised as follows. Section 4.1 explores the effect of oil shocks on the economy from theoretical, historical and empirical modelling perspectives. Section 4.2 develops a qualitative and quantitative assessment of likely impacts of global oil depletion on the five subsystems, assuming a business-as-usual policy framework. Section 4.3 discusses three possible national responses to global oil depletion. Conclusions are drawn in Section 4.4.

4.1 Oil shocks and the economy

Oil shocks typically involve at least one of the following occurrences: (1) a rapid and significant upward movement in the price of oil; and (2) a quantitatively significant reduction in the quantity of available oil.[101] In the economics literature, oil shocks have usually been defined in terms of price fluctuations, but these may in turn emanate from changes in either the supply of or the demand for oil. Historically, the supply side has been primarily responsible for observed oil price shocks, at least as an initial trigger. In practice it is unlikely for demand to grow rapidly enough to cause a sudden price shock unless it is motivated by fears of supply shortages. However, a more gradual, cumulative price shock may be driven by rapid growth in oil demand, as in 2007-2008 (Hamilton, 2009).[102] There are at least three important dimensions of an oil price shock. The first is the *magnitude* of the price increase, which is usually most usefully measured in relative terms (e.g. in percentage changes from a base date).[103] The second aspect is the *speed* or suddenness with which the oil price rises, e.g. over a period of one or two quarters or more than a year. The speed of a shock is important as it affects the ability of economies to adjust, which is typically very restricted in the short run (up to one year). The third dimension is the *durability* of the price increase, i.e. whether it is temporary or more permanent, since this carries implications for the extent and durability of the consequences. Oil shocks of the second type, namely physical shortages, have historically been rare and isolated events, but will become the norm once global oil production enters its inevitable long-term decline phase. The mainstream (neoclassical) economics perspective has always emphasized price shocks, while ecological (and biophysical) economics emphasize the importance of physical energy shortages.

[101] A "shock" is defined as "a sudden, unexpected and usually unpleasant event or experience" (Cambridge Dictionaries Online, 2011).

[102] 'Negative' price shocks (i.e. rapid falls in the oil price) are also possible, but are not a major concern in this dissertation.

[103] When comparing various oil shock episodes over time, it is useful to use "real" oil prices, i.e. those that have been adjusted for general consumer (or producer) price inflation.

This section considers both price shocks and supply restrictions, since both will be important aspects of the post oil peak environment. Section 4.1.1 delineates the direct and indirect transmission of international oil shocks to the South African macro-economy. Section 4.1.2 conducts a historical analysis of the impact of four past oil shocks on South Africa in order to draw lessons from experience. Section 4.1.3 reviews several types of empirical models that have been used to analyse the macro- and micro-economic impacts of oil price shocks on South Africa.

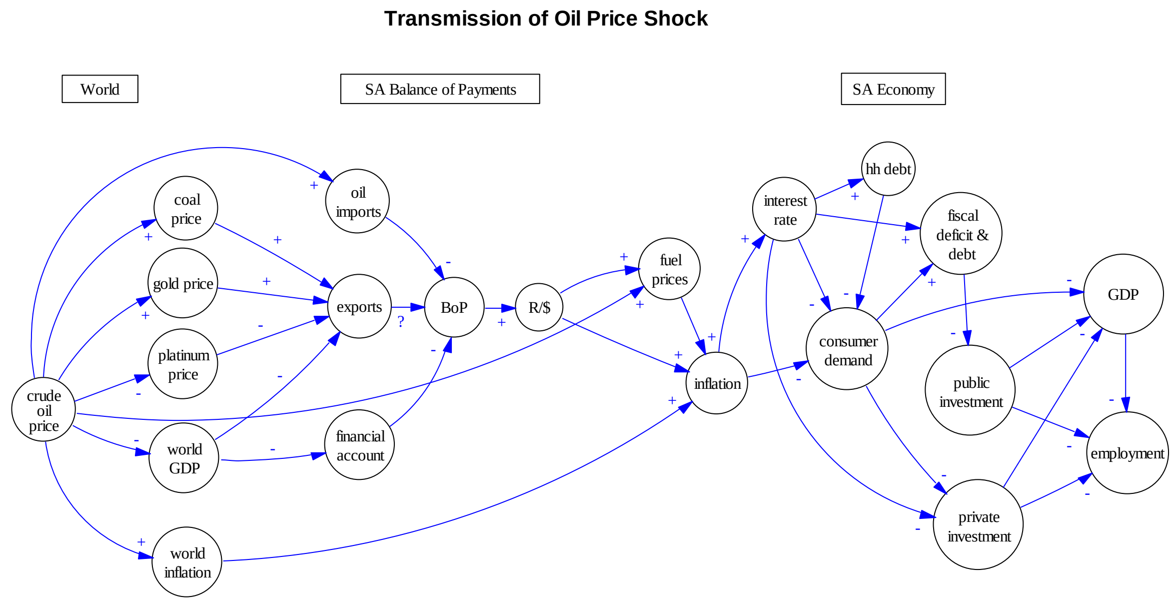
4.1.1 Transmission of oil shocks

The economic effects of oil price and quantity shocks are somewhat different, and are discussed in turn in the following two subsections.

Oil price shocks

As long as oil remains a globally traded commodity, the initial impact of declining quantities of world oil exports will be felt through rising oil prices. Oil price shocks are transmitted to the South African economy through two main channels: indirectly via their impact on the global economy, and directly through higher prices of imported crude oil and refined fuels. These channels are summarised in Figure 4-1 below and are discussed in greater detail in the paragraphs that follow.

Figure 4-1: Transmission of an oil price shock to the South African economy



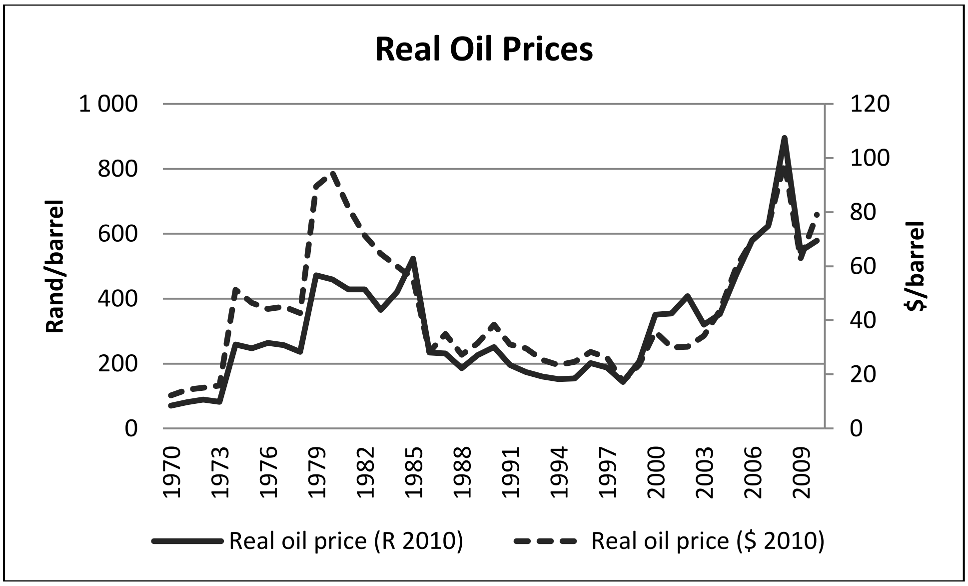
Notes: A + (-) sign next to an arrow implies that an increase in the base variable is assumed to lead to an increase (decrease) in the target variable, ceteris paribus*. A question mark implies that the causality is indeterminate. BoP = balance of payments. hh = household.*

The indirect impact of an oil price shock on South Africa's economy occurs by way of the balance of payments, which includes the current account (exports less imports) and the financial account. Firstly, the oil import bill will rise, assuming an inelastic demand for oil. Secondly, an international oil price shock means that foreign consumers have to spend a greater proportion of their incomes on oil, and hence have less money to spend on other imported goods and services.[104] If foreign monetary authorities raise interest rates in order to curb inflationary pressures, the likely result is

[104] All of South Africa's major trading partner countries (China, Japan, Germany, the United Kingdom and the United States) are net oil importers.

decreased consumption and investment expenditure and hence a decline in economic growth. Thus an oil shock typically results in diminished demand for many of South Africa's tradable goods and services. However, demand for certain specific export commodities might actually rise in response to an oil price shock. Demand for South African coal and uranium exports is likely to rise, at least in the medium to longer term. The demand for gold is also likely to rise as gold is seen as a hedge against inflation and a store of value during periods of economic and financial risk and uncertainty. The net change in demand for South African exports will depend on the relative increases for coal, uranium and gold, and decreases for most other merchandise items. A third impact on the balance of payments results from the uncertainty created by oil price shocks, which typically raises perceptions of risk, particularly with respect to emerging market economies such as South Africa, and usually results in capital flight. If the combination of capital flight, a higher oil import bill and reduced demand for (most) exports outweighs the positive impact on coal, uranium and gold exports, then the rand will weaken. In addition, an oil price shock tends to raise the general price level in oil importing countries including South Africa's trading partners, which in turn implies rising prices of imported goods and services. These higher import prices will be compounded by any weakening of the exchange rate.

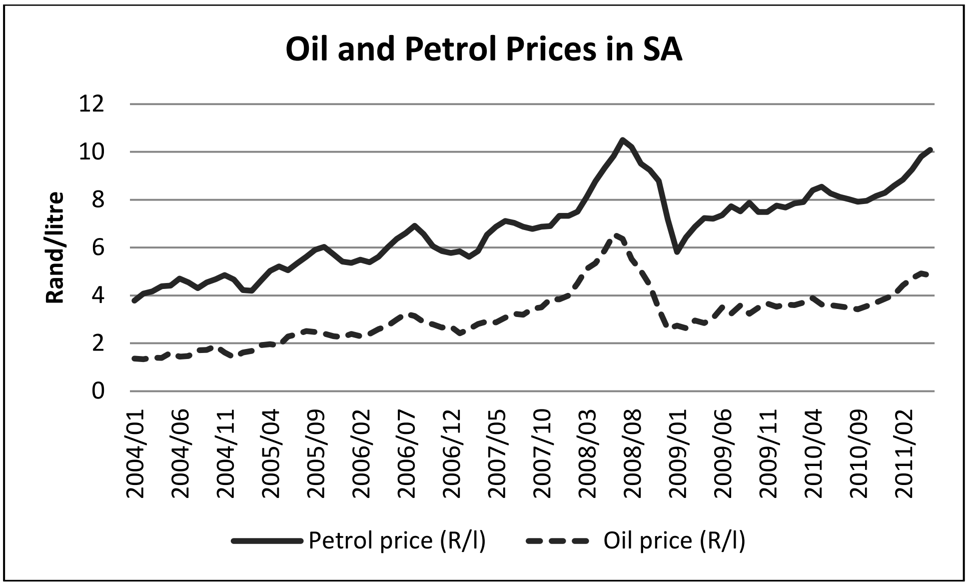
Figure 4-2: Real annual average oil price in 2010 dollars and rands, 1970-2010



Source: IMF (2011a) and own calculations

The direct impacts of oil price shocks occur via higher fuel prices and have reverberations on several important macroeconomic variables. In 2009, South Africa ranked as the 17th largest oil importing country in the world (see Appendix A). The country is clearly a price taker on the international oil market. Domestically, the downstream liquid fuels industry is subject to extensive government regulation. Prices of petroleum fuels (petrol, diesel, paraffin and LPG) are administered by the State, which imposes various levies and taxes and determines retail and wholesale margins, over-and-above a 'basic fuel price'. The basic fuel price is determined by an import parity pricing formula which depends on the international spot price of refined oil (SAPIA, 2010). Sasol and PetroSA's synthetic liquid fuels (converted from coal and gas, respectively) are accorded the same status in the domestic market as fuels that are refined from imported crude oil. The basic fuel price is influenced by two primary factors: the dollar price of crude oil traded on international markets; and the rand/dollar exchange rate. Volatility in both of these variables has historically had a significant impact on the rand denominated price of oil (see Figure 4-2).[105] As can be seen in Figure 4-3, domestic petrol prices closely track the rand price of crude oil.

Figure 4-3: Nominal crude oil and petrol prices, 1990-2011



Source: Author's calculations based on DoE (2011a), IMF (2011a)

Note: The petrol price is for 93 octane lead replacement petrol (leaded until December 2005) sold in Gauteng.

Table 4-1 shows the composition of petrol (diesel) prices in December 2010: the basic fuel price comprised 51% (59%), taxes and levies 30% (30%), and retail and transport margins 19% (11%), respectively. This means that a 10% increase in the crude oil price translates into an approximately 5% increase in petrol and diesel prices.[106]

Table 4-1: Composition of petrol and diesel prices, December 2010

Price component	Petrol	Diesel
Basic fuel price	51%	59%
Taxes & levies	30%	30%
Retail & transport margins	19%	11%

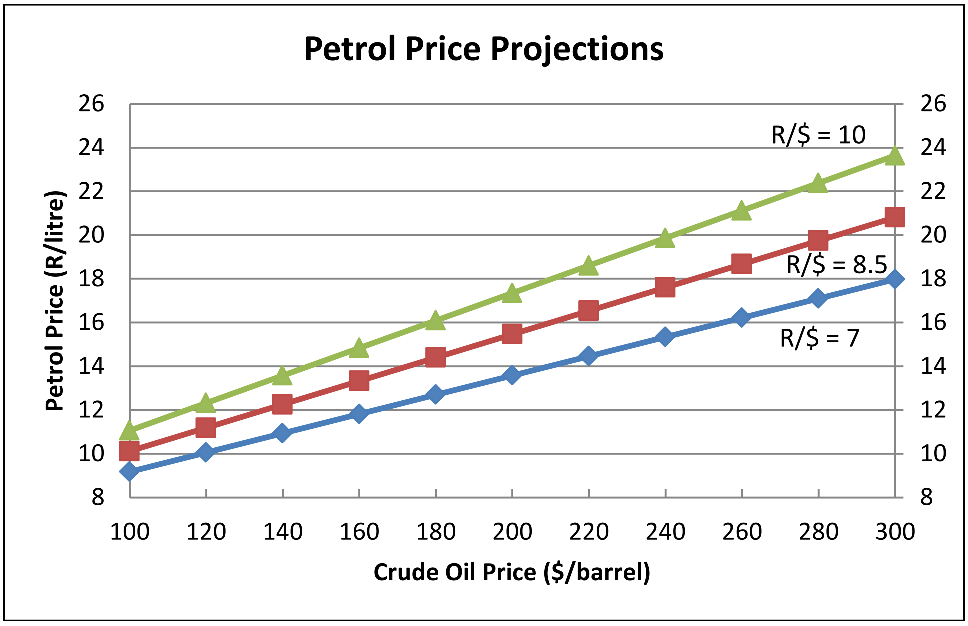
Source: SAPIA (2010)

Figure 4-4 presents projections of the domestic petrol price in rands per litre based on variations in the international crude oil price, for various levels of the rand/dollar exchange. The calculations assume a fixed international refining margin, and fixed domestic fuel levies and retail margins based on actual figures from December 2010 provided by SAPIA (2010). At an exchange rate (R/$) of 7.00 and an oil price of $120 per barrel, the petrol price is approximately R10 per litre (as was the case in July 2011). If the price of oil were to rise to $200 per barrel but the exchange rate remained

[105] Notably, the oil price shocks of 1973 and 1979 were somewhat muted in rand terms, thanks to the relative strength of the rand then (which was supported by a high gold price). The rand oil price in 2008 was almost double that of 1979 in real (inflation-adjusted) terms.
[106] Since the BFP includes benchmark international refining costs, it does not adjust fully to crude oil price changes.

unchanged, the petrol price would be nearly R14 per litre. At a price of $300/barrel and an exchange rate of R10/dollar, the petrol price would be almost R24/litre.

Figure 4-4: Petrol price projections



Source: Author's calculations.

The most immediate, direct effect of an oil price shock will be a rise in the prices of liquid transport fuels (petrol, diesel, jet fuel and heavy fuel oil), paraffin, LPG and other oil-based petrochemical products. Additionally, there will be an indirect price effect via transported commodities, especially food products. Thirdly, and perhaps most importantly, there is a likelihood of second round effects on inflation expectations and associated wage-price spirals, which have the potential to extend the inflationary impact beyond the initial once-off rise.[107]

National income, measured by GDP, will suffer a negative income effect as the oil import bill rises. The magnitude of this impact will depend on the proportion of household consumption expenditure devoted to petroleum products (Hamilton, 2009). GDP will contract further to the extent that world demand for South African exports is depressed, although this may theoretically be offset partially, wholly or even to a greater extent by rising revenue for exports of gold and coal, at least temporarily (Dagut, 1978: 26-27). If the monetary authorities raise interest rates in order to contain inflation within the target range (currently 3-6%), household and private debt service costs will rise, and the appetite for new debt will decline, thereby dampening consumer spending and private investment and ultimately reducing GDP. Furthermore, oil shocks can be expected to generate increased volatility in and uncertainty about inflation, interest rates, exports, and the exchange rate, and therefore could undermine confidence, consumption and investment. As a result of these factors as well as rising production costs, labour demand is likely to fall and the unemployment rate to rise. On a sectoral level, employment impacts of an oil price shock will largely follow from the output effects and changes in relative prices, and will also be partly determined by factors such as wage (in)flexibility. In some industries the higher cost of fuel could encourage a degree of substitution of

[107] A once-off fuel price rise will result in a higher rate of consumer price inflation for 12 months, since inflation is measured as the year-on-year percentage change in the consumer price index. Continued fuel price increases will extend the period of higher inflation.

labour for machine capital, especially where the latter relies directly on petroleum fuels, but this is unlikely in the short term.

A transitory oil price spike would not generally be expected to have major long-term consequences. However, a sustained oil price shock would set in motion a series of behavioural adjustments on both the supply side and the demand side in the medium to longer term. On the supply side, one can anticipate a possible substitution of alternative energy sources such as coal- and gas-to-liquid fuel conversion and biofuels. Furthermore, one can expect structural changes in the economy away from energy-intensive sectors and towards higher labour intensity of production (Dagut, 1978: 31). On the demand side, the behavioural responses of households and businesses will depend on the magnitude of relative price changes as well as the extent to which they regard an oil price shock as temporary or permanent (Fofana, Mabugu & Chitiga, 2008: 12). A lasting oil price shock will induce greater energy efficiency and conservation by both producers and consumers. However, in the short to medium term demand for oil tends to be highly inelastic as most oil-burning capital equipment and appliances cannot be substituted for immediately (Nkomo, 2006: 14). In the longer term, there is likely to be a shift towards less oil-intensive capital equipment (Dagut, 1978: 26), such as electric trains and vehicles and even a new approach to spatial development. Positive responses such as these are dealt with Chapter 5. The way that South Africa has been affected by oil price shocks in the past is discussed in the Section 4.1.2.

Physical shortages of oil

Once world oil production begins its terminal descent, the price mechanism will function to reduce demand for oil to bring it in line with annually diminishing supplies. In addition, less energy will be available (from oil) to do work in the economy each year, which in turn implies in the absence of efficiency gains that economic activity will be curtailed. More specifically, since oil is used primarily for transport fuels the mobility of people and goods will be progressively constrained, at least until sufficient efficiency and substitution measures are adopted. People will drive less for leisure purposes and fewer goods will be transported into and around the country. The impacts of fuel shortages would clearly be most severe for those sectors or regions of the country that are highly dependent on both oil and its derived products. If the shortages are sufficiently large and persistent, vulnerable sections of the economy could be paralysed, at least in the short term. In the longer term, the economy will have to restructure to adapt to declining petroleum supplies: fuel intensive sectors and activities will shrink.

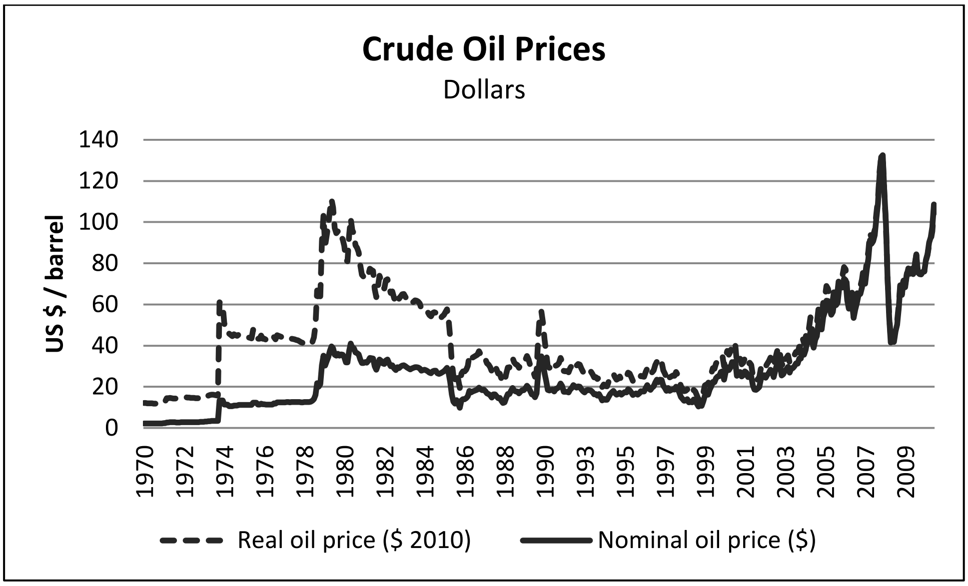
4.1.2 Historical impact of oil shocks

The conventional view is that there have been four international oil price shocks in the post-World War II era: 1973-4; 1979-80; 1990; and 2007-2008 (see Figure 4-5). These shocks each involved at least a doubling of the oil price within a year or two.[108] In real dollar terms, the oil price in 2007/8 briefly exceeded the maximum level reached in 1980, which was the previous highest level; the 1974 and 1990 local maxima were substantially lower. The origins and nature of each shock and its impacts on South Africa are discussed briefly in the following subsections.[109]

[108] The dollar price of oil rose by 140% between December 1998 and December 1999, which could be construed as an oil shock. However, at least part of this rise was a correction back towards the longer run trend following the aftermath of the Asian Financial Crisis of 1997, which depressed the oil price below the long-term average. The 1999 price rise is not usually regarded as an oil shock (see Hamilton, 2009). In addition, the oil price trebled between 2003 and 2006, but this was a more gradual upward trend and therefore is not interpreted as a (sudden) shock. A 'reverse' or negative oil shock occurred in 1986 after OPEC flooded the international market with oil.

[109] After plunging from a high of $147 per barrel in July 2008 to $40 per barrel in December that year, the oil price once again rose sharply to a sustained level over $100 for most of 2011. Most if not all of this price

Figure 4-5: Nominal and real monthly average dollar oil prices, 1970-2010

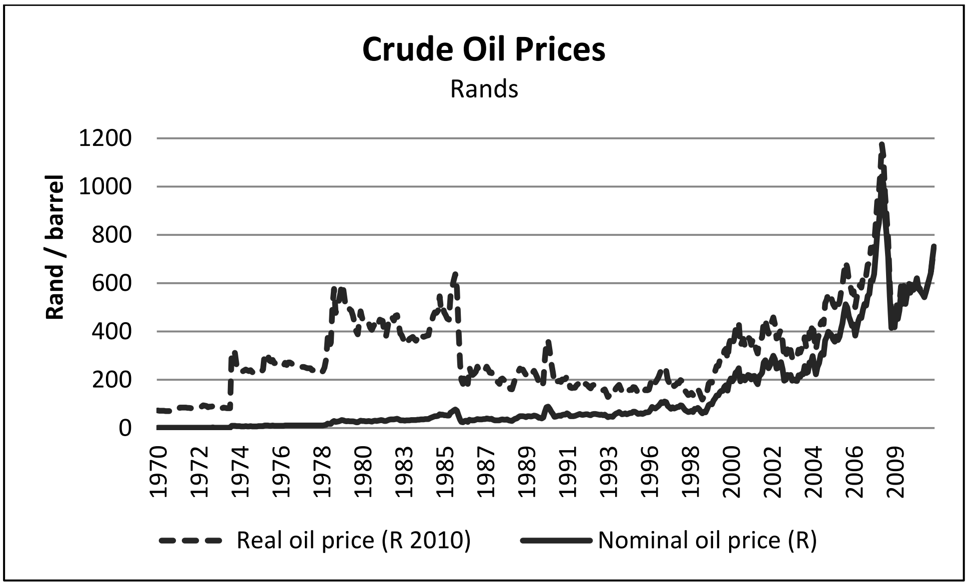


Source: IMF (2011a)

Note: The real oil price is the nominal price deflated by the US consumer price index.

In rand terms, the oil price shocks identified above were all very significant (see Figure 4-6). In addition, the rand price of oil rose 41% in 1985 as a result of a rapid depreciation in the rand exchange rate. Another shock arguably occurred in 1999, when the rand price of oil rose by 150%. In real terms, the 2007/8 maximum was nearly twice as high as the price attained in 1980, thanks mainly to the much weaker exchange rate.

Figure 4-6: Nominal and real monthly average rand oil prices, 1970-2010

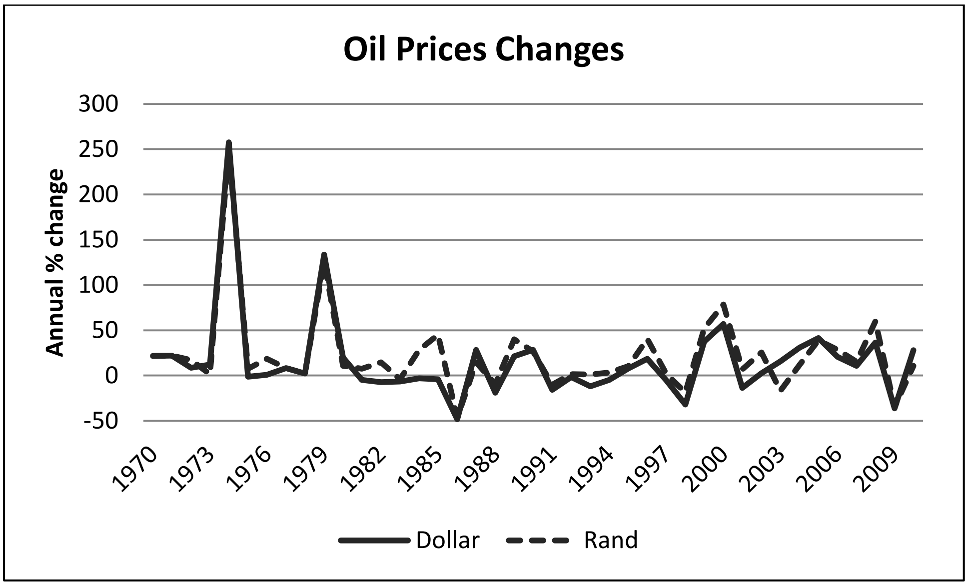


Source: IMF (2011a) and author's calculations

increase can be viewed as a correction of the foregoing price plunge, which resulted from the financial crisis and ensuing 'Great Recession'; thus it is not analysed as a separate oil shock here.

Figure 4-7 displays the annual percentage changes in crude oil prices, denominated in dollars and rands. The 1973/4 shock clearly stands out, as oil prices rose by 250% in one year. In 1979/80, the price rose by approximately 130%. The 1990 spike hardly shows up because the price rose and fell within one year. Figure 4-7 clearly shows the cumulative nature of the 2007/8 shock: the annual percentage increase in dollar oil prices did not exceed 40% between 2004 and 2008, but cumulatively the price rose 230% over 5 years. In rand terms, the oil price rose by 52% in 1999 and by 78% in 2000; the corresponding dollar increases were 38% and 57%, respectively.

Figure 4-7: Annual percentage change in oil prices, 1970-2010



Source: IMF (2011a) and author's calculations

The first oil shock, 1973-4

The first oil shock was catalysed by the Arab-Israeli war, which resulted in various Arab oil-producing nations placing an embargo on oil exports to the Unites States, the Netherlands and South Africa, which were seen as strongly pro-Israel. In addition, the Organisation of Petroleum Exporting Countries (OPEC) asserted its oligopolistic power in the oil market by colluding to reduce production volumes by 5% and thereby collectively setting the price (van der Merwe & Meijer, 1990: 6).[110] The oil price rose by a factor of nearly four, from about $3 per barrel prior to the war to around $11.50 per barrel in 1974 (see Figure 4-5), and stayed at this level until the next shock in 1979.

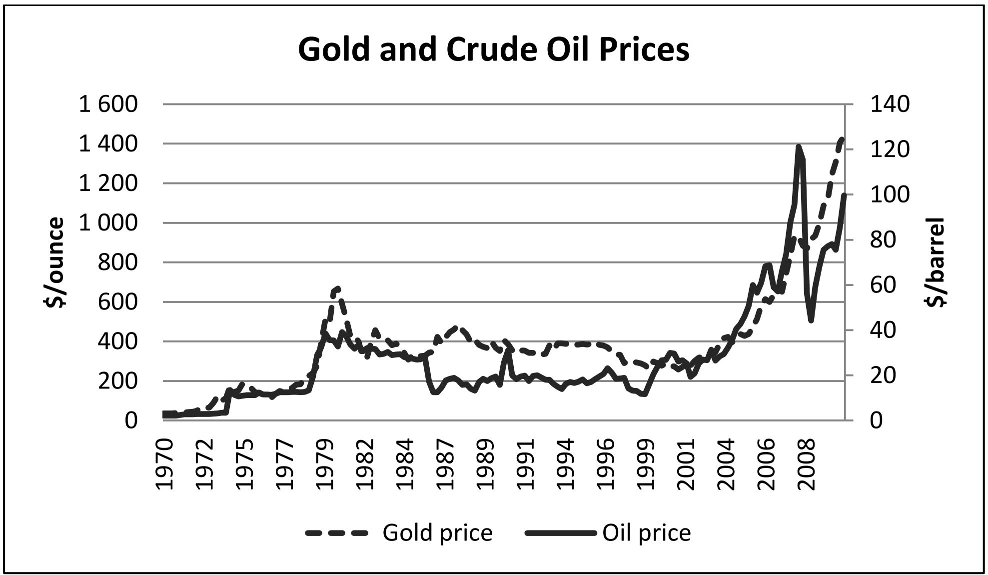
This first oil shock had severe repercussions for many of the advanced industrial economies, including sharply rising producer and consumer prices – which induced a wage-price spiral – and a recession; hence the term 'stagflation' entered the lexicon. Subsequently, developing countries suffered from the decline in world trade and a fall in primary commodity prices (Dagut, 1978: 29). In response to inflation and international monetary instability, the average gold price rose 66 percent from 1973 to 1974 (see Figure 4-8). However, the following year the gold price stagnated and by 1977 it had made a partial retreat. Dagut (1978: 30) claims that governments forced down the price of gold to bolster faith in the value of currencies and to restore stability to the financial markets.

From 1974 to 1976, South Africa's merchandise import bill rose on average by 13.8% per annum. The overall terms of trade received an initial boost from the rise in the gold price, but this was followed

[110] Hamilton (2009) argues that while demand pressures added to the upward pressure on oil prices (as argued by Barsky and Kilian, 2002), the supply reduction was the primary factor.

by a marked deterioration, especially in 1975. The rand/dollar exchange rate also weakened, and the inflation rate climbed from mostly single digits in 1972 to an annualised high of 17.8 percent in the final quarter of 1974, before easing again somewhat. More seriously, the GDP growth path altered, with the rate of growth in the three years following the oil shock averaging 1.73 percent, compared to an average of 5.32 percent in the preceding 19 years. According to Dagut (1978: 32), the "main lesson of the [first] energy crisis is that the adjustment process is a slow one."

Figure 4-8: Gold and crude oil prices, 1970-2011



Source: IMF (2011a)

Note: The gold price series is end of quarter values, while the oil price is quarterly averages (based on data availability).

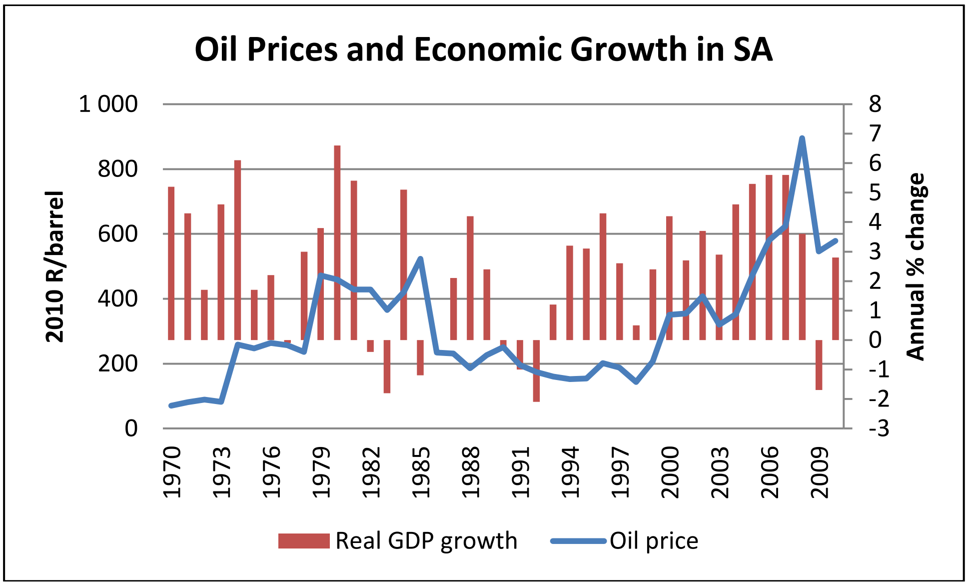
The second oil shock, 1979-80

The second oil shock occurred in the wake of the Iranian Revolution in 1978-79 and the subsequent outbreak of war between Iraq and Iran in 1980, which caused Iranian (and later Iraqi) oil exports to dry up altogether. Again, approximately 5% of world oil production was taken off the markets. As in the previous oil crisis, the magnitude of the price hike (almost a three-fold increase) was exacerbated by panic reactions and hoarding behaviour (van der Merwe & Meijer, 1990: 6). This oil shock gave rise to another serious bout of inflation internationally, especially in the heavily oil-dependent industrial nations. Rather than accommodating the inflation as in 1974, many central banks – notably the US Federal Reserve Bank – raised interest rates significantly to quell inflationary expectations. This action contributed to a severe international recession.

Worsening inflation and uncertainty gave rise to a massive increase in the gold price; however, as in the previous case, this proved unsustainable. Van der Merwe and Meijer (1990: 12) note that the "gold price increases effectively cushioned the adverse effects of the first two oil price shocks on the [South African] balance of payments and the 'real' economy", but that "these gold price surges inspired unduly optimistic views of the long-term prospects for the price of gold". Similarly, the average world prices of coal and uranium, two important energy-export commodities for South Africa, initially rose in response to the first two oil shocks, but soon retreated as a result of the induced supply response as well as falling demand from stagnating industrialised economies (van der Merwe & Meijer, 1990: 15). South Africa's terms of trade – with or without gold exports – worsened considerably in the wake of the second oil crisis (van der Merwe and Meijer, 1990: 15). The rate of consumer price inflation ratcheted up to double figures and became much more volatile between

1979 and 1981. Boosted by gold, real GDP grew robustly in 1980 (6.6%) and 1981 (5.4%), but thereafter declined precipitously after the Reserve Bank raised interest rates sharply to cool the economy, triggering a steep recession in 1983 (see Figure 4-9). Once again, therefore, the lesson was that the South African economy is not immune to oil shocks once the full adjustment process takes its course, but it also underscored the role played by monetary authorities and key export commodities.

Figure 4-9: Real oil price and real GDP growth, 1970-2010



Source: SARB (2011), IMF (2011a)

The third oil shock, 1990

The third oil price shock was triggered by the Iraqi invasion of Kuwait in August 1990. As a consequence of fear-driven stockpiling, and the elimination of Iraq and Kuwait's approximately 7 percent share of daily world oil production following the imposition of United Nations sanctions, the price of oil climbed by a factor of about two from $17 per barrel in July 1990 to an average of $35 per barrel in October (van der Merwe & Meijer, 1990: 4). However, the shock proved to be short-lived, with the price dropping to below $20 per barrel by February 1991.[111] The quick retreat in the oil price was thanks mainly to the rapid deployment of US and Allied military forces and their swift victory in the Gulf War in early 1991, which prevented the crisis from spreading and calmed sentiments in the oil markets. Again, this episode demonstrated the importance of expectations in determining the level of oil prices.

Some major industrialised nations (e.g. the US, UK and Germany) suffered a fairly severe recession around this time, which was exacerbated by – but not entirely due to – the oil spike. In contrast to the two previous shocks, the gold price did not react notably to the oil price spike in 1990, rising less than 10 percent and subsequently retracting partially. Van der Merwe and Meijer (1990: 14) attribute this to gold's diminished status as a safe-haven during the 1980s. At the time of this third oil shock, South Africa was already in the early stages of a downturn in economic activity as a result of several factors. These included, *inter alia*, weak international demand for SA exports coupled with sanctions, the early stages of an intensive domestic drought, a tightening monetary policy stance, and political uncertainty following the unbanning of the African National Congress early in 1990.

[111] The rand price of oil rose by 100% from R44/barrel in June to R88/barrel in October 1990, but fell to R48/barrel in February 1991.

Thus it is difficult to determine precisely the separate impact of the oil spike, although its transitory nature seems to have resulted in muted effects on the South African economy relative to the earlier shocks.

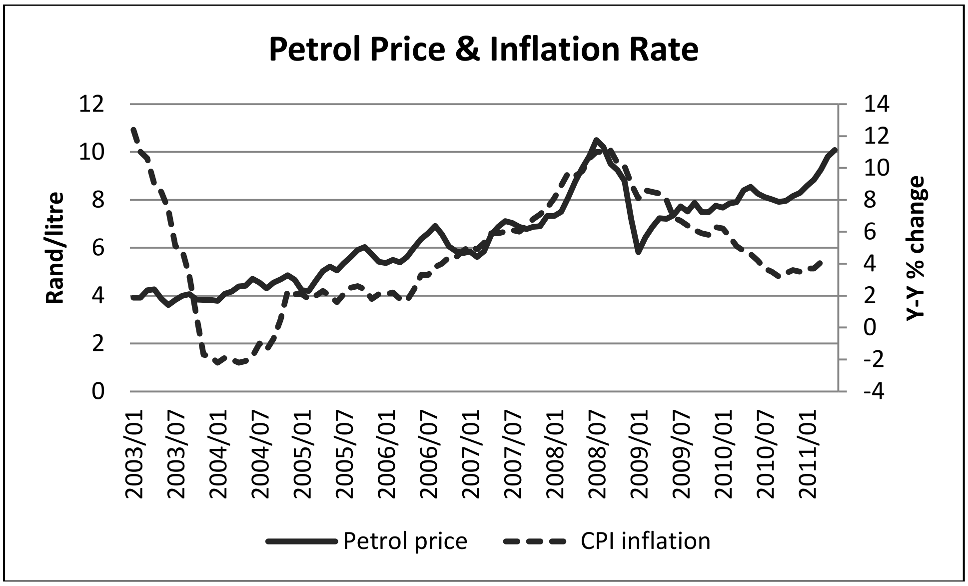
The fourth oil shock, 2007-8

After averaging roughly $20 per barrel between 1986 and 2003, the price of crude oil rose steadily for several years, reaching $64/barrel on average in 2006. It then spiked more dramatically, reaching a record high of US$147 per barrel in July 2008 (see Figure 4-5). Subsequently, the oil price fell sharply to about $40 per barrel by December 2008. There was intense debate in the media over the causes of the fourth oil shock. Most probably it was a combination of several factors. Fundamentally, the balance between supply and demand in the oil market gradually tightened between 2005 and 2008 (Hamilton, 2009). This is partly attributable to steeply rising demand on the back of robust global economic growth, especially in large emerging economies such as China and India. At the same time, crude oil supply essentially flattened out (as seen in Chapter 2). This stagnation in supply can be attributed to a range of factors, including: a lack of sufficient investment in oil production; disruptions to oil production in conflict-ridden areas such as Iraq and Nigeria; and the decline in production from mature oil fields. In addition, speculative activity by institutional investors taking advantage of tight conditions in the oil market most probably amplified the price rise, especially in 2008. A third contributing factor was a decline in the value of the dollar during much of this period, which pushed up the dollar-denominated price of oil and other commodities. Overall, Hamilton (2009) argues that the tight supply/demand balance was the major factor. Global production of all liquid fuels was essentially flat, while the price of crude oil rose from $38/barrel in 2004 to $97/barrel in 2008 (an average increase of 28% per annum). Had oil supplies continued to grow at the average rate for the period 1986 to 2004 (1.8% per annum) between 2005 and 2008, they would have increased by 4.5 million barrels per day. Thus the price of oil trebled in order to damp demand by a little over 5% – a similar order of magnitude to the 1973/4 and 1979/80 oil shocks.

The more gradual increase in the oil price between 2004 and 2006 did not appear to have much economic impact, at least initially. This was partly because of offsetting factors such as declining prices of (particularly Asian) manufactured goods, low interest rates and cost-reducing technological innovations. However, the rising oil price fuelled debt accumulation and inflation in many of the world's economies, which prompted central banks to initiate an interest rate tightening cycle from 2005 to 2007. Rising interest rates together with growing household expenditures on energy and food were major factors responsible for the bursting of the US housing bubble from mid-2006, which in turn triggered the financial crisis of 2008 (Hamilton, 2009).

In inflation-adjusted rand terms, the fourth oil shock was far more severe than the previous three shocks, with the price of oil reaching nearly R1 200 per barrel in mid-2008 compared with R500 per barrel in November 1979 and R537 in November 1985 following a currency crisis. South Africa was initially buffered to a degree from the upward oil price trend by a relatively strong currency, which was supported by robust commodity prices and domestic economic growth. However, in the latter half of 2008 the economy experienced rapid capital flight, with the result that the rand depreciated sharply from R7.63/dollar to around R10/dollar, thereby boosting the rand price of oil and other imported goods. Local liquid fuel prices rose from around R4 per litre in 2003 to over R10 per litre in the middle of 2008 (see Figure 4-10). This increase, together with rapidly accelerating food prices, was a major factor that drove the rate of consumer price inflation from negative territory in 2004 to breach the 6% upper end of the target range in July 2007 and to reach a peak of 11% in mid-2008. In response, the SARB raised its repo rate by a cumulative 5 percentage points between June 2006 and June 2008.

Figure 4-10: Petrol price and consumer price inflation, 2003-2010



Source: DoE (2011a), SARB (2011)

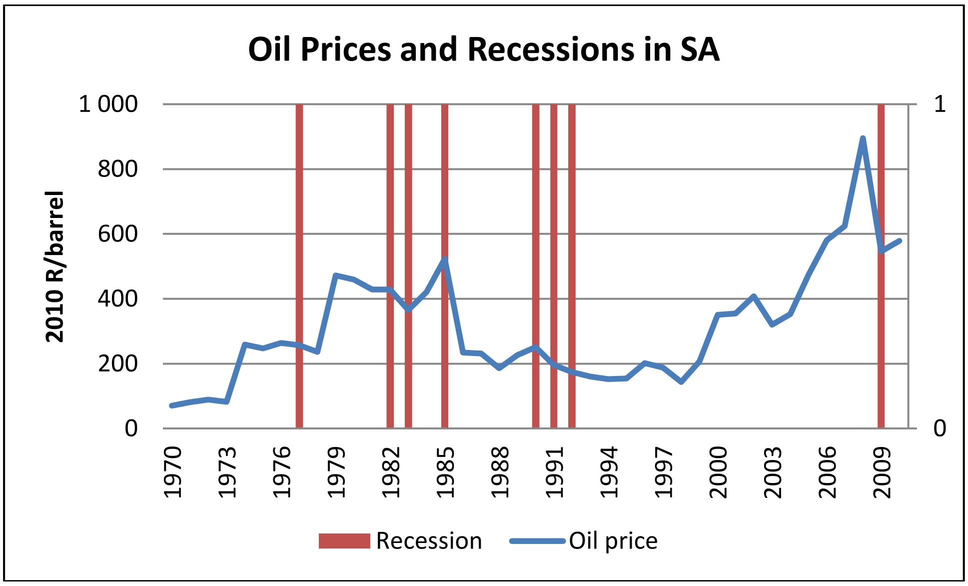
Note: The petrol price is that of 93 octane lead replacement petrol (leaded until December 2005) in Gauteng Province.

The domestic interest rate hikes, together with the depressing effect of the global economic recession on South Africa's exports, had a profound impact on the real economy. After recording a real GDP growth rate of around 5% between 2005 and 2007, in the last quarter of 2008 the economy sank into its first recession since 1992 (Figure 4-9). The contraction in the first quarter of 2009 (-6.4% at a seasonally adjusted and annualised rate) was the steepest drop in real GDP since the third quarter of 1984. This was followed by a contraction of -3.0% in the second quarter. Exports shrunk by a dramatic 55% in 2009Q1, while imports fell by 28%. Private consumption expenditure fell by 4.9%, although gross fixed capital formation grew by 2.6% thanks mainly to the government's infrastructure spending programme. Although the gold price remained relatively high, the price of platinum plummeted, mainly as a result of the global collapse in demand for new motor vehicles and hence catalytic converters.

Oil shocks and economic recessions

Figure 4-11 depicts real rand oil prices and years in which economic recessions took place (i.e. in which the annual rate of real GDP growth was negative). Four observations stand out. First, substantial oil price increases have historically neither been necessary nor sufficient conditions for economic recessions in South Africa. Not all recessions were preceded by oil price shocks: the 1985 recession (as well as the rapid exchange rate depreciation that forced rand oil prices higher) was triggered by political events; and the recession of 1990 to 1992 was caused by a number of factors, with oil prices possibly playing a minor contributing role. Oil prices in 2005-6 were higher (in real terms) than they were in 1979/80, but no recession ensued. Second, the oil price shocks of the 1970s and 2008 can arguably be identified as at least major contributing factors to the ensuing recessions, mainly via their impact on global demand for South Africa's export commodities. Third, the economic impact of world oil price shocks appeared to occur with a time lag of around 2-3 years in the 1970s but about one year in 2007/08. It is notable that in the latter period (1) gold provided a much smaller buffer (see Figure 3-34) and (2) South Africa's economy was much more integrated into the global economy, which could have shortened the impact time lag. The historical evidence suggests that the indirect impact of oil shocks via the global economy seems to be more important than the direct impact on fuel prices in South Africa. As a corollary, there does not appear to be any specific "threshold" for oil expenditures as a percentage of GDP that triggers a recession in SA (see Figure 4-12), as has been suggested for the United States (Hamilton, 2009). Overall, this historical analysis indicates that there is no stable, tight temporal correlation between real rand (or dollar) oil prices and economic growth in South Africa, which implies that econometric models assuming linear relationships between these variables with fixed parameters would probably perform poorly and be of limited usefulness. Nonetheless, it appears likely that South Africa's vulnerability to global oil shocks has increased over time as a result of the country's re-integration to the world economy.

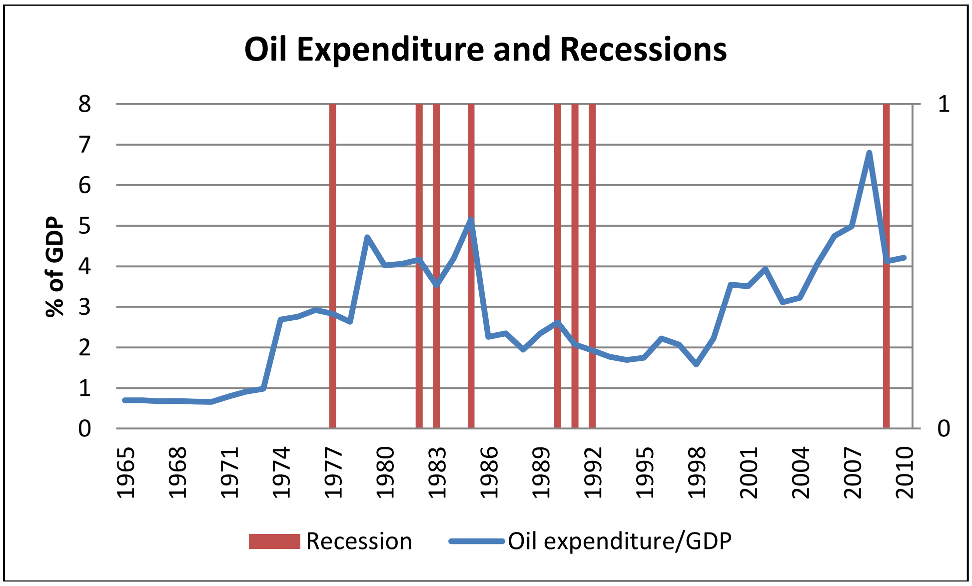
Figure 4-11: Oil price shocks and economic recessions in South Africa, 1970-2010



Source: Author's calculations based on SARB (2011), IMF (2011a)

Comparing Figure 4-11 (above) and Figure 4-12 (below), it is clear that the proportion of GDP spent on oil is highly correlated to the price of oil, which indicates the very low price elasticity of demand for oil.[112]

Figure 4-12: Oil expenditures and recessions in South Africa, 1965-2010



Source: Author's calculations based on BP (2011), SARB (2011), IMF (2011a)

[112] Hamilton (2009) reports the same relationship for the USA.

Historical shortages of fuel

As a result of the Arab Oil Embargo in 1973/4, shortages of fuel were experienced in South Africa, which led to long queues at filling stations and conservation responses by the government such as reduced road speed limits. In recent years, South Africa has experienced limited instances of physical fuel supply shortages, including the following episode:

> "During December 2005, ahead of the introduction of cleaner fuels, South Africa experienced a series of interruptions to fuel supplies. There were stock-outs at many locations throughout the country, including shortages of jet fuel at Cape Town International Airport (CTIA). These supply interruptions negatively impacted many sectors of the economy with the severity of the hardship ranging from relative consumer inconvenience to loss of business and reputation damage." (DME, 2007a: 17)

More recently, in July 2011 a strike in the chemical sector sparked panic buying by consumers and resulted in over 400 filling stations running dry in the country (Reuters, 2011). While not arising from shortages of imported crude oil, this episode once again demonstrated the serious impact of fuel shortages on economic activity and personal mobility.

4.1.3 Review of empirical models

A number of studies have investigated the impact of crude oil and/or refined petroleum fuel price increases on the South African economy, using different empirical methods. These are critically reviewed in the following paragraphs with a view to understanding the likely effects of declining world oil production and associated oil price shocks on South Africa.

One class of studies has employed time series econometric models. Based on the 1979/80 oil shock experience, Kantor and Barr (1986) estimated that a 10 percent increase in the price of petrol resulted in a 0.7 percentage point increase in consumer inflation (net of food prices) after seven months, although the simulated rate of inflation subsequently declined to below its starting rate. Swanepoel (2006) used a vector autoregression (VAR) model to analyse the impact of three external shocks, including oil prices, on South African rates of import, producer and consumer price inflation. Swanepoel (2006: 9-12) paradoxically found a negative response of non-oil import prices to an oil price shock. However, such a shock was found to have a (barely significant) positive effect on producer prices (but insignificant and negative after one or more lags), while the effect on consumer prices was statistically insignificant no matter what the time lag. These types of models are of limited usefulness for analysing the impact of global oil depletion, as they include too few variables and assume constant coefficients over time.

The Department of Transport (DoT, 2008) commissioned a study on the macroeconomic impact of rising fuel costs. The researchers employed a macro-econometric model of the economy using quarterly data and simulated the impact of a 25% per annum rise in the oil price, compared to the actual average oil price rise of 15%, for the period 1998 to 2008Q1. They found that on average annual terms: CPI inflation was 3% higher; average PPI inflation was 1.7% higher; real Gross Domestic Expenditure (GDE) growth was 1.5% lower; real GDP growth was 2% lower; total employment was 0.5% lower; the current account deficit (as a percentage of GDP) was 1.05% larger; real import growth was 2.3% lower; and real export growth was 5% lower under the high oil price scenario.[113] For every 1% increase in the oil price, the simulation results suggested that: CPI (PPI)

[113] The simulations did not take into account likely changes in demand for South Africa's exports resulting from the impact of the oil price rise on South Africa's trading partners, and hence probably underestimated the negative impact of the oil price shock.

inflation would have increased by 0.2% (0.17%); real GDE would have declined by 0.12%; real GDP would have fallen by 0.14%; total employment would have decreased by 0.04%; the current account balance would have deteriorated by 0.04% of GDP; real imports would have contracted by 0.17%; and real exports would have fallen by 0.32%. At a sectoral level, the simulations found the greatest negative impact on the manufacturing sector, the electricity, gas and water sector, and construction. While providing somewhat useful estimates which generally conform to theoretical expectations, the DoT model and results have several limitations. First, the model does not account for the indirect channel of oil shock impacts, as it keeps the "exogenous variables" (such as demand for South Africa's exports and capital flows) constant. Second, the model assumes a constant government deficit-to-GDP ratio, which historically has not been the case in the wake of oil price shocks. This assumption results in counter-intuitive estimates for the impact on government revenues, expenditure and debt levels. Third, the model assumes that a 1% rise in the oil price translates into a 0.81% rise in the petrol price, whereas the crude oil component of the petrol price did not exceed 52% in the period under consideration. Fourth, it is counter-intuitive that the agriculture and transport sectors are amongst the least affected, since these sectors are most heavily dependent on petroleum fuels as a proportion of their total energy use (see Chapter 3). Finally, this model shares the limitation of other time series methods in that it assumes linear relationships among the variables and that the coefficients remain constant over time, which might not be an accurate reflection of economic responses to oil price shocks.

A second category of studies have analysed quantitatively the impact of exogenous oil price shocks on the South African economy at a point in time, using input-output and/or computable general equilibrium (CGE) models linked to household survey data sets. The results of three such studies are summarised in Table 4-2. In the subsequent paragraphs, the major results of these studies are presented according to macroeconomic impacts on the balance of payments and exchange rate, consumer prices, real output (GDP), employment and wages, and household-level impacts on poverty and inequality.

McDonald and van Schoor (2005) employed a CGE model linked to a household survey data set to estimate the economy-wide and sectoral impacts of a 20% rise in the crude oil price. In their most realistic scenario, which allows for increases in the prices of other energy sources and energy-intensive commodities (such as coal, gold, and iron ore), they report: a 2.9% appreciation in the rand exchange rate; a 0.2% (0.3%) fall in GDP in the short term (long term); declining wages for both skilled (-0.9%) and unskilled (-0.6%) workers; rising import expenditures (0.8%) and export values (0.9%); and a fall in government dissaving as a percentage of GDP by 2.1%. McDonald & van Schoor (2005) find that the prices of energy intensive goods and services, including plastics, chemicals and transport increase, but by smaller percentages (under 2%) than might have been expected. This is attributed to the relatively small share of petroleum in total costs for most industries. In terms of sectoral winners and losers, they found that the petroleum industry suffered the most, given that crude oil accounted for half of its total costs. The greatest limitation of McDonald & van Schoor's (2005) model is that the overall CPI is held constant by assumption, as it acts as the numeraire for the model. This means that there is no monetary policy response to rising inflation, which historically has had a major impact on the economy following oil shocks.

Essama-Nssah et al. (2007) employed a disaggregated CGE model together with micro-simulation analysis of household survey data to analyse the macroeconomic and distributional impacts of a 125% oil price shock on the South African economy.[114] The oil price shock drives a real depreciation of the currency, which in turn serves to boost exports (including several manufacturing industries) and dampen imports and non-traded sectors (especially services).The major findings are that: GDP

[114] The results summarised here are from a variation of the experiment which includes spill-over effects of oil prices to the prices of imported chemical products and other commodities.

contracts by approximately 2%; household consumption declines by approximately 7%; there are relatively small increases in food and transportation prices, while the prices of a range of other goods and services actually decline as a result of reductions in demand driven by falling wages; and low- and semi-skilled employment declines, reflecting output changes, with labour shifting from (largely non-traded) services into agriculture and industry. High-skilled workers are found to gain, as they are not as susceptible to job losses and their consumption baskets are not skewed towards basic goods whose prices rise the most (food, transport and fuel). The poverty rate increases slightly (by 0.5 percentage points), as does the degree of inequality (the Gini coefficient rises by 1%).

Table 4-2: Review of empirical estimates of the impact of oil price shocks on South Africa

Authors	McDonald & van Schoor (2005)	Essama-Nssah et al. (2007)	Fofana et al. (2008)
Oil price shock (%)	20%	125%	50%
$/barrel increase	4	40	10
Domestic fuel prices	10.4%	68%	25%
Imports	0.8%	-10.3%	-4.6%
Exports	0.9%	9.1%	0.6%
Exchange rate (R/$)	-2.9%		--
Real exchange rate (R/FCU)[a]		22.4%	decrease
CPI	--	2.7%	-2.1%
Real GDP	-0.2%	-2.5%	-2.2%
Household consumption		-8.8%	
Employment		-2.7%	
Unemployment (% points)			10-35%
Wages - skilled	-0.9%	-15%	-15%
Wages - unskilled	-0.6%	0%	
Government dissaving	-2.1%		-22%
Sectors benefitting	exporters mining electricity	exporters transport equipment leather, wood	mining synfuels electricity
Sectors suffering	agriculture petroleum services	food basic chemicals services	agriculture manufacturing private services
Income inequality (Gini)		1%	0.7%
Poverty (headcount)		0.5%	1.2%
Equivalent oil price shock[b]	100%	100%	100%
Imports	4.0%	-8.2%	-9.2%
Exports	4.5%	7.3%	1.2%
CPI	--	2.2%	-4.2%
Real GDP	-1.0%	-2.0%	-4.4%
Income inequality (Gini)		0.8%	1.4%
Poverty (headcount)		0.4%	2.4%

Source: McDonald and van Schoor (2005), Essama-Nssah et al. (2007), Fofana et al. (2008)

Notes:

a. *FCU = foreign currency unit*
b. *In the lower part of the table, the impacts are standardised for a 100% oil price rise.*

Fofana et al. (2008) utilised a CGE model with an explicit energy component, combined with a micro-simulation household model, to analyse the macro and micro economic impacts of an oil price shock. Following a 50% increase in crude oil prices, they find that: real GDP contracts by 2.2%; consumer prices fall by 2.1%; imports decline by 4.6% while exports rise by 0.6%; the real exchange rate depreciates; skilled wages fall by about 30% in rural areas but by less than 4% in urban areas; the unemployment rate rises, especially for unskilled workers and females (between 20 and 35 percentage points). Inequality rises in the country as a whole (Gini coefficient rises by 0.7), but declines in rural areas. Poverty increases by both the headcount and poverty gap measures and the poorest suffer the most, especially in rural areas. Fofana et al. (2008) find that substitutes for crude oil, such as synthetic fuels and electricity, benefit from higher oil prices, while mining receives a boost from exchange rate depreciation. However, a fall in aggregate demand has a negative effect on all other sectors, and especially on agriculture, food, light manufacturing and private services.

Comparing the results of the three CGE-based studies, it is clear that they are mostly in broad agreement with one another. For example, they identify essentially the same set of sectors that suffer the most and benefit the most from an oil price shock. All three studies estimate an increase in exports, although McDonald and van Schoor (2005) find that imports rise, whereas the other studies find that imports contract. Essama-Nssah et al. (2007) find that CPI increases, while Fofana et al. (2008) estimate the opposite. Both of these studies find that income inequality and headcount poverty rise, although the magnitudes are more than twice as large in Fofana et al. (2008) for an equivalent oil price shock. All three studies find a negative impact on GDP, but the magnitudes are quite different for a 100% oil price increase. These differences could be explained by different assumptions made by the modellers, as well as the fact that the Essama-Nssah et al. (2007) study used data from 2003 whereas the other studies were based on 2000 data.

These CGE models make an important contribution to understanding the macroeconomic and distributive impacts of oil price shocks by incorporating economy-wide interactions and adjustments. A particular strength of the linked CGE-household models is that they allow analysis on three level, i.e. macro, meso (sectoral) and micro. Nonetheless, these models also have certain limitations. First, at a theoretical level CGE models assume competitive conditions exist in markets, allowing prices to adjust to balance demand and supply. In practice, the South African economy is characterised by a high degree of concentration, which is likely to impact on the way markets respond to shocks. In addition, a high degree of factor substitutability is often assumed, but may not be feasible in practice. Second, certain marked differences in the modelling results obtained for example by Fofana et al. (2008) and Essama-Nssah et al. (2007) indicate the sensitivity of CGE type models to some key assumptions, and also underscore the uncertainty involved in predicting the impacts of oil price shocks. Third, the models do not include the lagged, indirect effect of an oil price shock on the demand for South Africa's exports via its effect on the global economy; historical oil shocks have been associated with international recessions and reduced trade flows. Fourth, most of the CGE models account for short run effects but not longer term impacts. Fifth, none of the models addresses the impact of physical oil shortages on economic activity. Sixth, the models are mostly based on data from the year 2000, which was before the steep rise in oil prices that resulted in oil comprising a significantly greater share of domestic expenditure; thus the models likely underestimate the impacts of future oil shocks. Finally, there are some counter-intuitive results that are not fully explained, such as Fofana et al.'s (2008) finding of slightly larger increases in poverty and inequality in a scenario in which the government subsidises petroleum products.

Demand for petroleum products

A third set of empirical investigations relates to the price and income elasticity of demand for petroleum fuels. According to conventional economic theory, demand for fuel is hypothesized to have a positive income elasticity (i.e., when income rises, people buy more fuel, *ceteris paribus*) and a negative price elasticity (i.e. when the price of fuel rises, demand falls, *ceteris paribus*).

Furthermore, the level of new vehicle sales is hypothesized to influence the demand for fuel with a positive elasticity. It is useful to separate petrol and diesel demand, as the former is mostly used for passenger transport and thus depends on the disposable income of households, while the latter is used mainly for freight transport and productive activities (e.g. agriculture, mining and construction), and hence depends mainly on the overall level of economic activity (GDP). Theron (2008) provides a review of empirical fuel demand studies and also provides her own elasticity estimates. Theron (2008: 273) states that "[t]he evidence from the literature as well as the SA data is that the income variable is the most important determinant of fuel demand; the GDP growth rate in the case of diesel and real disposable income in the case of petrol. There is a negative relationship between the real prices and volumes sold, but this relationship is weaker than the income relationship." I applied the autoregressive distributed lag (ARDL) modelling approach to estimate price and income elasticities of demand for petrol and diesel for the period 1994 to 2008Q3.[115] The results conformed to theoretical expectations for the demand functions and were in line with previous estimates, but used a superior time series methodology. Key figures from the literature are summarised in Table 4-3. As mentioned earlier, however, the assumptions underlying these estimates (linearity and parameter constancy) might not hold in the longer term in the post oil peak era, as behavioural patterns are likely to undergo fundamental shifts.

Table 4-3: Price and income elasticity of demand for petrol and diesel in South Africa

		Short run		Long run	
Author(s)	Elasticity	Petrol	Diesel	Petrol	Diesel
Wakeford	Price	-0.17	-0.14	-0.52	-0.14
1994-2008	Income	0.16	0.94	0.51	1.41
BER (2005)	Price	–0.19		–0.62	–0.10
1984-2004	Income	0.10		1.00	1.36
Econometrix (2005)*	Price			-0.24	-0.14
1999-2004	Income			0.38	1.47
BER (2003)	Price	–0.21	–0.18	–0.51	–0.06

Source: Theron (2008) and author's estimates

*Note: * It was not stipulated whether these were long run or short run estimates, but they are closer to other long run estimates.*

Between 1995 and 2009, the average annual growth rates of real GDP and petroleum consumption were 3.3% and 2.1%, respectively. The growth rates were fairly closely coupled except between 1999 and 2001, and to a lesser extent between 2005 and 2006, periods during which the rand price of oil rose substantially (see Figure 4-13). The steep drop in petroleum consumption in 2008 preceded the recession, and again can be explained by the spike in the oil price.

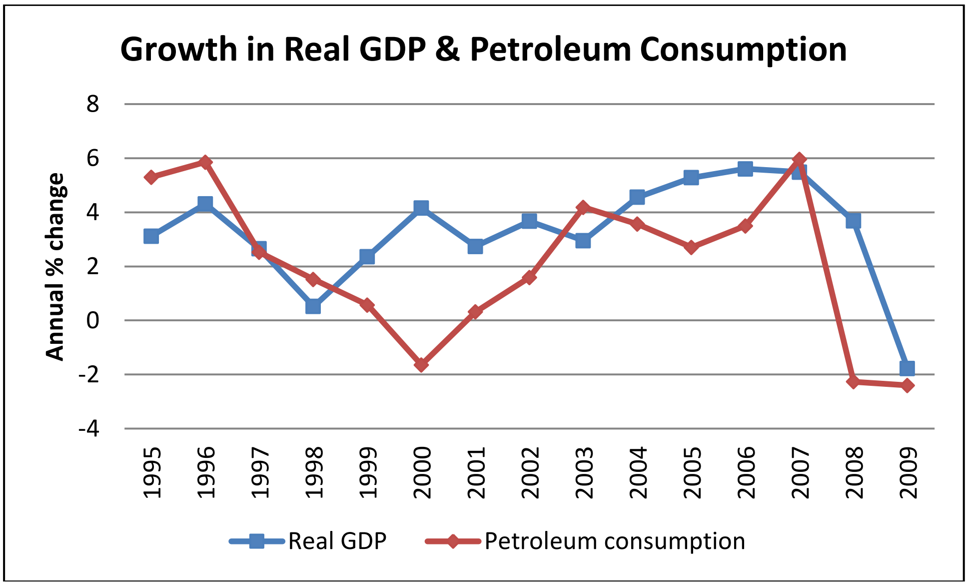
Impact of fuel shortages

Physical shortages of petroleum fuels might have somewhat different economic impacts to those of price shocks, but there is little empirical research on this issue. According to the DME (2007: 8), "[t]he cost of fuel shortages on the economy has been conservatively estimated at 273 c/l [cents per litre]." Furthermore, the DME found that a total disruption to economy-wide fuel supplies was estimated to result in losses to the economy of R1,340 million per day (in 2010 prices), which

[115] This period was determined by the availability of petroleum sales data from SAPIA (2009). SAPIA stopped publishing these data after September 2008; the Department of Energy was supposed to assume responsibility for publication of these data, but as of July 2011 had not done so. The details of the estimation methodology and results are contained in Appendix D.

represents 18% of GDP on an annualised basis. In accordance with the biophysical economics perspective, a lack of fuel means that there is less energy available to do useful work, and economic activity will be inhibited. Clearly, the sectors depending most heavily on road transport will be affected to a greater degree.

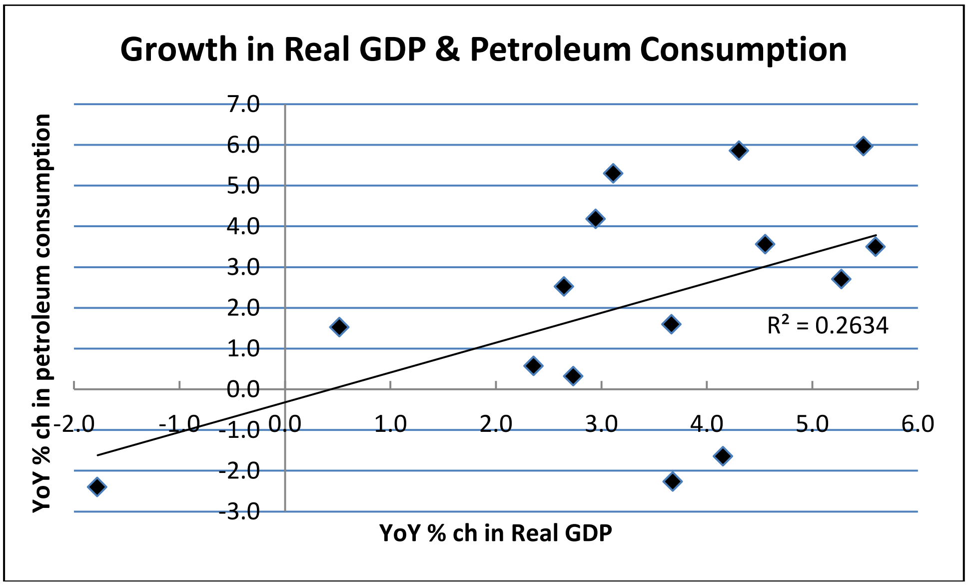
Figure 4-13: Growth in real GDP and petroleum consumption, 1995-2009



Source: Author's calculations based on SAPIA (2009) and SARB (2011)

Figure 4-14 below shows that the statistical correlation between growth in real GDP and growth in petroleum consumption has been rather weak, with an R-squared of just 0.26. This partly reflects the absence of other variables such as fuel prices.

Figure 4-14: Correlation between real GDP and petroleum consumption



Source: Based on SAPIA (2009) and SARB (2011)

4.1.4 Summary

The review of historical experience and various empirical estimates of the impact of oil price shocks on South Africa are broadly consistent. They demonstrate that rising crude oil prices generally result in: a depreciation of the exchange rate; a boost for some export commodities, at least initially; higher rates of producer and consumer price inflation; lower (or negative) growth in real GDP; falling employment and real wages; and greater poverty and inequality. The sectors most adversely affected include agriculture, light manufacturing and private services, while the sectors benefitting most in relative terms are domestic synfuels, electricity, and coal and gold mining. Demand for petroleum fuels is more responsive to income than to price, especially in the case of diesel. With this background, the likely socioeconomic impacts of global oil depletion on South Africa in the absence of proactive policy interventions are described below.

4.2 Scenarios for impacts of global oil depletion

As mentioned at the beginning of this chapter, the global peaking and decline in oil supplies is an unprecedented phenomenon, and there is thus considerable uncertainty about its likely impacts at both a global level (as noted in Chapter 2) and at a national level. The historical experience and review of empirical studies provide useful pointers about the likely impact of oil price shocks, at least in the short to medium term. In the next several years at least, the impacts of global oil depletion are likely to be felt mainly through rising (and volatile) fuel prices. A key difference in the future, however, is the likelihood of repeated and cumulative shocks occurring over a period of 10 years and more. Furthermore, as time progresses the likelihood of physical shortages will increase, perhaps on a sporadic basis initially (i.e. lasting for a few months at a time), but eventually becoming chronic in the longer term.

This section develops impact scenarios for the five subsystems of the socio-economy, based on the assumptions listed in the introduction to this chapter, restated here for clarity:

- global oil production begins to decline by 2-5% per annum, but oil export supply declines slightly faster on account of rising domestic consumption in oil exporting countries and possible resource nationalism;
- no prior programme of mitigation has been undertaken at either global or South African levels, and there is no co-ordinated international policy response;
- oil prices continue to follow a rising trend, but with significant volatility around that trend; and
- physical fuel supply disruptions and shortages are experienced from time to time.

These subsystem scenarios correspond to the global impacts described in sections 2.3.1 to 2.3.4, and assume a gradual 'oscillating economic decline' in line with the 'long descent' scenario outlined in section 2.3.6. Section 4.2.6 considers the possibility of a more rapid, systemic collapse in the South African economy, corresponding to the 'collapse' scenario developed in Section 2.3.6.

4.2.1 Energy

South Africa's energy system relies on petroleum fuels to meet nearly a third of final energy demand (see Section 3.1). This section considers the likely impacts of rising prices and declining volumes of crude and refined oil imports on South Africa's energy system.

Rising oil prices will gradually dampen demand and result in less petroleum energy being consumed in the country, especially in the longer term. The prices of other energy sources, especially those that are to some extent or other substitutable for oil, such as coal and gas, are likely to rise along with the oil price. These price rises will in turn put upward pressure on the price of electricity, since coal is the feedstock for about 90% of national power generation. Furthermore, because approximately one third of the coal feeding Eskom's coal-fired power stations is transported by truck, the costs of this feedstock will rise as diesel prices rise. Higher prices of refined diesel fuel will also raise Eskom's costs of running open cycle gas turbines (OCGTs), which are used to meet peak electricity demand. The costs of buying or manufacturing, transporting and installing alternative energy infrastructure, including wind turbines and solar panels, will also increase to some extent as a result of rising fuel costs. The rising cost of alternative energy sources illustrates their dependence on an economic infrastructure that is itself dependent on oil. Thus there will be added upward pressure on electricity prices, in addition to the pressure imposed by funding requirements for Eskom's new build programme.[116] However, the rising cost of fossil fuel energy will make renewable energy (RE) sources relatively more competitive and is likely to stimulate investment in this sector. Increased production of RE technologies could deliver economies of scale and learning, and hence reduce their prices, setting off a positive feedback loop. Thus over the longer term, one can expect a process of (partial) substitution of renewable energy for oil and coal. If economic conditions are deteriorating (as discussed in Section 4.2.4 below), however, the expansion of RE might not be rapid enough to offset declining consumption of fossil fuels, resulting in diminishing total energy consumption.

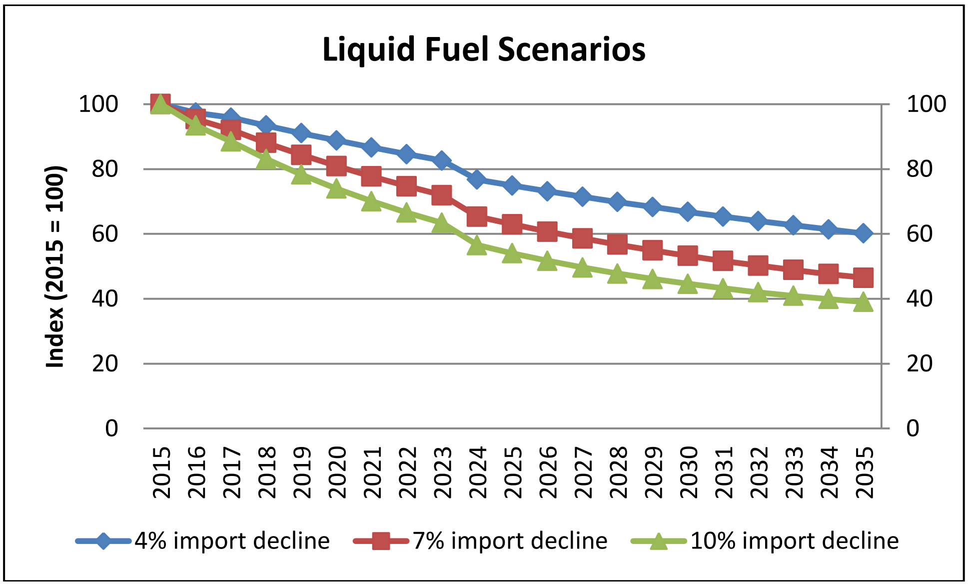
Acute physical shortages of oil products, which could arise from time to time owing to global supply interruptions, could have more serious consequences than gradually rising (or volatile) energy costs. Most immediately, Eskom's demand for diesel fuel to run its open cycle gas turbines will have to compete with transport, agriculture and other demand sectors for scarce diesel supplies. Perhaps most significantly, a sudden interruption of liquid fuel supplies could disrupt the flow of coal to power stations and thereby seriously compromise Eskom's ability to maintain sufficient power generation to keep the national electricity grid stable. Although not caused by liquid fuel shortages, a similar situation arose in early 2008 when problems in the procurement and transportation of coal resulted in insufficient stockpiles at some power stations, contributing to the electricity crisis which involved blackouts and load shedding. Power outages would in turn hamper the refining of petroleum fuels and their distribution through pipelines and at retail outlets, thus setting in motion a self-reinforcing feedback loop with very adverse consequences.

It is instructive to create scenarios for future liquid fuel supplies in South Africa, based on assumptions and evidence discussed in Chapter 2. As shown in Section 2.1.6, world oil exports peaked in 2005, and between 2006 and 2009 declined by an average of 1.8% per annum (p.a.). World oil production is expected to decline by between 2-5% in a mild scenario (Hirsch, 2008). Thus a conservative assumption is that world oil exports will decline by about 4-7% p.a. once global oil production begins to decline, which is assumed here to be in 2015. In a worst case scenario, if oil exporters withhold oil or resource wars result in production stoppages in some areas, the rate of decline could be as high as 10% p.a., at least in some years. The simplest assumption for South Africa's oil imports is that they will decline at a similar rate to world exports, which assumes that South Africa maintains its share of world oil imports, which was 1% in 2011. If anything, this is an optimistic assumption, as larger and richer nations are more likely to be able to out-bid South Africans for declining supplies of oil. For domestic synthetic fuel supply, it is assumed for this scenario that Sasol increases its 2011 level of production by 3.2% in 2014 as per its stated plans (Sasol, 2010) and maintains this level until 2035, assuming that its Secunda facilities commissioned in the early 1980s have an expected lifespan of about 50-60 years. Furthermore, it is assumed that PetroSA maintains its 2011 level of production for eight years, sustained by the newly found F-O gas field (PetroSA, 2010), after which it runs out of feedstock. In this scenario, biofuels do not make a

[116] The Integrated Resource Plan for Electricity Generation (IRP2010) is discussed in the next chapter.

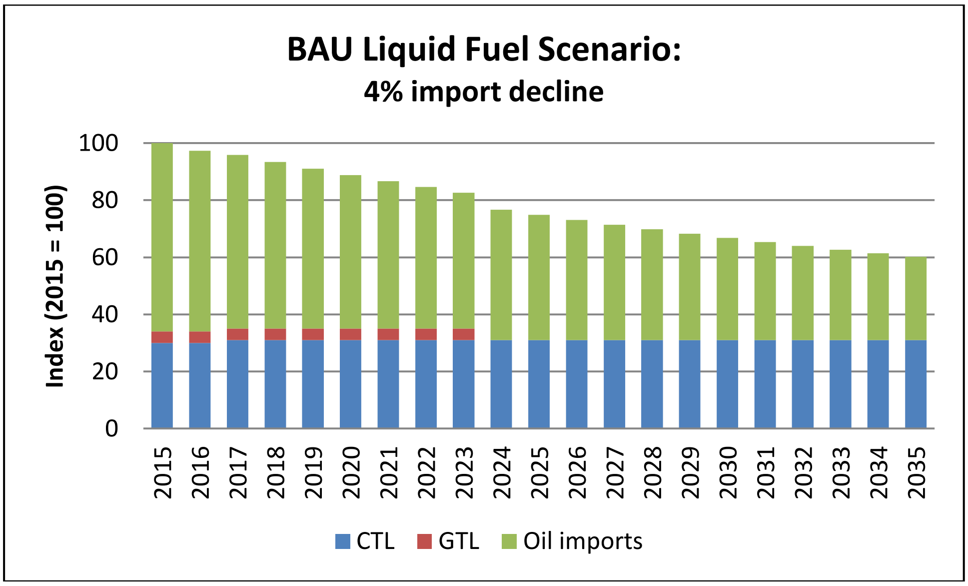
material contribution to liquid fuel supplies as a result of constraints on water and arable land. These liquid fuel projections are shown graphically in Figure 4-15. Assuming a 4% (10%) decline in oil imports beginning after 2015, total liquid fuel supply would be 75% (54%) of its 2015 level by 2025, and 60% (39%) of its 2015 level by 2035. Should the onset of global 'all oil' production decline occur sooner or later than 2015, the depletion profiles would simply be shifted earlier or later by the corresponding number of years. The relative contributions of imports and domestic fuels supplies are shown for the 4% decline scenario in Figure 4-16.

Figure 4-15: Liquid fuel scenarios under business-as-usual for various decline rates



Source: Author's calculations

Figure 4-16: Liquid fuel scenario under business-as-usual (BAU)



Source: Author's calculations

4.2.2 Transport

As shown in Chapter 3, transport is the sector with the greatest vulnerability to diminishing oil supplies. The impact on various modes of transport will depend on their relative oil-intensity. Airplanes are the most energy intensive, followed by cars, trucks and buses, trains and ships. The impacts of rising fuel prices and physical fuel shortages for passenger and freight transport are considered in turn, followed by a brief discussion of rising road maintenance costs.

Rising fuel prices will progressively weaken the affordability of various passenger transport modes. The costs of air travel, being the most oil intensive mode of transport, will be most heavily affected by oil price increases. Fuel comprises the largest share of costs for air transport (Heinberg, 2006: 48). Domestic short-haul flights are the least energy efficient and over a number of years some of these routes are likely to become uneconomic and hence terminated. As a result, small airports (e.g. in smaller cities like Bloemfontein, George and Nelspruit) will most likely experience falling traffic volumes and in the longer term could become commercially unviable and be disused. The overall trend for air travel will be towards larger planes flying fewer routes, to ensure higher occupancy and therefore lower fuel use per passenger kilometre (Gilbert & Perl, 2010: 7). Airlines will have to make every effort to cut costs, for example by shedding in-flight services. In the absence of a miraculous technological breakthrough in jet propulsion technology, the likelihood is that air travel will become increasingly unaffordable except for the very wealthy segment of society.

Rising fuel prices will also have a significant impact on road passenger transport. Motorists will respond to higher fuel prices with a range of behavioural adaptations. These will begin with reduced discretionary driving (e.g. for leisure and social purposes). Where motorised road transport is absolutely necessary for accessing employment, shops and schools, households will have to adjust by reducing spending on other items in their consumption baskets. In neighbourhoods or communities with strong bonds and high levels of trust, ride and car sharing arrangements could arise spontaneously. Over a number of years, a growing number of individuals might find that fuel costs for daily commutes exceeds their affordable threshold, and would then have to shift to one or more forms of public transport and/or non-motorised transport. On the positive side, reductions in the extent of road transport can bring several benefits. Lower traffic volumes should translate into a lower incidence of road accidents. Less traffic also means less pollution, including greenhouse gas emissions, other forms of air pollution (such as particulate matter), water pollution (from road runoff) and noise. Reduced pollution would in turn bring health improvements and lower health-care costs. Reduced traffic congestion would have economic benefits, raise fuel efficiency, and attenuate travellers' stress. Overall, reduced traffic would have a beneficial impact on human health and well-being, which might partially offset the inconveniences caused by restrictions on mobility.

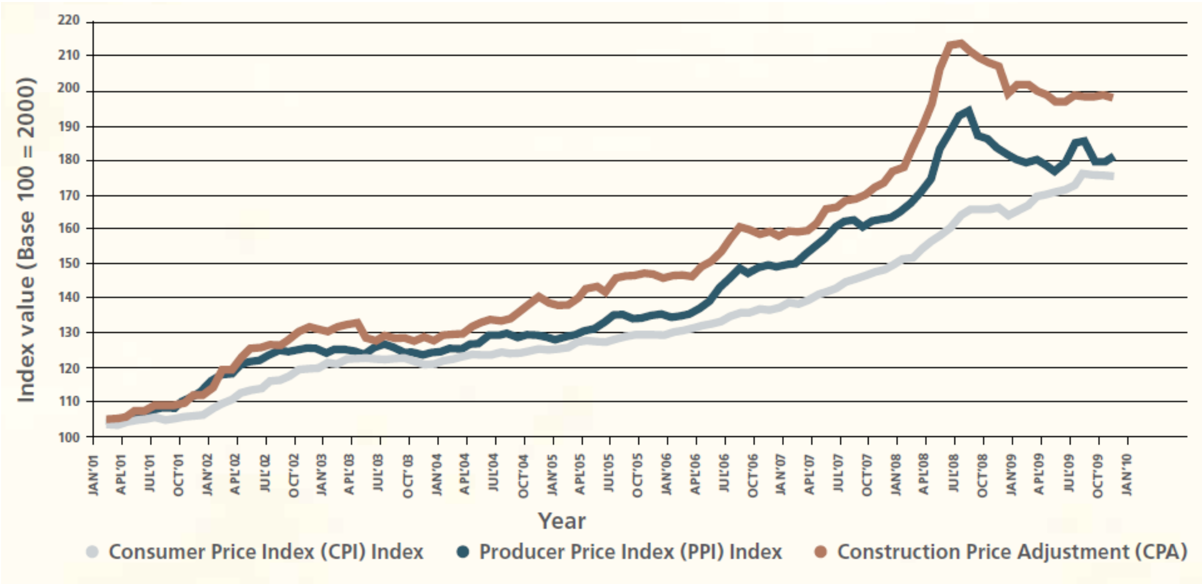
As some car owners sought alternative means of transport, there would be increasing demand for existing public transport facilities, resulting eventually in crowding of buses and trains if the capacity of mass transit was not increased. However, users of public transport vehicles that run on petroleum fuels, such as minibus taxis and buses, would also be affected by rising fuel prices since fares will rise accordingly. Most people using minibus taxis and other forms of public transport are currently from low-income households that are already financially stretched, and if fares became unaffordable their only fall-back would be to walk further distances or cycle if they could afford bicycles. Increases in fuel prices are likely to lead to a shift in patronage from minibus taxis to buses, as the latter are subsidised (DoT, 2008: 32). This could lead to protest action by elements of the taxi industry. South Africa's commuter trains run on electricity as opposed to diesel, but ticket prices are still likely to rise on account of the upward pressure on electricity prices noted in the previous section. Presently, very few South Africans use ships for passenger transport. In the longer term, passenger travel by ship might increase, at least relative to air travel, since ships are the most energy efficient means of transport (Gilbert & Perl, 2009).

Given the overwhelming dependence of freight movement on road transport, rising fuel prices will have a significant impact on the trend in freight and logistics costs. The CSIR (2010: 16) estimated that a tripling in the fuel price would raise logistics costs by 53% under conditions pertaining in 2008. Consequently, transport costs as a share of GDP would rise from 7.4% to 12.8% (CSIR, 2010: 17). Some industries and retailers might absorb a portion of the added freight costs internally, but in general higher freight costs will be passed along the value chain to final consumers in the form of higher retail prices for goods. A fuel surcharge could be added at every step in the distribution chain, from international to national, regional and local levels and from producers to wholesalers and retailers (Heinberg, 2006: 48). Businesses with a high degree of reliance on freight movement (i.e. where transport costs are a significant proportion of the final costs of goods) will find that rising fuel costs steadily erode their profit margins. A prime example is supermarkets, which might be gradually forced to source more of their products locally. For international trade, rising fuel costs will act like a tariff barrier, favouring local trade over long-distance trade (see Rubin, 2009). Being highly energy intensive, air freight is much more sensitive to fuel prices than other modes of freight transport. In the long term, costs of air freight may become prohibitively high, resulting in the collapse of markets for all but the highest-value goods.

Short term, sudden shortages of fuel could have a drastic impact on transport. For example, a sudden interruption of jet fuel supplies could have serious implications. The Department of Minerals and Energy (DME, 2007a: 21) warned that “indications are that there is not enough space in South African airports to park all airplanes that are, at any one time, heading for or in South Africa.” Thus if insufficient jet fuel were available at South African airports, some planes may have to land on large freeways that had been cleared of road traffic. For road passengers (whether using private or public vehicles), localised fuel shortages could result in disabling immobility. Shortages are likely to result in extensive queuing and possibly even conflict at filling stations, while hoarding responses are also possible. Persistent fuel shortages would in the longer term result in road vehicles and aircraft becoming stranded assets. In the case of freight, fuel shortages would result in disruptions to logistics chains. The longer the production chains involved, the greater the potential for disabling disruptions. Just-in-time delivery systems are particularly at risk of logistics failures (Rubin, 2009), with the result that shortages of various commodities could arise at the retail level. For example, a fuel truckers strike in the UK in 2000 interrupted the delivery of food stocks to supermarkets, whose shelves were going bare after just five days (Strahan, 2007: 13). In the longer term, businesses might have to adjust by modifying their logistics and delivery systems, for example by making use of larger storage facilities, which would add to costs and either erode profits or raise consumer prices, and by transporting their stocks by electric trains where possible.

Oil depletion also has implications for the maintenance of road infrastructure. As the price of crude oil rises, the cost of bitumen, a product of oil refining that is used for road surfacing, will also rise. Diesel is also used to power road-building vehicles and machinery. Bitumen prices rose from R2,000 per ton in 2003 to R3,500 per ton by the end of 2007 (DoT, 2008). According to SANRAL (2010: 15), a “spiralling cost of bitumen” along with rising fuels prices were major reasons underpinning the upward trend in road construction prices in the 2000s, considerably above the rate of consumer price inflation (see Figure 4-17). Diminishing affordability of road maintenance would lead to an increased rate of deterioration of road surfaces and “drastic increases in vehicle maintenance and repair costs” for companies and private vehicle owners, as well as an increase in road accidents (CSIR, 2010: 24). Similar concerns apply to the maintenance of airport runways, although with even more critical safety implications.

Figure 4-17: Road construction prices in relation to producer and consumer prices, 2001-2010



Source: SANRAL (2010)

In summary, rising fuel costs and physical shortages will restrict people's mobility and raise the costs of transporting goods (and possibly disrupt their flow). Since transport is so fundamental to so much economic activity, these potential impacts on the transport system will have ramifications for the wider economy and society that will be explored in the following three sections.

4.2.3 Agriculture

Energy, especially in the form of liquid fuels derived from oil, is used intensively in all stages of the commercial agricultural production and food distribution system, which is dominated by relatively large-scale, industrialised enterprises (see Section 3.3). This system is therefore highly vulnerable to oil price rises and supply constraints.[117] The potential impacts have serious implications for South Africa's national food security in the medium to long term.

Rising fuel prices will raise direct input costs for fuel and chemical products that use oil (and oil substitutes) in their manufacture, including pesticides, fertilisers and packing materials (see Figure 4-18).[118] In addition, rising transport costs will add to the prices of chemical inputs, and raise the costs of transporting produce to food processors, wholesalers and markets. If production costs rise faster than sales prices, then agricultural output will decline. Given the highly concentrated nature of the food processing and retail sectors in South Africa (Mather, 2005), individual farmers are not able to pass on all cost increases to consumers, which exposes farmers to possible bankruptcy if costs rise too much. For exporters, higher world commodity prices could offset higher input costs. Profitability

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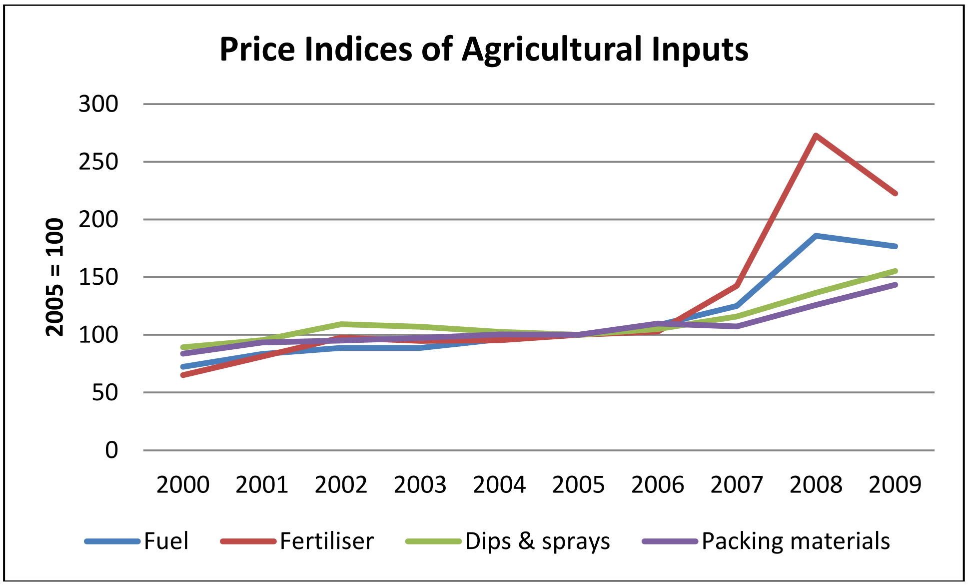
[117] In the 1970s, South Africa's agricultural sector was significantly sheltered from the effects of the two oil price shocks, for example by government subsidies on key inputs such as fertilizers. Presently, however, the commercial agriculture sector does not benefit from any significant government subsidies or protection.

[118] Fuel and fertilisers contributed 17.9% and 10.4%, respectively, to total expenditure on intermediate inputs in 2008/09 (DAFF, 2010). These two inputs recorded the largest price increases out of all intermediates between 2007 and 2008, at 49% and 91%, respectively. In 2008/09, fuel costs amounted to R12.1 billion, fertilisers R7 billion, dips and sprays R4.4 billion, and packing materials R3.8 billion, or 9.2%, 5.4%, 3.4% and 2.9% of the total value of agricultural output, respectively (DAFF, 2010).

would depend greatly on exchange rate movements.[119] The short-term volatility in oil prices will create a great deal of uncertainty for farmers, who will face difficult choices about whether to plant crops, and which crops to plant. The historical trend of consolidation of farms into larger units that was made possible largely by the mechanisation of farming is likely to reverse in a future of dwindling fuel supplies and growing financial pressures on farmers. Higher oil prices and shortages of oil will likely force farmers to revert to more labour-intensive and organic methods of production that rely less on petroleum based fuels and pesticides.

Figure 4-18: Price indices of intermediate goods in agriculture, 2000-2009



Source: DAFF (2010)

Any physical shortage of liquid fuels arising in rural areas would compromise the production of agricultural commodities. Since key farming operations, such as planting and harvesting, are highly time-dependent, fuel shortages at such critical times could be devastating to output. Fuel shortages would also curtail the distribution of farming products to processing facilities and markets in towns and cities. The likelihood of fuel shortages emerging in rural areas is greater than that in urban areas due to the location of South Africa's oil refineries in or near to just four major urban centres (Cape Town, Durban, Mossel Bay, and Sasolburg and Secunda near Johannesburg).

In the longer term, rising and volatile input costs and fuel shortages, combined with the impact of other factors such as soil degradation, rising water scarcity and cost, and climate-related variability and extremes of weather, are likely to cause an increasing rate of bankruptcy amongst farmers. Falling agricultural production volumes would erode self-sufficiency in certain products, thereby compromising national food security. Any further loss of farming knowledge and skills, in addition to what has occurred over the past several decades, would exacerbate this. Higher international food prices, in combination with a weakening exchange rate (resulting from pressure on balance of payments exerted by rising oil import costs and capital flight), would reduce the affordability of food

[119] McDonald and van Schoor's (2005) CGE model simulations of an oil price shock found that while agriculture suffers income losses overall due to the higher input costs, this impact is partially offset by higher export revenues following a depreciation of the exchange rate.

imports.[120] Finally, growing demand for biofuels will place additional pressure on arable land and water resources and is likely to further compromise food security.

4.2.4 Macro-economy

The historical record and empirical models on the impact of oil shocks reviewed in Section 4.1 provide a strong body of evidence from which to extrapolate the likely impacts of global oil depletion on the macro-economy, at least for the medium term future (the next 10 years or so). However, there are two key differences when looking forward. First, previous oil shocks were temporary, in that oil prices either stabilised or fell after a few months or at most a few years, while in the future one can anticipate an upward trend (with short-term volatility) in oil prices over many years. Second, since the onset of declining world oil production implies cumulative annual contractions in the supply of oil, physical fuel shortages will be a growing problem. As in the previous sections, the implications of both oil price increases and reductions in physical supply of oil are considered. In the neoclassical economics view, declining oil supplies imply that oil prices will rise, changing economic incentives and shifting patterns of production and consumption. According to the ecological economics perspective, declining oil imports means that (other things being equal) there will be less energy available each year to perform useful work in the economy. If no concerted mitigating policies are implemented, then there are two likely scenarios for the future. The first, which is discussed in this section, is that the standard oil shock impacts persist and worsen year after year, leading to a gradual contraction in economic activity, and probably greater cyclical volatility. In the second scenario, which is discussed in Section 4.2.5, various positive feedback loops accelerate the economic decline until critical thresholds are passed, resulting in a rapid and systemic collapse of the economy.

Key macroeconomic impacts

The initial impact of declining world oil production will be on the balance of payments, and will depend on the price elasticity of demand for oil imports. Should the percentage rise in the oil price be greater than the percentage reduction in demand, as seems highly likely based on historical demand inelasticity, then the oil import bill will rise. As discussed earlier, the value of some export goods will increase while others will decrease, depending on international demand responses. The greater likelihood is that South Africa's trade balance will deteriorate, with the result that the rand exchange rate will depreciate against currencies of stronger economies.

Rising oil prices will result in higher domestic inflation and higher imported price inflation, which will be compounded by the weakening exchange rate. Petrol accounted for 3.93% of the headline consumer price index (CPI) in May 2011 (StatsSA, 2011: P0141). Other contributions partially related to oil prices included "other running costs" for private transport (0.89%) and public transport (2.73%). In total, direct fuel costs comprise approximately 5% of the CPI. A 100% increase in the price of crude oil would translate into an approximately 50% rise in the price of petrol and diesel, and a 2.5% increase in the CPI (which would imply a 2.5 percentage point increase in the year-on-year rate of inflation for twelve months, assuming the price shock was permanent and once-off). However, the prices of many other goods and services are affected to some degree by petroleum fuel prices,

[120] The experience of the Democratic People's Republic of Korea (DPRK) provides an example of the possible impact of energy shortages on agriculture (Pfeiffer, 2006). After the fall of the Soviet Union in 1990, the DPRK's main source of oil imports (from Russia) was drastically reduced. In the early 1990s, agricultural production fell by nearly 30%, in line with the fall in petroleum consumption. Lack of diesel fuel contributed to an 80% decline in the use of farm equipment, while the proportion of the workforce employed in agriculture rose from 25% in the 1980s to 36% in the mid-1990s (Pfeiffer, 2006: 47). The decline in agriculture was compounded by a number of interacting factors, including soil degradation, infrastructure failures, and natural disasters, and resulted in chronic malnutrition and widespread starvation in the DPRK.

and thus additional second-round inflationary impacts would also be expected, which could be exacerbated by a rise in inflationary expectations. Since oil prices are expected to trend upwards as global oil production continues to decline, the inflation shocks will not be temporary, but rather ongoing and cumulative. Rising prices for basic goods and services could precipitate a wage-price spiral as workers bargain for higher wages and these are passed on by businesses to consumers.

Should the Reserve Bank continue to pursue the 3 to 6% inflation target, it will almost certainly increase the repo rate, perhaps in lock-step with the rising inflation rate. This in turn will dampen the demand for credit, consumption and investment expenditure. Demand for durable goods (especially automobiles) and discretionary services (e.g. tourism, leisure activities and catering) will contract the fastest and most severely. The multiplier effect transmits reduced spending to other sectors of the economy since some workers in the most vulnerable sectors will lose their jobs and hence reduce their overall expenditures (Hamilton, 2009). Once it is generally recognised that the world has passed peak oil production, business and consumer sentiment will deteriorate, further contributing to the decline in consumption and investment.

Asset prices are likely to plunge, for two main reasons. First, property prices will decline in real terms as interest rates rise, disposable incomes contract, and indebtedness forces more households into foreclosure and companies into liquidation. The values of residential and commercial properties that are located further from city centres and from public transport routes can be expected to decline relatively more rapidly. Second, international and domestic recession would likely lead to a decline in stock market indices as business profits fall and investor confidence wanes.

Declining consumption expenditure, net exports, investment, and asset prices will result in a contraction of GDP. The elasticity estimates reviewed in Section 4.1.3 suggest that for each 1% decline in petroleum fuel demand, GDP will need to decline by approximately 1% in the long run.[121] However, some of the dampening of demand will result from rising fuel prices. Historically, the business-as-usual rate of relative decoupling between petroleum consumption and GDP was about 1.6% p.a. If this were to continue, it would provide some cushion between falling petroleum consumption and economic activity. However, given that this decoupling took place mostly in periods of low fuel prices, the future rate of relative decoupling (even in the absence of mitigating policy interventions) could be somewhat higher as a result of behavioural changes such as conservation and efficiency initiatives and transport modal shifts. A conservative estimate is that a 3.3% annual decline in petroleum fuel consumption (corresponding to a 5% per annum decrease in oil imports, which constituted approximately 66% of petroleum demand in 2009) will correspond to on the order of a 1.5% annual decline in income (GDP). For aggregate petroleum use to decline by 50% over 20 years (see Figure 4-15 in Section 4.2.1), real GDP might conceivably have to decline by at least 20%. Contraction of the real economy would lead to net job losses (especially in the most vulnerable sectors identified in Chapter 3) and a rising rate of unemployment.

Government will come under increasing pressure to raise its expenditure on welfare and job creation in order to compensate for the decline in the economy. However, tax revenues from various sources will contract. If the fuel tax rate remains the same, then fuel tax revenues will contract by the same percentage as petroleum demand (e.g. 3.3% per annum according to the above assumptions). Secondly, higher oil prices will dampen international trade and therefore reduce customs and excise duties. Thirdly, as GDP contracts, so will income tax, company tax and value added tax (VAT) revenues. Falling tax revenues will in the short term force the government either to reduce spending, or to increase borrowing, or a combination of the two. Beyond a few

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[121] This is in line with Hirsch's (2008) estimate of a roughly one-to-one relationship between oil decline and GDP contraction.

years at most, however, increasing borrowing will not be sustainable and government expenditures will have to be reduced if hyperinflation is to be avoided.

Sectoral impacts

Declining oil imports will result in a changing structure of the economy: while many sectors are likely to contract, some will do so more rapidly than others, and some sectors may grow in absolute terms. Changes in relative factor input prices will result in changes in sectoral patterns of production, demand for labour, and wage rates. In general, the sectors with better prospects for withstanding or even benefitting from oil shocks are those that are less oil and energy intensive, those that produce oil substitutes, those that produce necessities rather than luxuries, and those that favour local production over international trade.[122] For example, manufacturing sectors that are geared towards import substitution and production for the domestic market will probably fare better than export-oriented sectors, especially in the longer run. Beneficiation of raw materials, including agricultural products and minerals, might receive a boost as global value chains shrink in response to rising shipping costs, although this could be offset by higher energy costs for energy-intensive beneficiation processes. Sectors that produce substitutes for imported oil, such as the synthetic fuels industry, coal mining, and renewable energy manufacturing, stand to benefit, as do sectors that manufacture less oil-dependent transport vehicles. Another sector that will benefit consists of services that are geared towards improving sustainability and reducing inputs, such as re-use, recycling and repair services that extend product lifetimes (see City of Portland, 2007: 43).

In the longer term, export-oriented sectors will suffer from higher transport costs and weaker international demand, which will likely offset short-term benefits from a depreciating rand exchange rate. Most vulnerable of all is the international tourism sector, which will likely contract dramatically as international air travel becomes progressively more expensive due to rising fuel costs and less affordable due to declining real incomes abroad. Inter-continental air travel might well become the preserve of the extremely wealthy if no adequate substitute for oil-powered aviation materialises (Gilbert & Perl, 2010: 1). Some South African citizens might travel more locally rather than visiting foreign countries, but in general local tourism will also suffer from higher transport costs. The automobile manufacturing sector will face diminishing demand as a result of rising fuel prices and declining disposable incomes. In the long term, energy-intensive mining activities will contract as a result of rising costs, resource depletion and reduced energy supplies. Construction is also highly energy intensive, including the production and transport of cement and other building materials. The heavy reliance on road freight in South Africa means that a wide range of goods prices are affected by oil prices; this, together will declining real incomes, will probably result in a gradual contraction of the retail sector. The household service sector could also experience large-scale job losses as middle-income households find their budgets squeezed by rising energy, transport and food costs. Finally, the adverse financial consequences of declining world oil production, as discussed in Chapter 2, will in all likelihood spell a substantial contraction in the finance, real estate and business services sector.

The progressive decline in the economy postulated above is not likely to be smooth, but is more likely to follow an oscillating pattern, with periods of partial recovery or stagnation punctuating the “long descent” (Greer, 2008). As noted in Chapter 2 (Section 2.3.4), the post-peak oil economy could transition through various phases, e.g. an age of ‘scarcity industrialism’ characterised by increased efficiency and conservation, followed by a ‘salvage economy’ (Greer, 2009). In the latter phase materials would be recycled from oil-dependent capital infrastructure that has become ‘stranded’, most notably internal combustion engine vehicles but also buildings in areas that have become depopulated owing to mobility restrictions.

[122] Since agriculture was discussed in the previous section, it is not included here.

4.2.5 Society

A progressive, sustained contraction in the economy, together with growing restrictions on mobility, will place great strain on South African society. This section discusses the outlook for poverty and inequality, household food security, human settlement patterns, national security, and social cohesion under the assumption of business-as-usual policies, i.e. a lack of concerted national planning and responses to global oil depletion.

Poverty and inequality

Changes in household poverty and inequality will largely be determined by the macroeconomic impacts of declining world oil production, which are likely to include economic recession, higher price inflation (especially for food and transport), rising unemployment, and falling real incomes.[123] These trends will all contribute to a rise in the incidence and depth of poverty. Those who are already poor will suffer the most as they spend a high proportion of their meagre incomes on food and fuel (including paraffin for cooking) and lack the requisite resources to adapt (City of Portland, 2007: 31). Those who lose their jobs are at the greatest risk of joining the ranks of the poor. On the other hand, rising costs of petrol and diesel have the greatest direct impact on middle income households, since poorer households cannot afford private vehicles. Pensioners who rely on fixed incomes and equity investments will find their real incomes eroded by the rising cost of living and falling value of equities. Tighter government budgets may constrain government from increasing the value of social grants to match the rate of price inflation, resulting in falling real incomes for the approximately 14 million citizens who depend on social grants (see Section 3.5.1). Municipalities are also likely to find their budgets under increasing pressure, both from the revenue side (if transfers from national government fall and defaults on payments of rates rise) as well as the cost side (e.g. rising expenditures on transport and road maintenance). Tighter municipal budgets would tend to negatively affect service delivery, compounding socioeconomic hardships. As indicated by the empirical models reviewed earlier, income inequality is also expected to rise as a consequence of repeated oil shocks. This is largely because low- and semi-skilled workers are more likely to lose their jobs than high-skilled workers (Essama-Nssah et al., 2007).

Household food security

In the medium term, household food security will deteriorate as rising food prices combine with falling real incomes to reduce the affordability of food. This will lead to increasing rates of hunger and malnutrition and growing demands on state food support systems. In the longer term, the physical access to food could also be compromised as a result of declining domestic agricultural production (see Section 4.3 above) and because fuel shortages and immobility will likely disrupt the distribution of food products to consumers in urban areas.

Settlement patterns

The direct consequences of increasing oil scarcity, such as rising transport costs and restrictions on mobility, as well as the indirect impacts via changing economic conditions, will have significant consequences for patterns of human settlement and migration. In the short term, most people will respond to rising transport costs by adapting as best they can where they currently live. In the medium term, higher fuel prices will incentivise people who have the means to move closer to employment opportunities, schools, etc., although adverse economic and financial conditions will make it increasingly difficult for people to sell their houses and relocate, especially those living in outlying suburbs. Poorer people (e.g. those living in informal settlements) face even greater

[123] According to Essama-Nssah et al. (2007:10), "we would expect the distributional impact of macroeconomic events to have three types of effects on the distribution of economic welfare: (1) endowment effects due to changes in the amount of resources available to individuals, (2) the price effects reflecting changes in the reward of these resources, and (3) occupational effects linked to changes in resource allocation."

constraints to relocation. Some businesses might also choose to relocate in an effort to be closer to suppliers, consumers or employees, depending on which makes the greatest difference to their bottom line. Thus new opportunities might arise in some neighbourhoods and towns that are geographically well situated.

Economic conditions are likely to deteriorate faster in rural areas than in urban areas in the early years after the global oil peak, since wealth, purchasing power and employment opportunities tend to be concentrated in urban areas. This is likely to result in continued (or possibly accelerated) rural-urban migration. The commercial viability of farming enterprises may be the biggest determinant of whether rural land-owners remain where they are or are forced to abandon their farms and seek opportunities elsewhere. The trend towards farm-workers being moved off farms and into rural towns and informal settlements could accelerate if farmers' ability to afford wages is undermined by rising input costs (e.g. fuel, fertilisers and pesticides), but this could be offset if some farmers find housing labour on their farms to be more cost effective than transporting labourers to and from towns.

In urban areas, the relative demand for housing near to city centres that offer mobility by walking, and neighbourhoods close to public transport corridors, will rise. Conversely, demand for residential properties in suburbs further from the urban core and public transport routes will decline. These changing patterns of demand will be reflected in shifting relative property values, which in general will increase the economic marginalisation of lower-middle income households. There will be a trend towards urban densification, which might be accelerated by an increasing average household size (see City of Portland, 2007). Should restrictions on fuel supplies be particularly severe, certain physical assets could become stranded. For example, many recent housing developments, including up-market residential properties and low-cost housing, have been constructed far from city centres and without established public transit facilities. The same applies to many large shopping malls that have been built to service out-lying suburbs. Informal settlements are likely to spring up on any available land closer to centres offering prospects of employment, since the very poor will be less able to afford to commute longer distances.

In the longer term, patterns of rural-urban migration are more likely to shift into reverse, with a decanting of urban populations into rural areas (Heinberg, 2005). This would likely be driven by a rising incidence crime and violence in crowded cities where social services (including provision of safe water) are deteriorating, and also by food shortages forcing people to return to the land to grow their own food. Thus most development of new housing after a decade or so is likely to take place in rural areas with resilient local economies.

National security

South Africa's rich endowment of mineral resources (summarised in Table 4-4) may conceivably pose a geo-strategic risk in terms of possible political intervention or even military invasion by foreign powers (e.g. the USA and China) seeking to secure access to these resources (Burgess, 2010). While SA does not possess significant oil or gas reserves (although exploration is continuing off the west coast), this country ranks eighth in the world in terms of national coal reserves, possessing some 3.5 per cent of the world total. Europe is already reliant on coal imports from SA, and in recent years India has begun importing large quantities of coal from SA, which is one of only a handful of coal exporting countries. With some experts forecasting a peak in global coal energy production in 2011 (Patzek & Croft, 2010), the competition for coal is set to increase markedly. SA has the world's fifth-largest deposits of uranium, another strategically important energy resource. In addition, SA possesses very large reserves of some strategically important non-energy minerals, such as platinum group metals (an essential ingredient in hydrogen fuel cells), manganese and chromium ore, and phosphate rock (see Table 4-4). In addition to the minerals listed in the table, a rare earth metal (REM) deposit in the Northern Cape Province is reputed to be very significant in world terms

(Burgess, 2010). REMs are used in electronic devices including electric vehicles and some renewable energy technologies such as wind turbines. Citibank estimated in 2010 that the value of South Africa's mineral reserves stood at R2.5 trillion (GCIS, 2011: 366).

Table 4-4: South Africa's endowment of mineral resources

Mineral	Unit	Reserves	% of world	World ranking
Alumino-silicates	kt	51	n/a	1
Antimony	t	200	4.7	4
Chrome ore	Mt	5,500	72.4	1
Coal[a]	Mt	30,156	3.5	8
Copper	kt	13,000	1.4	14
Fluorspar	Mt	80	16,7	2
Gold[b]	kt	3	n/a	4
Iron ore	Mt	1,500	0.9	9
Lead	kt	3,000	2.1	6
Manganese ore	Mt	4,000	80	1
Phosphate rock	Mt	2,500	5	4
Platinum group metals[c]	t	70	87.7	1
Titanium minerals	Mt	244	16.9	2
Uranium[d]	kt	295	5	5
Vanadium	kt	12,000	32	1
Vermiculite	kt	80,000	40	2
Zinc metal	kt	15,000	3.3	8
Zirconium	kt	4,000	19.4	2

Sources: GCIS (2010), Hartnady (2009), BP (2011), WNA (2011)

Notes:

- *Mt = million tonnes; kt = thousand tonnes.*

a. *Figures from BP (2011). GCIS (2011) estimates reserves at 27,981 Mt; Rutledge (2011) estimates reserves at approximately 10,000 Mt.*

b. *Figures from Hartnady (2009).*

c. *Burgess (2010) cites the percentage of world reserves as 75%.*

d. *Figures from WNA (2011).*

While some of South Africa's immediate neighbours do depend partly on her for energy, it seems implausible that they pose a significant military threat. On the other hand, the relative size and strength of South Africa's economy in the context of the southern African region means that this country attracts immigrants in times of regional crisis. During the 2000s, South Africa received a flood of refugees from neighbouring countries suffering from the effects of droughts, HIV/AIDS and especially Zimbabwe's economic collapse. Such immigration is likely to increase as the effects of declining world oil production and climate change on neighbouring populations intensify. This will place extra strain on already over-stretched social services and could aggravate social tensions.

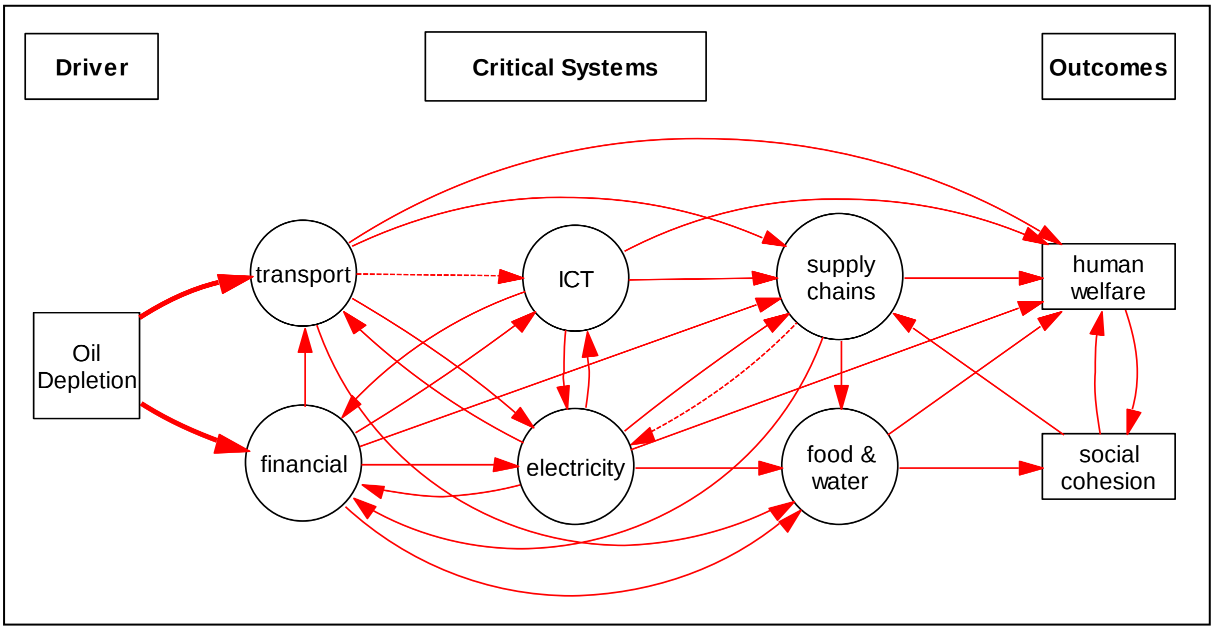
Social cohesion

In the scenario of progressive economic contraction, satisfaction of poor people's basic needs will increasingly be in jeopardy. At the same time, HIV/AIDS mortality will be rising and will be compounded by an increasing prevalence of joblessness and hunger. This in turn will place added strain on social services, the provision of which will be hampered as economic activity contracts, tax revenues decline and costs mount. Deteriorating service delivery, together with rising food and energy prices and constrained mobility, will spark an increase in social protests. The high levels of poverty and inequality, high levels of violent crime, and recent episodes of xenophobic violence, raise the possibility of large-scale class or ethnic conflict, especially in cities, and a possible break-down in the rule of law.

4.2.6 Systemic collapse

The possibility and mechanisms for a rapid and systemic collapse of critical systems and the globalised economy were discussed in Chapter 2 (Section 2.4.6). These global complexities, and their associated tipping points and positive feedback loops, are replicated in the South African socioeconomic system, which could therefore experience similar systemic crises or collapse. The national socioeconomic system is comprised of interconnected subsystems, such as energy, transport, communication, financial, water, sewage and food systems, each relying on interdependent critical infrastructures.

Figure 4-19: Critical system linkages



Key: bold arrow = primary causative force; solid arrow = short-term impact transfer; dotted arrow = medium/longer term impact transfer.

Figure 4-19 represents schematically the linkages between six of the major critical systems operating in the South African economy, as well as their connections to human welfare and social cohesion. Global oil depletion will impact most directly on the transport and financial systems (the latter via the global and local economies). The transport system affects electricity generation (e.g. via truck deliveries of coal to power stations), supply chains (distribution of components and final products), food (production, processing and distribution to markets), and in the longer term information and communication technology (by affecting maintenance of ICT infrastructure). The financial system affects all five other critical systems by facilitating economic investments and transactions. The electricity system enables the functioning of all the other systems, either wholly (e.g. ICT) or partially (e.g. food via irrigation, processing and cold storage). The ICT system is integral to the functioning of the financial, electrical and supply chain systems. Economic supply chains are critical to the food system and feed back to the health of the financial system and (in the medium term) to the electricity system (by supplying components required for maintenance). Human welfare is dependent on the transport, ICT, supply chain and food systems. The major determinants of social cohesion are human welfare and access to food. The state of social cohesion feeds back to human welfare and the functioning of supply chains. A major crisis in any one of the interlinked subsystems will be transmitted to other subsystems until it reverberates through the entire socio-economy. A collapse process may take just a few days in the event of an electrical grid failure or systemic banking freeze, resulting in widespread hunger, riots, looting and a breakdown of the rule of law (see Simms, 2008).

4.3 Potential national responses to global oil depletion

As mentioned in the introduction to this chapter, there are many uncertainties surrounding the future impacts of global oil depletion on South Africa. One of the main sources of uncertainty is the response of national governments around the world and in this country. Several authors have suggested three or four possible national response scenarios. These are briefly summarised and then evaluated in terms of their likelihood of occurrence in the South African context.

Heinberg (2004) proposes four scenarios for how countries might respond to oil depletion. In the "*last man standing*" scenario, governments engage in military adventures in attempts to control foreign oil resources. In the "*waiting for the magic elixir*" scenario, governments (and societies) maintain a cornucopian hope that technologies will be invented and commercialised that will ensure a smooth transition to alternative energy sources. In the "*powerdown*" option, societies undertake deliberate actions to relocalise their economies and reduce energy consumption while strengthening community relations. The final scenario sees the emergence of "*lifeboat communities*" that attempt to preserve the best aspects of civilisation in a context of growing resource scarcity and climate change impacts and a gradual or more rapid societal collapse. Heinberg (2004) essentially recommends a combination of powerdown with lifeboat communities.[124]

Based on historical case studies of countries that faced significant oil shortages, Friedrichs (2010) develops three hypotheses about how nations might respond to peak oil. The first strategy is "*predatory militarism"*, as practised by Japan between 1918 and 1945, when it embarked on military conquests in attempts to secure foreign oil resources. The second is "*totalitarian retrenchment"*, which occurred in North Korea in the 1990s following the demise of the Soviet Union, which led to a steep reduction of cheap oil imports. In this case, "[e]lite privileges were preserved in the face of hundreds of thousands of North Koreans dying from hunger" (Friedrichs, 2010: 4563). The third path of "*socioeconomic adaptation"* was followed by Cuba in the 1990s, also following the collapse of the Soviet Union and the consequent drying up of subsidised oil imports, and exacerbated by the US trade embargo on Cuba. Friedrichs (2010: 4563) reports that "Cubans relied on social networks and non-industrial modes of production to cope with energy scarcity and the concomitant shortage of food."[125]

Clearly, there is a considerable overlap in the scenarios or pathways suggested by these authors. In particular, Heinberg's (2004) "last man standing" is roughly equivalent to Friedrich's (2010) "predatory nationalism"; and "powerdown" is akin to "socioeconomic adaptation". A combination of

[124] North (2010: 586) refers to the "waiting for the magic elixir" strategy as "technocentric cornucopianism", while he suggests that the positive "lifeboat communities" scenario might be replaced with a negative fragmentation of society into xenophobic, autarkic communities or in the worst case, "warring localised tribes".

[125] Morrigan (2010) suggests "populist regimes" as another alternative governance response, but does not elaborate on the concept.

responses may be adopted by any one country (North, 2010). In recent years China has followed a different strategy to secure access to foreign oil resources, namely bilateral agreements with oil producing countries; often China grants large loans and/or builds infrastructure in these oil-rich nations in exchange for exclusive rights to oil reserves (Brautigam, 2010). This strategy might be termed "economic imperialism". It is useful to consider the likelihood of South Africa following each of the response scenarios.

As of November 2011, the stance of the ANC government with respect to the implications of declining world oil production appeared to be one of either lack of awareness or understanding of the magnitude and urgency of the issue, or a technocentric cornucopian belief that markets and technology will ensure a smooth transition to alternative energy sources.[126] Global oil depletion is not explicitly reflected in any major national policy documents, except very briefly in the National Framework for Sustainable Development and more extensively in the background reports for the National Transport Master Plan.[127] Should world oil production enter its decline phase soon, and should the impacts be severe (e.g. declining total net energy supply and a sustained contraction or cascading collapse of the global economy), this cornucopian stance will most likely devolve into one of the other response pathways discussed below.

Predatory militarism does not appear to be a viable option for South Africa. On the one hand, South Africa's military hardware is of a similar magnitude to the rest of the Southern African Development Community (SADC) combined (Harris, 2002), and has in recent years been modernised through the "arms deal" acquisition of new fighter aircraft, four corvettes and three submarines. However, le Roux and Boschoff (2005: 196) note that "the SA Air Force has too few transport aircraft to rapidly deploy even a small ground force" and the Navy's "strike craft lack the endurance to support a ground force". Thus it is doubtful whether SA has sufficient force projection to wrest control of oil and gas resources in its immediate regional neighbours Namibia[128] and Mozambique, let alone a wealthier country such as Angola. Moreover, given the strategic interest in the oil exports of such countries by major powers (especially the US and China), it seems likely that any aggressive intervention by South Africa could elicit a counter-response by such powers. On the other hand, South Africa is perhaps more likely to be a target for military intervention by large powers, such as the US and China, because of its large deposits of coal, uranium and other strategic mineral resources (see Burgess, 2010). South Africa also lacks the economic strength to pursue a strategy of economic imperialism in the region, since it cannot match the financial resources of powers like China and the USA.

There is no history of totalitarianism amongst the currently ruling political elite in South Africa, the country having enjoyed democratic governance since 1994. However, there are plenty of examples of dictatorial regimes in other African countries (some of which were previously democracies), notably Zimbabwe under the presidency of Robert Mugabe in the 2000s. It is not inconceivable that the new elite might engage in some level of authoritarian retrenchment in order to preserve their

[126] Some top officials in the South African government know about the concept of peak oil. The former Chairperson of the Association for the Study of Peak Oil South Africa (ASPO-SA), Simon Ratcliffe, briefed then-Secretary General of the African National Congress, Kgalema Mothlanthe, on 'peak oil' in 2006; as of July 2011, Mothlanthe was Deputy President of the Republic of South Africa. Dr Yaj Chetty, Communications Officer of ASPO-SA, engaged the Minister in the Presidency for National Planning, Trevor Manuel, on the issue of peak oil on a live radio programme in June 2011. The Deputy Minister of Transport, Jeremy Cronin, told the author in May 2011 that the majority of the Cabinet were "not convinced" that peak oil presented a problem (Cronin, 2011).

[127] All of the important and relevant policy documents are briefly reviewed in Chapter 5.

[128] In July 2011 the Namibian Minister of Mining and Energy announced that several billion barrels of oil had been discovered off Namibia's coast, and that production was expected to begin by 2015 (Sapa, 2011).

newly found wealth and power. It could be argued that the transfer of asset ownership to the new black elite under "black economic empowerment" policies, in the face of persistent poverty and growing inequality, represent the first steps along that path (see Mbeki, 2011). Furthermore, certain actions by the government of President Jacob Zuma between 2009 and 2011, such as the draft Protection of Information Bill, might be construed as steps towards increasing authoritarian control.

A variation on the totalitarian retrenchment scenario could be a populist regime that rides a wave of ethnic-based nationalism. The African National Congress (ANC) Youth League appeared to be heading in this direction in 2011 under the leadership of its president, Julius Malema. In its June 2011 elective conference, the Youth League adopted nationalisation (of land, mines and banks) as official policy, and indicated that it would seek to have nationalisation adopted by the parent organisation at the ANC's policy conference in 2012 (Mkokeli, 2011). This would set the scene for government expropriation and redistribution of property and wealth (and/or state sanctioned land invasions), which could result in the kind of economic collapse experienced by Zimbabwe in the 2000s.[129]

In a more positive scenario, the experience of a peaceful democratic transition in 1994 might be paralleled in the path of socioeconomic adaptation, involving powerdown and economic localisation, and drawing on community-centred values such as *ubuntu*. For this to take place on a country-wide scale might depend on the emergence of a strong, benevolent leader who emulates the role played by Nelson Mandela in the political transition of the 1990s. Chapters 5 and 6 present the elements of a proactive path of socioeconomic adaptation to global oil depletion led by national government, essentially amounting to a managed transition to a sustainable socioeconomic regime.

Should this positive pathway not materialise, a possible eventual outcome is a societal fragmentation as tightening resource constraints gradually erode the capacity of centralised government to maintain law and order, leading ultimately to a failed state. By default, power would devolve to the local level, and various communities would likely organise themselves in different ways. In small, rural communities in less densely populated parts of the country that have favourable agricultural conditions, one might see the emergence of lifeboat communities that seek to uphold localised democratic governance and preserve existing culture. However, these communities would likely attract streams of immigrants escaping from over-populated urban centres. In highly populated, poor rural areas (predominantly the former Bantustans), subsistence farming practices will most likely continue much as before, although declining state transfers would make survival in areas characterised by poor soils and limited water resources increasingly tenuous. In urban townships there would likely be xenophobic, autarkic communities run by local warlords and gangs. Many middle-income urban areas would likely experience a rapid decline in service provision, access to food and water, and safety and security. More affluent urban communities would likely use their resources to protect themselves as best they could with private security, although reliable access to water, food and energy could pose serious problems.

The essential point of these scenarios is to illustrate the fact that conscious policy choices and actions can be taken to avoid the worst outcomes and harness the opportunities for positive change that crises present.

[129] An alternative view of the Youth League's call for nationalisation, expressed for example by Friedman (2011), is that it is actually meant to serve the economic interests of a black business elite. If this were the case, then the nationalisation route might play out more according to the retrenchment scenario.

4.4 Conclusions

Unless it is mitigated by a co-ordinated international effort, the imminent decline in world oil production is almost certain to result in cumulative oil price shocks as well as growing physical shortages of oil. From a conventional economics point of view, oil price shocks can be expected to have a range of impacts on the financial and real economies, most of them negative. From an ecological economics perspective based on the laws of thermodynamics, declining oil availability implies that there will be less and less energy to do useful work in the economy, and hence the level of economic activity will contract.[130] While the peak and decline in global oil production is a completely novel event for the world, and therefore predictions regarding its effects are highly uncertain, historical experience and empirical models can provide the basis for reasonable scenarios of an oil-constrained future.

The theoretical review of oil shocks highlighted the complex transmission of higher oil prices to the domestic economy, as well as the indirect impacts via the global economy, in particular the demand for South African exports and international capital flows. The historical record shows that South Africa was by no means immune to international oil price shocks, although they tended to affect the economy after a time lag of between one and three years. This seems to be because the indirect impact of oil shocks via the global economy has been more important than the direct impact of higher fuel prices. All of the empirical studies that have analysed the impact of oil price shocks on the South African economy have indicated significant and mainly negative macro- and micro-economic effects, although they also point out that there are both winners and losers, at least in relative terms (and in some cases in absolute terms). In summary, both historical evidence and empirical models demonstrate that oil price shocks have negative impacts overall on GDP, inflation, unemployment, poverty and inequality.

Oil imports will become increasingly expensive, and at some point South Africans will consequently begin to reduce their demand for oil. National petroleum consumption could decline by a rate between 4-10% per annum, depending on the rate of declining net energy from world oil exports. Given the high dependence on petroleum based motorised passenger and freight transport, this decline will raise transport prices and constrain mobility. The agriculture sector is also highly dependent on oil products, so that some farmers might face bankruptcy, which could in turn compromise national food security. Without effective mitigation policies, the economy as a whole can be expected to contract by approximately 1.5-2% per annum for a more gradual rate of oil import decline, or possibly up to 5% per annum if the decline is faster. The cost of living will increase and most asset values will fall. In the worst case, the financial system could collapse if debt defaults reach a critical threshold.

For society in general, declining quantities and rising prices of oil imports implies a growing incidence and depth of poverty, rising income inequality and deteriorating food security. The most vulnerable socioeconomic groups include the unemployed (especially the youth who lack skills and experience), poorer public transport commuters, low-income pensioners and marginal farmers. Middle-income motorists will also be affected fairly severely, especially those living in outlying suburbs whose property values fall. The deteriorating economic conditions are likely to breed increasing social protests and possibly increased crime and violence. In the short term, rising fuel prices and economic distress could lead to an increase in the rate of urbanisation, while in the long term there is likely to be a reversal of the urbanisation trend as an increasing number of people seek to escape deteriorating conditions in cities and as more labour is needed to grow food on farms.

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[130] This is unless alternative energy sources can be scaled up sufficiently to offset the decline in oil, or economic activity can be effectively decoupled from energy consumption.

These subsystems are interconnected and interdependent components of a socioeconomic system, properties that resemble those of a complex adaptive system. A common feature of complex systems is that they require high rates of throughput of (net) energy to sustain their complexity (Tainter, 1987). Furthermore, complex systems are characterised by inter-linkages, tipping points and positive feedbacks, all of which mean that they are prone to large-scale and possibly rapid state changes. In particular, a sustained and cumulative reduction in energy inflows can lead to threshold effects, in which there is a fairly rapid collapse in the level of complexity. In concrete terms, increasing energy costs and declining petroleum supplies could at some point trigger a set of failures in the transport subsystem and the economy, which in turn could cascade into failures in the related systems of electricity, information and community technology, supply chains, and food production and distribution.

A range of possible national responses to global oil depletion drawn from the literature was interrogated from a South African perspective. It was concluded that predatory nationalism is unlikely to be a feasible option for South Africa given the small size of its military; conversely, however, this country's substantial mineral resources might become a target for intervention or acquisition by foreign powers such as the US or China. A totalitarian retrenchment is possible, whereby political and economic elites entrench their favoured positions with authoritarian repression, while allowing the majority of the population to sink deeper into poverty and possibly starvation. Nationalistic populism is also a possibility, but this would likely have disastrous consequences for the economy, following in the footsteps of Zimbabwe in the 2000s. In a third possible trajectory, more likely under a systemic collapse scenario, centralised government might progressively lose its ability to govern effectively, resulting in a fragmentation of society into conflicting ethnic groupings, along with possible lifeboat communities that attempt to preserve aspects of contemporary culture. A final, more positive pathway is that of socioeconomic adaptation, involving cooperation and sharing of depleting resources, and a localisation of the economy aimed at improving resilience to shocks. Policies and measures that would support and enable this last scenario are considered in the next chapter.

CHAPTER FIVE

5. Policy Recommendations for Mitigation, Adaptation and Resilience

The pursuit of sustainable development, which requires sustainability, cannot be left to markets – there is an inescapable role for government.

Common & Stagl (2005: xxx)

The potential impacts and risks presented by global oil depletion in the face of business-as-usual policies presents a strong pragmatic rationale for government-led, proactive mitigation initiatives.[131] This rationale is further underpinned theoretically by the existence of market failures (such as incomplete information, collective action problems and social externalities of private actions) as well as the precautionary principle, which advises that mitigation policies seek to reduce the risks of large negative impacts on society, while recognising the uncertainty surrounding the timing of the global oil peak and the steepness of the subsequent production decline.[132] Mitigation it is also consistent with the South African government's commitment to the notion of a "developmental state"[133] (Presidency, 2010), "developmental local government",[134] and the country's vision for sustainable development:

> "South Africa aspires to be a sustainable, economically prosperous and self-reliant nation state that safeguards its democracy by meeting the fundamental human needs of its people, by managing its limited ecological resources responsibly for current and future generations, and by advancing efficient and effective integrated planning and governance through national, regional and global collaboration" (Department of Environmental Affairs and Tourism (DEAT), 2008: 8).

A peak oil mitigation strategy must begin with explicit socioeconomic ends (goals) and include specific means (policies and measures) to attain these ends. Following from Chapter 1 and the country's vision statement just mentioned, the over-arching goal is to achieve sustainable development, which in turn requires economic efficiency, social equity (e.g. reduction of poverty, the creation of sustainable livelihoods and improvements in inter- and intra-generational equity) and environmental sustainability. More specifically, the objectives involve mitigation, adaptation, and building resilience. Mitigation aims to proactively lessen the future impact of oil scarcity and price shocks by reducing reliance on imported oil, for example by developing alternative energy supply

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131 According to Cambridge Dictionaries Online (2011), "mitigate" means "to make something less harmful, unpleasant or bad". The word mitigation is used in this dissertation in this general sense, as opposed to the specific meaning attached to mitigation in the context of climate change, where it is understood to mean reducing emissions of greenhouse gases (IPCC, 2007).

132 "Hesitation [in implementing mitigating policies] will risk high oil price induced negative macroeconomic consequences in the future, which will demand even more drastic policy measures to reduce oil-price GDP elasticity" (Owen, Inderwildi & King, 2010: 4748).

133 The concept of a "developmental state", and its desirable characteristics in the South African context, will be explored in greater detail in Chapter 6.

134 The White Paper on Local Government (1998) defines "developmental local government" as: "Local government committed to working with citizens and groups within the community to find sustainable ways to meet their social, economic and material needs, and improve the quality of their lives."

and reducing demand for oil. Adaptation implies coping with higher oil prices and making do with less oil, i.e. reacting to evolving circumstances as global oil supplies deplete. Building resilience entails, *inter alia*, measures to boost energy security, food security and food sovereignty in the face of oil-related economic shocks. The means to achieve these ends include policies and measures designed to alter the behaviour of consumers and producers, including market-based incentives, government regulations, and education and awareness campaigns (see Chapter 1).

This chapter seeks to determine what strategies, policies and measures can best mitigate the impact of global oil depletion on South Africa. More specifically, it addresses the following questions:

- What are the most viable and sustainable energy and material substitutes for imported oil?
- How can the transport system be transformed to reduce its oil dependency?
- How can the oil dependency of the agricultural system be attenuated and its resilience improved?
- What macroeconomic policies can increase the economy's resilience to oil shocks?
- How can basic human needs be met and social cohesion maintained in the face of oil price and supply shocks and declining mobility?

In order to answer these questions, this chapter employs the methodology of policy analysis. Mitigation strategies, policies and measures are categorised according to: (1) subsystems of the socioeconomic regime (i.e. energy, transport, agriculture, macro-economy and society); (2) supply side (technology, innovation and infrastructure) and demand side (conservation and efficiency) interventions; (3) short-term (less than two years), medium term (two to five years) and long-term (more than five years) measures; (4) global, macro, meso and micro scales; and (5) international, national, provincial, and local levels of policy formulation and implementation. Policies are evaluated according to one or more criteria, depending on available information, such as benefit-cost analysis, cost-effectiveness analysis and risk analysis. The principle actor in the mitigation strategy is assumed to be the "developmental state", including mainly national government departments, but also the local sphere of government. Businesses and communities (e.g. civil society organisations) are also important actors, but are not the primary focus here. A key assumption underlying the recommendations is that the current political order will endure long enough to enable the implementation of these policies. If a collapse scenario were to unfold rapidly, it could seriously erode the ability of governmental structures (at all levels) to implement the mitigation policies. In that case, responsibility would devolve to community groups to organise responses from the ground up in their local areas.

A mitigation strategy needs to take account of, and build upon, existing government policies. The South African government as a whole does not as yet (as of October 2011) have an overarching, integrated policy framework to address the wide-ranging socioeconomic implications of global oil depletion. Nevertheless, some policy documents do refer to the challenge of oil depletion and/or improving energy security. A draft National Strategy for Sustainable Development (NSSD) was gazetted by the Department of Environmental Affairs (DEA) in May 2010, building on the earlier National Framework for Sustainable Development (NFSD) that was adopted by Cabinet in June 2008. One of five strategic priorities identified in the NSSD was "Responding appropriately to emerging human development, economic and environmental challenges (including climate change, *rising oil prices*, globalisation and trade" (DEA, 2010: 8; emphasis added). The NSSD recognises that "oil scarcity is likely to become a significant issue over the next decade" (DEA, 2010: 7), but it does not include any strategies or policies specifically aimed at reducing dependency on imported oil. Many key departments, such as the Presidency (including the National Planning Commission), National Treasury and Department of Agriculture, have given no specific indication of contingency planning for the impact of future oil supply constraints and price shocks.[135] Some government departments have addressed the issue of liquid fuel security, including the Department of Energy and the Department of Transport, but only to a limited extent.[136] The relevant existing government policies will be discussed at the beginning of each major section below.

This chapter is organised according to the familiar subsystems within the socioeconomic system, namely: energy, transport, agriculture, macro-economy and society. Within each section, the following aspects are addressed: specific goals; relevant existing policies; recommended mitigating measures and policies; constraints and risks (e.g. institutional, economic, social and environmental) facing mitigation measures; and conclusions. The final section provides a concise summary.

5.1 Energy

In terms of mitigating the impacts of global oil depletion, the primary goal for the energy sector is to reduce reliance on imported oil. This should involve a combination of a shift to sustainable energy sources and curtailment of demand for oil products. The government's main approach to liquid fuel supply is summarised in the *Energy Security Master Plan – Liquid Fuels* (DME, 2007a).[137] This document recommended a set of mostly infrastructural short- to medium-term strategies, and longer term strategies which essentially amounted to the development of modelling capacity and policy formulation. The infrastructural strategies emphasized the need for adequate quantities of refined fuels to be made available to meet rising demand, especially in the economic heartland of Gauteng. Thus the two major infrastructure projects are Transnet's new multi-product fuel pipeline being constructed between Durban and Gauteng, and PetroSA's proposed new refinery project to be located at Coega in the Eastern Cape. Both projects assume that increasing quantities of crude oil will be available and affordable over their life spans. Other recommendations included: the procurement by PetroSA of 30% of South Africa's crude oil supply, in order to reduce the risks of reliance on a few sources of oil imports; the promotion of local liquid fuel production; mandating energy companies to ensure adequate commercial fuel inventories; and the cross-sectoral promotion of energy efficiency, noting in particular the risks of over-reliance on oil by the transport sector. However, the *Liquid Fuels Master Plan* does very little to address the future limitations on crude oil imports that will be imposed by global oil depletion.

To address this policy gap, Section 5.1.1 explores the alternative sources of energy supply that could substitute for imported crude oil and refined petroleum fuels. Section 5.1.2 discusses demand side management, in terms of energy efficiency and conservation initiatives, and motivates for South Africa to form part of an international Oil Depletion Protocol to guide a co-ordinated reduction in oil consumption. Section 5.1.3 concludes the discussion of energy mitigation options.

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[135] The Presidency (2010)'s "Strategic Plan 2010/11 to 2012/13" does not specifically mention global oil depletion or mitigation thereof. As of April 2011, the National Planning Commission had yet to publish any reports (aside from the Development Indicators 2010), and had given no indication of planning for global oil depletion.

[136] The "Energy security master plan: liquid fuels", published by the Department of Minerals and Energy in 2007, does not directly address the issue of global oil depletion, although it does allude to depleting supplies of a finite resource. The Department of Transport's "National Transport Master Plan 2005-2050" explicitly acknowledges the forthcoming peak and decline in global oil production.

[137] The following three paragraphs are based on the author's contribution to the chapter on "Greening the South African Growth Path" in the Development Bank of Southern Africa's 2010 Development Report.

5.1.1 Supply side: potential substitutes for imported oil[138]

As discussed in Chapter 2, crude oil refining produces a variety of petroleum products. The bulk of these are transport fuels (petrol, diesel, jet fuel and heavy fuel oil), but additional uses include paraffin, LPG, bitumen and feedstock for petrochemical products. There are several possible options for replacing imported oil with domestically produced energy sources. These include coal-to-liquids, gas-to-liquids, biofuels and electricity (generated from renewable and nuclear energy sources). All of these supply side alternatives are by their nature medium- to long-term interventions since the necessary infrastructure requires a minimum of several years to construct. Alternatives also exist for the non-energy uses of oil products, as discussed below.

Coal-to-liquids

As noted in Chapter 3, Sasol currently supplies approximately one quarter of South Africa's annual liquid fuel demand from its coal-to-liquid (CTL) synthetic fuels (synfuels) plant at Secunda. The major advantage of CTL is that it is a reliable technology with a proven track record, which produces synthetic petroleum fuels (including petrol, diesel and jet fuel) that are usable in existing transport infrastructure, as well as petrochemical products. Expanding domestic CTL production would therefore reduce South Africa's dependency on oil imports and save foreign exchange. In March 2010 Sasol's board approved the first phase of a project to expand the synfuels and electricity generation capacity of the Secunda plant by approximately 3.2%, using natural gas imported from Mozambique as feedstock (Creamer, 2010a; Sasol, 2010). The Secunda expansion was budgeted at R14.2 billion (including new gas-fired electricity generation) and was due to come on stream in 2014.

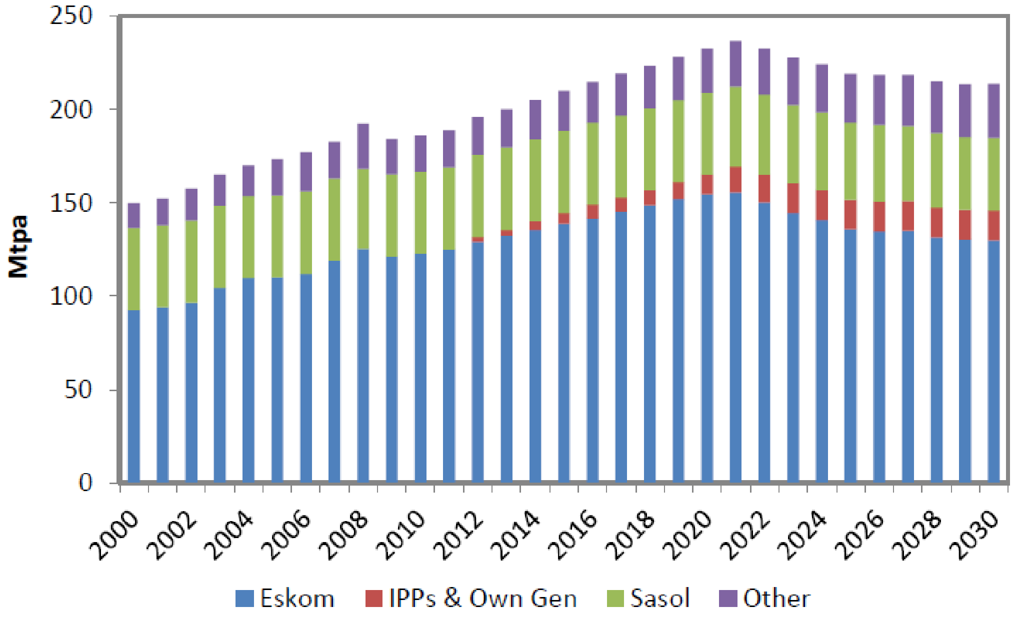
Sasol is also investigating a proposed new CTL plant to be located at the Waterberg coal field in Limpopo Province (Sasol, 2010: 20). Named Project Mafutha, the plant has a proposed capacity of 80,000 barrels of liquid fuels per day, which is slightly more than half of Sasol's 2010 synfuel production volume from its Secunda plant. Sasol has indicated that it would not be the sole investor in such a large scale project, which is estimated to cost in the region of R160 billion, and the company sought financial support from government (Njobeni, 2010; Donnelly, 2010). In 2008 Sasol signed a Memorandum of Understanding with the Industrial Development Corporation for a planned investment in the project (Sasol, 2010), and the company also held investment talks with the departments of Trade and Industry and Minerals and Energy. According to Sasol, Project Mafutha would likely take up to 10 years to complete. If both Project Mafutha and the Secunda extension materialised, Sasol's synfuels would meet about 40% of the country's 2009 liquid fuel demand.

Construction of a new CTL plant faces several risks and would entails costs other than purely financial costs. First, such a project would be viable only if sufficient coal feedstock could be secured for the lifetime of the project. While the Waterberg coal field is relatively underutilised, South Africa's remaining coal reserves are the subject of much contention. The official government figure for reserves was revised downward greatly from over 50 gigatonnes (Gt) to under 30 Gt in 2007 (GCIS, 2007). However, recent research casts doubt on even this latter figure. Rutledge (2011) estimates that remaining recoverable coal reserves in Southern Africa (the vast majority of which are in South Africa) may be as low as 10 Gt. Using the Hubbert linearization technique, Mohr and Evans (2009) produce a low estimate of South Africa's coal URR at 18 Gt, which yields a forecast of peak annual production in 2012. Patzek and Croft (2010), recognising that over time the quality and energy content of mined coal deteriorates, estimate that South Africa's coal production, when measured in energy units, peaked in 2007. Hartnady (2010) forecasts a peak in domestic coal production at about 284 million tonnes per annum (mtpa) in 2020. On the other hand, Eskom's demand for coal for electricity generation is set to rise by approximately 30 mtpa (to feed its new Medupi and Kusile power plants) to a peak of around 155 mtpa in 2021, thereafter declining as old

[138] This section draws on the author's contribution to ASPO-SA et al. (2008c), Reducing Oil Dependency.

power plants are decommissioned (Eberhard, 2011).[139] Total domestic demand could also peak in 2021 at approximately 235 mtpa, including Sasol's consumption of 44 mtpa plus consumption by industry, new independent power producers and households (see Figure 5-1). Meanwhile, the coal industry has plans to increase exports from about 65 mt in 2010 to over 90 mt by 2020 (Eberhard, 2011). The proposed Mafutha CTL plant would require an additional approximately 25 mtpa. If the reserves-based supply forecasts noted above turn out to be accurate, then coal production in the country as a whole will not be able to rise sufficiently to meet projected growth in demand by Eskom, other domestic users, exports and a new CTL plant. Tradeoffs amongst these competing uses of coal will have to be made at some point, and coal prices are likely to rise considerably. Under these circumstances, it might make more sense for the Waterberg coal to be used to maintain electricity production from existing power plants rather than to feed a costly new CTL plant. Some of this electricity could be used to power transportation (e.g. electric trains and road vehicles).

Figure 5-1: Projected domestic coal demand in South Africa



Source: Eberhard (2011: Figure 15)

The second risk is that, even if sufficient feedstock were procured, the energy return on investment (EROI) for CTL is very low and the EROI for coal mining declines over time as the quality of ore grades diminishes, hence raising production costs (see Chapter 2). Third, expansion of domestic synfuel capacity would come with high environmental costs in the form of water and air pollution, including additional greenhouse gas (GHG) emissions, which contribute to climate change. In view of South Africa's climate mitigation commitments under the Copenhagen Accord of 2009, Sasol may be required to install carbon capture and storage (CCS) technology at a new CTL plant, which would raise its costs considerably. Costs of CTL fuels would also rise if a carbon tax or a carbon trading system were implemented.[140] Fourth, CTL facilities require large quantities of water, which is an increasingly scarce resource in Southern Africa in general, and in the Waterberg area in particular (Hartnady, 2010). An external expert warned Sasol that competition for water resources amongst

[139] This assumes that no further new coal plants are built after Kusile as a result of CO_2 emission caps.

[140] In September 2010 Sasol's Chief Executive Officer announced that the feasibility phase would take longer than previously anticipated as the potential for carbon capture and storage (CCS) was explored and as clarity was awaited regarding PetroSA's proposed new oil refinery (project Mthombo) (Creamer, 2010b).

different social and economic claims could be intense (Sasol, 2009: 30). Finally, the pollution resulting from coal mining and combustion can also have negative impacts on human health, such as respiratory diseases (Spalding-Fecher & Matibe, 2003).

In summary, additional CTL capacity would bring considerable benefits from a liquid fuel security point of view, but these need to be traded off relative to several significant costs and risks, including coal resource depletion and environmental degradation. CTL needs to be evaluated relative to the benefits and costs of alternatives, for example using the coal to produce electricity. From a sustainability point of view, government funds should rather be spent on renewable energy and electric-powered transport systems (see Section 5.2).

Gas-to-liquids

As discussed in Chapter 3, PetroSA produces liquid fuels using natural gas and crude oil as feedstock at its gas-to-liquids (GTL) refinery at Mossel Bay. Production volumes amount to no more than 45,000 barrels per day, or 7% of South Africa's liquid fuel consumption (DME, 2007a). The existing oil and gas fields in the Bredasdorp basin are rapidly depleting and were expected to cease delivering by 2012 or soon thereafter (PetroSA, 2010). The company was thus under considerable pressure to find additional feedstock to maintain its existing production volumes. PetroSA is continuing exploration in the region but as of late 2011 had not announced the discovery of any substantial new oil or gas fields. Even if new gas and oil fields were discovered off South Africa's western or southern coasts, they would take several years to deliver fuels to the market. PetroSA has also considered the possibility of importing gas from Namibia's Kudu gas field, located offshore just north of the border with South Africa, or from Mozambique. However, in either case gas imports would require the construction of costly additional pipelines (to Mossel Bay in the case of the Kudu gas field).

The Department of Energy and PetroSA also explored the feasibility of importing liquefied natural gas (LNG). LNG has to be transported in special tanker ships and then re-gasified before it can be used onshore, which requires expensive infrastructure. According to the Central Energy Fund (CEF, 2008), a feasibility study has been conducted for an LNG terminal at the port of Coega in the Eastern Cape. In 2008, PetroSA and Eskom were considering a joint venture which would provide feedstock to the Mossel Bay GTL refinery as well as to a new gas-fired power station at Coega (Business Report, 2008). However, LNG prices have been closely correlated to oil prices over the past decade. Global LNG supplies are likely to come under increasing pressure over the coming decades as the depletion of conventional natural gas reserves continues in many regions, especially North America and Europe. The major existing markets for LNG are Japan, South Korea and Europe, while new markets are developing in China and India. Thus South Africa will most likely face increasingly stiff competition and higher prices for LNG in the long term. In 2010 PetroSA management decided that commercial conditions did not favour the LNG option, and opted instead for the development of the previously discovered F-O gas field, located 40 kilometres from the existing F-A production platform (Creamer, 2010c). The F-O field was expected to begin production in 2013 and extend the life of the GTL plant by eight years (PetroSA, 2010).

Another possible source of gas feedstock is coal bed methane (CBM), i.e. methane gas that occurs with coal seams. CBM projects are under way in neighbouring Botswana (Mining Weekly, 2008), but as of 2011 CBM was still in the research and development phase in South Africa. As is the case with all fossil energy projects, there are substantial lead times as well as environmental factors (such as GHG emissions) to consider. The IEA (2011b) did not mention any CBM potential for South Africa in its special report entitled *Are we entering a golden age of gas?*

A further source of feedstock for GTL could potentially come from a process called underground coal gasification (UCG). Eskom and Sasol are both currently working to develop this alternative technology for extracting the energy from coal. UCG is a process whereby coal is ignited *in situ* underground, fed through a borehole by air or oxygen and yielding a synthetic gas (syngas). The syngas can be used for electricity generation, for the production of synthetic liquid fuels or for industrial uses (e.g. the manufacture of petrochemicals) (Shafirovich & Varma, 2009). In addition to this flexibility, several other advantages are claimed for UCG (Shafirovich & Varma, 2009; Eskom, 2010). First, otherwise uneconomical resources can be utilised; Eskom estimates that an additional 45 billion tons of coal could be exploited through UCG, over and above existing proved reserves (Eskom, 2010). Second, capital investment costs are lower than for conventional coal plants. Third, there are no costs incurred for transporting coal. Fourth, there is no need for traditional mining and associated health and safety risks for miners. Fifth, indications from a pilot UCG project in Australia indicate that the process has a much lower environmental impact (in terms of groundwater contamination, land degradation and subsidence, and greenhouse gas emissions) when compared to conventional coal mining. In addition, cavities resulting from UCG could potentially be used to sequester CO_2. Eskom has a small pilot UCG plant in operation at its Majuba power station in Mpumalanga, and began commercial co-firing of gas and coal in October 2010. Eskom is optimistic that the costs will compare favourably with those of conventional coal mining and power generation (Eskom, 2010). Nonetheless, there are disadvantages and several risks attached to UCG. First, although UCG might produce a smaller volume of GHGs per unit of energy than conventional coal, there are still considerable emissions to deal with. Second, there are concerns about possible underground water contamination and land subsidence (Shafirovich & Varma, 2009).

Finally, shale gas is another potential source of feedstock for GTL plants (or for other uses of gas). According to the EIA (2011b), South Africa has large potential for shale gas deposits in the Karoo Basin, estimated at 485 trillion cubic feet of technically recoverable resources. This is equivalent to 485 quadrillion Btus or approximately 90 times the country's primary energy supply in 2008. However, as discussed in Chapter 2 (section 2.2.1), research by some analysts has questioned the economic viability of shale gas (Berman, 2010; Berman & Pittinger, 2011; Hughes, 2011) and raised serious concerns about potential negative environmental side-effects (Hughes, 2011; Howarth et al., 2011). Of particular concern are supplies of and contamination of fresh water, which is a very scarce resource in the Karoo area.[141] In April 2011 the South African Cabinet endorsed a moratorium on shale gas exploration pending further research into its environmental and health implications (Agbroko, 2011), and in September 2011 the moratorium was extended for a further six months. Sasol, one of the companies exploring for shale gas in the Karoo, stated that it would likely be at least 10 years before any gas were produced (Lourens, 2010). As of this writing, therefore, the potential of shale gas to contribute to the energy supply in South Africa remains highly uncertain, and it is seems very unlikely to play a meaningful role this decade.

In conclusion, PetroSA faces a significant challenge in the medium term to maintain its existing GTL production levels. There are various possibilities for expanding GTL production from domestically produced gas in the longer term, but they are by no means certain, and would require costly infrastructure investments. In addition, there are serious environmental concerns about most of the alternatives, especially shale gas.

Liquid biofuels

Biofuels were identified as one of the renewable energy sources to contribute to the target set in the 2003 White Paper on Renewable Energy (DME, 2003). In December 2005 the South African Cabinet endorsed the development of a biofuels industrial strategy, aimed mainly at employment creation in the agriculture and biofuels value chain (DoE, 2011c). A Biofuels Task Team (BTT) was initiated to explore opportunities for commercialisation of biofuels and to make recommendations to Government. Based on the BTT's report (Biofuels Task Team, 2006), the Department of Minerals and Energy released its *Draft Biofuels Industrial Strategy* for public comment in December 2006. The

[141] According to Hughes (2011: 23), a single shale gas well could use between 8 and 24 million litres of water.

Draft Strategy recommended a target of 4.5% of liquid fuels to be derived from biofuels by 2013, using maize and soya beans as primary feedstocks.[142] However, in the latter part of 2007 the strategy was revised as concerns emerged about potential competition between food and fuel and the impact of these "first generation" biofuels (made from food crops) on food prices.[143] Other potential problems with these biofuels include water scarcity and generally low net energy returns (see Section 2.2). According to Chakauya et al. (2009: 174), perhaps the most promising first generation feedstock for South Africa is sweet sorghum, since it could yield both food and bioethanol at relatively high EROI and without undermining food security. Subsequently, the Cabinet approved an amended *Biofuels Industrial Strategy* (DME, 2007b) in December 2007, which excluded maize as a feedstock for ethanol, relying instead on sugar cane and sugar beet. The Strategy also proposes that biodiesel be produced from soya beans, canola and sunflower oil. The target was adjusted downward to just 2% of liquid road fuels by 2013 in an initial five-year pilot phase. As of June 2011, there were four biofuels projects operating in the country, with investments from the Industrial Development Corporation (IDC) (GCIS, 2011: 181).

The food security concerns related to biofuels made from food crops have stimulated interest in non-food feedstock crops. One such example that has attracted substantial foreign and local interest is the Jatropha plant, which yields oil-bearing fruit that can be used to produce biodiesel (No, 2011; Abdulla, Chan & Ravindra, 2011). Advocates argue that Jatropha can be grown on marginal lands in dry and drought-prone conditions, so that it does not compete with food production (Chakauya et al., 2009). Other advantages and uses of Jatropha include: the production of useful by-products such as soap; various medicinal uses; use for reduction of erosion and as a natural hedge to protect crops, since it is not browsed by livestock (Chakauya et al., 2009; Henning, undated). Furthermore, all processing can be done locally, which means that value added accrues to the local community (Henning, undated). However, other research indicates that for yields to be sufficient for commercial purposes, Jatropha plantations may require significant irrigation and can cause conflict over water resources (Ariza-Montobbio & Lele, 2010). Another potential drawback of the plant is its toxicity to humans and animals (Devappa, Makkar & Becker, 2010). Several years ago, the South African Department of Agriculture placed a moratorium on the Jatropha plant while it considered environmental concerns such as water usage and possible invasiveness (Groenewald, 2007). In 2008 the Water Resources Council published a case study that found no evidence that Jatropha reduced water runoff (Holl, Gush, Hallowes & Versfeld, 2007). As of early 2011, Jatropha was being cultivated in parts of KwaZulu-Natal, with support from the provincial Agricultural Extension Service.

Another possible avenue is so-called "second-generation" biofuels, such as cellulosic ethanol, which utilises non-food crops, agricultural waste and wood chips as feedstock (Woodson & Jablonowski, 2008), and biodiesel produced from algae (Rhodes, 2009). The problem with cellulosic ethanol is that there is no ecological 'free lunch': for arable land to remain fertile, a significant proportion of the nutrients contained in the 'waste' must be returned to the soil – the more so when synthetic fertilisers become relatively scarcer and more costly.[144] Although these are promising developments, high costs have thus far prohibited their commercialisation, which may take a decade or more.

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[142] The average surplus of South African maize production over domestic consumption between 1994 and 2009 was 2.46 million tonnes (based on DoA, 2010). Assuming that maize can be converted into ethanol at a rate of 420 litres per tonne (calculation based on figures provided by Barradas, 2007), this surplus would yield 1,035 million litres of ethanol, or 9.1% of the country's total petrol consumption of 11,313 million litres in 2009. However, that would leave no maize for export to neighbouring countries, putting their food security at risk.

[143] These concerns were expressed by various civil society organisations as well as by the National Treasury, the Governor of the South African Reserve Bank, and the Department of Trade and Industry (see Nieuwoudt, 2007.

[144] Using Life Cycle Assessment, Amigun et al. (2008: 138) show that "diverting bagasse without efficiency improvements from its current use to an ethanol bio-refinery would indeed backfire for all environmental

The economics of biofuel production and consumption hinges on several locally specific conditions, including: "(a) the cost of biomass materials..., depending on land availability, agricultural productivity, labour costs, etc.; (b) biofuel production costs, which depend on the plant location, size and technology...; (c) the cost of corresponding fossil fuel (e.g., gasoline, diesel)...; and (d) the strategic benefit of substituting imported petroleum with domestic resources" (Amigun et al., 2008: 698). In the case of biodiesel, the feedstock cost is the most significant determinant of economic viability, outweighing capital costs (Amigun et al., 2008: 701). Revenues from co-products (e.g. feed cake and glycerine) also influence the economics.

Obstacles to the development of biofuels in South Africa include: low levels of awareness about the opportunities inherent in biofuels; technical challenges; food insecurity concerns; difficulties accessing financing; human capacity constraints; and an uncertain policy and regulatory environment (Amigun et al., 2008; Chakauya et al., 2009: 174). In addition, as of 2011 large-scale production of biofuels was not economically feasible in South Africa. In 2006 Sasol stated that a large-scale biodiesel plant using soya as feedstock would not be economically viable without government support in the form of fuel-tax exemptions, feedstock subsidies and a contribution towards capital investment costs (Engineering News, 2006). It would also require a large increase in imports of soya beans. Ethanol Africa, a company that in 2006 planned to construct eight ethanol refineries in the Free State area, subsequently abandoned its plans as they were not financially viable given prevailing maize and petrol prices. Nolte (2007) found that the production of soybeans, sunflower seeds and canola would have to increase by factors of four, six and three, respectively, for South Africa to replace 10% of its diesel consumption with biodiesel produced from these oilseed crops. For the benefits of biofuels to be exploited, "there is a need to establish and nurture the development of capacity, in the value chain from production to consumption" (Chakauya et al, 2009: 174).

Given the above constraints imposed by water and land scarcity, it seems unlikely that biofuels will make a significant contribution to national liquid fuel security, at least in the medium term.[145] Probably the most promising option is small-scale, local biodiesel production, mainly by farmers for their own needs to power tractors and other farm machinery.[146] Biofuels and co-products have considerable potential to boost local rural economies (Chakauya et al., 2009). As oil prices continue to rise, economic incentives will encourage farmers to produce those biofuels with reasonably high EROI. Government subsidies for ethanol production should be avoided as they could distort these incentives and lead to outcomes that are economically and energetically inefficient, and compromise food security. However, there is a case for economic incentives (such as a waiver of tax on biodiesel production) and financing arrangements for helping to establish localised biodiesel production facilities. Further state support can come in the form of fuel blending regulations (as contained in the Biofuels Industrial Strategy), education and skill training programmes, and targeted research and development expenditure (Chakauya et al., 2009).

Biogas

Biogas, which is generated from the anaerobic fermentation of organic material, is a substitute for liquid petroleum gas (LPG). It has several advantages (Amigun et al., 2008: 701-2): (1) it can be produced from organic waste matter and therefore control pollution, including GHG emissions; (2)

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impacts studied" and conclude that "Investments into energy efficiency are therefore a precondition for diverting cellulosic residues into biofuel production."

[145] Interestingly, the DME's (2007) *Liquid Fuels Master Plan* did not identify biofuels as one of its recommendations to enhance fuel security.

[146] According to Amigun and von Blottnitz (2005, in Nolte, 2007), the optimum capacity for a biodiesel plant in South Africa is between 1500 and 3000 kilograms per hour.

useful by-products include fertiliser and water; (3) production technology is simple and efficient at both large and small scales, in rural and urban settings; (4) it alleviates pressure on wood resources, deforestation and related environmental impacts; and (5) biogas systems can be constructed and operated locally. Capital costs represent the largest component of biogas costs, while operation and maintenance costs are relatively low and the feedstock is often free as it consists of various waste materials (Amigun et al., 2008: 702). The biogas can be used for heating and cooking, or it can be converted into electricity. Transport costs are the second largest component of manufacturing costs, and therefore decentralised plant location close to feedstock sources (and final consumption) is important (Nolte, 2007). Biogas therefore presents a very good opportunity for sustainable energy supply on a modest, local scale. It has been estimated that 300,000 (mainly rural) households could utilise biogas digesters in South Africa (Trollip & Marquard, 2010).

Electricity

Electricity can in principle replace petroleum-based transport fuels, although this will require a costly and time-consuming replacement of the current petroleum-based vehicle fleet with electrified transport infrastructure (various options are discussed in Section 5.2 below). Electricity can also substitute for paraffin (which is used chiefly by low-income households for lighting and cooking) and LPG (also used for cooking). However, these new uses of electricity would need to compete with other demand sectors such as industry, commerce, agriculture and the residential sector.[147] By 2007-2008, demand for electricity had already out-stripped Eskom's supply capacity, resulting in a near-collapse of the grid and subsequent power rationing. Eskom has warned that its generation capacity will be severely constrained until at least 2017, when the first unit of the second new base-load coal-fired power station (Kusile) is due to be commissioned (DoE, 2010).

Table 5-1: Electricity generation capacity according to the IRP2010

Source	New build		Total in 2030	
	MW	%	MW	%
Coal	6,250	14.7	41,071	45.9
Nuclear	9,600	22.6	11,400	12.7
Gas	2,370	5.6	2,370	2.6
Diesel	3,910	9.2	7,330	8.2
Hydro	2,609	6.1	4,759	5.3
Pumped storage	0	0.0	2,912	3.3
Wind	8,400	19.7	9,200	10.3
Solar photovoltaic	8,400	19.7	8,400	9.4
Concentrated solar	1,000	2.4	1,200	1.3
Other	0	0.0	890	1.0
Total	42,539	100.0	89,532	100.0

Source: DoE (2011b)

In September 2010 the Department of Energy presented the "Draft Integrated Electricity Resource Plan for South Africa – 2010 to 2030", which aimed to project future electricity demand and how supply would meet this demand (DoE, 2010). Following a process of public consultation, the IRP was revised before being approved by Cabinet in March 2011 and gazetted in May 2011 (DoE, 2011b). The IRP2010 projections assume that the economy will grow at an average rate of 4.6% per annum between 2010 and 2030, and that this growth drives an increase in electricity demand. In the final

[147] As noted in Section 2.2, only 1.6% of electricity generated in South Africa was consumed by the transport sector in 2007.

"Policy-Adjusted IRP", total electricity generating capacity grows by 45,637 MW (104%) from 43,895 MW at the start of 2010 to 89,532 MW by the end of 2030 (see Table 5-1). The final electricity generation capacity mix in 2030 is comprised of 46% coal, 12.7% nuclear, 5.3% hydro, 3.3% pumped storage, 2.6% gas (combined-cycle gas turbines, or CCGT), 8.2% diesel (open-cycle gas turbines, or OCGT), 10.3% wind, 9.4% solar PV, 1.3% CSP and 1% 'other'. Of the new build, 42% is renewables, 23% nuclear and 15% coal (which excludes 10.1 GW of already 'committed' new coal-fired capacity). However, the share of electricity actually *generated* from renewable sources is forecast to be just 9% in 2030 (excluding 5% for hydro), as a result of the lower load factors for solar and wind power compared to other sources. Forecasted peak demand increases from 38,885 MW to 67,809 MW at an average annual rate of 2.82% over the same period, resulting in a 32% reserve margin in 2030.

Interestingly, the Department of Energy (DoE, 2011b: 14) partially justifies its decision to fully commit to building 9,6 MW of new nuclear generation capacity on the basis that it "should provide acceptable assurance of security of supply in the event of a peak oil-type increase in fuel prices". Nevertheless, several assumptions underlying the IRP2010 are problematic when account is taken of global oil depletion and its probable impacts. First, the assumption of 4.6% annual economic growth is highly unrealistic in the context of global oil price shocks and supply constraints. If the build programme were successful, there is a risk it could result in substantial stranded electricity capacity.[148] Second, obtaining the requisite financing for the build programme is likely to be much more difficult and costly than anticipated, and project costs are likely to escalate substantially as oil prices increase. Thus the ambitious targets might well be unaffordable. Third, diesel to fuel open cycle gas turbines may be prohibitively expensive by 2022 when the first new OCGT capacity is due to be commissioned. Fourth, imported coal will likely become too expensive in the context of growing demand from large countries such as China and India, and possible worldwide coal shortages (see Section 2.2.1). Fifth, domestic coal prices could rise substantially as a result of international competition; this would be compounded if South Africa's coal production were to peak and decline within the next decade, as some studies have indicated (see above). Finally, there is a significant risk that sufficient imports of coal and electric power will not be available from neighbouring countries due to negative impacts of oil shocks on their economies.[149]

Renewable electricity

In the light of these risks and likely constraints on fossil fuel based electricity generation, it is necessary to consider the realistic potential for the development of alternative sources of electricity. In 2003 the Department of Minerals and Energy (DME, 2003) promulgated the Renewable Energy White Paper (REWP), which set a target of 10,000 GWh of renewable energy by 2014. However, no implementation plan has been formulated and actual implementation has been very slow: less than 10% of the target had been met by late 2010 (Trollip & Marquard, 2010). In the South African context, potential renewable energy sources (for electricity generation) include hydro-electric, landfill gas, biomass cogeneration, wind, solar and ocean energy.

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[148] Trollip and Tyler (2011) make a similar point: they show that the demand forecast used in the IRP2010 assumes a demand growth rate twice that of historical average demand growth, and also note that this is out of alignment with the government's climate mitigation policies. Furthermore, Inglesi and Pouris (2010) argue that the doubling of electricity prices between 2010-2013 will substantially reduce demand for electricity, and that this has apparently not been factored in to Eskom's demand projections. (However, their estimate that electricity demand will fall by between 31% and 18% within a few years seems somewhat unrealistic from a biophysical perspective which notes that structural economic change away from energy-consuming sectors takes time.)

[149] Moreover, water scarcity could impose a much tougher binding constraint than is allowed for in the IRP2010 (Turton, 2008), and negative environmental and social externalities (such as air and water pollution and associated health impairment from coal combustion) are not sufficiently incorporated into the costs.

- South Africa's potential for large-scale hydropower is very limited, and has mostly been exploited already (Banks & Schaffler, 2006). However, there is estimated potential for micro-hydro generation on the order of 69 MW (Holm et al., 2008). Barta (2002, in Holm et al., 2008) estimated that nearly 2,000 MW of additional hydropower could be added.
- Lombard de Mattos and Associates (2004, in Holm et al., 2008) estimated that South Africa could generate 850 GWh of electricity from landfill gas (equivalent to 105 MW of installed capacity), while methane from sewage could provide a similar amount of electrical energy.
- Trollip and Marquard (2010) estimate that approximately 2.7 GW of biomass cogeneration capacity could be implemented over the coming decade on a cost-competitive basis.
- A mesoscale wind atlas of South Africa indicates low to moderate wind potential, with the best sites being in the Western Cape and Northern Cape Provinces (Hagemann, 2008). Hagemann (2008) estimated potential wind power capacity of 26 GW, which would yield approximately 80 TWh/year. Trollip and Marquard (2010) estimate that a 10 GW wind energy programme would be affordable and feasible over a 10-year period. The South African Wind Energy Association (SAWEA, 2010) estimated that 30 GW of wind power capacity could be installed by private operators by 2025, displacing some 6 GW of conventional base load power.[150] A project to develop a high resolution wind resource atlas for South Africa was underway in early 2011.
- South Africa has amongst the best solar resources in the world (Pegels, 2010: 4948). Banks and Schäffler (2006) estimate that an area of 720 km^2 devoted to concentrated solar power (CSP) and solar PV would be sufficient to meet South Africa's entire electricity demand. Fluri (2009) estimates the national nominal potential for concentrated solar power using existing, proven technology to be 548 GW, and an effective capacity of 212 GW, which is more than 5 times the country's total electricity generation capacity in 2010.[151] According to Trollip and Marquard (2010: 3), "[i]t is conceivable that CSP will have advanced down the learning curve sufficiently for multiple 100-MW-scale installations to be implemented by the end of this decade, and for these to become cost competitive with wind and conventional power generation." In addition, solar water heaters could displace coal-fired electricity geysers for some 4.2 million households and be cheaper as well (Trollip and Marquard, 2010: 4).
- Although ocean power technology is still in its infancy, wave power potential on the extensive coastline of South Africa has been estimated at between 8,000 and 10,000 MW (Holm et al., 2008).

Despite the very large potential resources, several of the renewable energy technologies face significant challenges and constraints, including intermittency and the need for storage technologies (see Section 2.2.1) and transmission infrastructure. Nevertheless, technological innovation is likely to alleviate these constraints over time, while distributed generation holds the potential to reduce the need for both transmission and storage of electricity (Banks & Schaffler, 2006). [152] Banks & Schaffler (2006: x) also note that "Effective large-scale [renewable energy] industries will take time to develop and, even at a 20 percent annual growth rate, it will take several years before they can start to add energy capacity to the grid on the scale required." Although the current financial costs of renewable technologies are mostly fairly high compared to existing conventional power generation, the cost trend for fossil fuel generated electricity is upwards (as the resources deplete), while the cost trend for renewable energy is downward as the technologies are improved. If negative environmental and health externalities associated with coal (and long term risks associated with nuclear accidents and waste disposal) were included, the competitiveness of renewables would be considerably enhanced. Perhaps the most serious potential constraint on a large deployment of current renewable energy

[150] This assumes that wind power generation has an average load factor of approximately 25%.

[151] However, Fluri (2009: 5079) notes that "a multi-GW roll-out of CSP in South Africa will only be feasible if dry or other water-wise cooling methods are implemented."

[152] Holm et al. (2008: 1) argue that "intermittency (despatchability) is not a disqualifying issue for renewables in South Africa."

technologies is posed by scarcity of material inputs (e.g. rare earth metals) and the fossil fuels currently used in the manufacture and installation of RE components.

The IRP2010 (DoE, 2011b) foresees the installation of 8,400 MW of wind power capacity, 8,400 MW of solar PV and 1,000 MW of CSP capacity by 2030. Other organisations have criticised this as being an inadequate rate of increase in renewables. For example, the WWF (2010), based on a modelling exercise, argues that a target of 50% renewable electricity by 2030 is both achievable and more cost effective than the IRP2010 "revised balanced scenario".[153] Moreover, renewables have greater potential for job creation and the stimulation of local industry. Based on detailed resource assessments, Banks & Schaffler (2006) develop a "progressive renewables scenario" in which over 70% of electricity is generated from renewable sources by 2050, and find that the total cost of electricity generated is likely to be significantly lower in the medium to long term compared to a business as usual scenario. Holm et al. (2008: 2) state that "When environmental, job creation and other factors are taken into account renewable energy options are economic (least cost) in a [broad] range of scenarios." Similarly, Greenpeace (2011) proposes an "Energy [R]evolution" scenario in which 77% of electricity is generated from renewable sources by 2050, and an "Advanced Energy [R]evolution" scenario where the percentage is 94%; in both cases projected average costs are lower than in a fossil fuel intensive reference scenario after 2030. The Advanced scenario would require $404 billion in fixed investment by 2050. The Advanced Energy [R]evolution scenario foresees that electricity contributes 14% of transport energy by 2030 and 53% by 2050.

In sum, many renewable energy resources are abundant in South Africa and the technologies to harness them (especially wind and solar) are already available and are becoming increasingly cost competitive. Moreover, RE presents the opportunity to develop local industries and create jobs. Nevertheless, there are significant economic and institutional barriers to a rapid scale-up of RE. First, the anticipated rise in oil prices will raise the costs of RE technology manufacture and installation. Second, the dominance of the minerals-energy complex (MEC),[154] and the prime place of the coal industry within that, presents an institutional barrier to more rapid uptake of renewables (Baker, 2011). Electricity sector governance and policy formulation is politically fraught as it involves several government departments (e.g. Departments of Energy and Public Enterprises, National Treasury), the national regulator (NERSA), the state-owned utility (Eskom), as well as several large private companies wielding substantial economic power (coal suppliers and energy-intensive industrial consumers). These governance issues are reinforced by lock-in to existing, fossil fuel based technological and knowledge infrastructures. Third, in the longer run certain material resource constraints (such as rare earth metals) may be an issue for large-scale expansion of renewables. In addition, as mentioned earlier electricity is not a direct substitute for oil in transport, but requires a complementary, large-scale investment in electrified transport infrastructure.

Internationally, an effective policy instrument for stimulating the uptake of renewable energy by businesses and households has been a feed-in-tariff system, whereby private entities that supply renewable energy into the national grid are paid a set tariff (Pegels, 2010). The National Energy Regulator of South Africa (NERSA) promulgated a renewable energy feed-in-tariff (REFIT) in 2008, but as of early 2011 it had yet to be implemented and was being reconsidered in favour of a competitive bidding system. The monopoly power of Eskom has been identified as a significant barrier to the entry of Independent Power Producers (Pegels, 2010; Baker, 2011). A second policy option is to promote innovation and research and development (R&D) in renewable energy

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[153] As mentioned earlier, this RBS was subsequently revised for the final, "Policy-Adjusted IRP2010", to include an additional amount of RE generation; however the latter is still far below the WWF scenario.

[154] The MEC consists in the main of a number of very large companies involved in the extraction and processing of coal, gold, platinum and other minerals and hydrocarbons (Baker, 2011; Fine, 2011).

technology, and related skill development (Pegels, 2010). To date such investment has been sorely lacking in South Africa,[155] and should become a much greater priority.

Nuclear power

Nuclear energy has long been and remains a highly contentious topic (e.g. see Fig, 2005). The main advantage of nuclear energy is that it provides a (mostly) reliable, large-scale source of base-load power. Furthermore, South Africa is endowed with substantial indigenous uranium resources, estimated by the World Nuclear Association as the world's fifth largest 'reasonably assured resources', or 5% of the world total (WNA, 2011). On the other hand, nuclear power has several major drawbacks. First, construction of nuclear plants incurs very high capital costs and long lead times. Second, South Africa currently relies on imports of enriched uranium, although the government's Nuclear Energy Policy (DME, 2008) aims to resuscitate Apartheid-era enrichment capabilities and develop the full nuclear fuel cycle. Third, there are risks of radioactive contamination from accidents and there is still no solution (locally or globally) to the problem of long-term waste disposal after decades of nuclear power use. Fourth, the full economic, social and environmental lifecycle costs, which include the construction, maintenance and decommissioning of the plant; the mining, processing and enrichment of uranium; and the disposal of radioactive waste, are likely to be much higher than the costs commonly declared (Thomas, 2005).

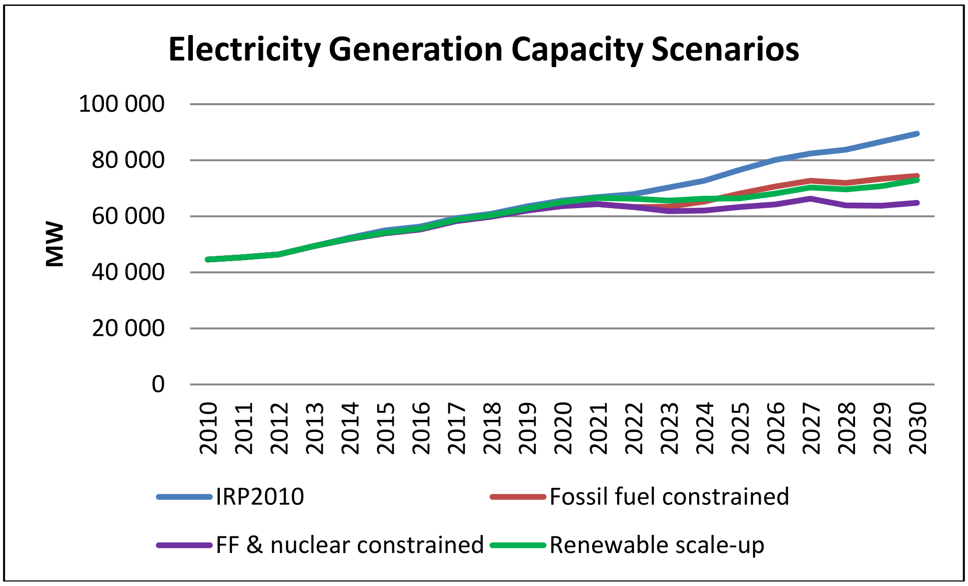
The IRP2010 foresees a new fleet of conventional nuclear power stations being constructed from 2023. However, global oil depletion presents some particular risks to the future of nuclear power in South Africa, including: increased world competition and prices for enriched uranium (which is currently imported by South Africa) if other countries decide to substitute nuclear for increasingly expensive fossil fuel based power generation (see Chapter 2);[156] increased costs of mining uranium domestically, especially as gold production continues its long-term decline (most uranium production to date has been a by-product of gold mining); escalating construction and financing costs; and risks to the transport of nuclear fuel and disposal of waste products posed by uncertain fuel supplies. Perhaps most importantly, the risk of a post-oil peak economic collapse could greatly increase the risk of nuclear power plants not being safely managed, maintained and decommissioned, which in turn could have adverse impacts on human and ecosystem health for thousands of years.

Figure 5-2 below displays four scenarios for future electricity generation capacity. The first scenario is the "Policy-Adjusted" IRP2010 as promulgated in May 2011 (DoE, 2011b). The second is a "fossil fuel constrained" scenario, which assumes that after 2020, new domestic or imported coal, gas and oil based generation (as well as imported hydro) are unaffordable due to global and local primary energy supply constraints and excess demand (Medupi and Kusile and other "committed build" projects are assumed to come on line as planned in the IRP2010). The third scenario assumes that the new nuclear build does not take place (in addition to the fossil fuel constraints), for example because it is unaffordable or deemed excessively risky. The fourth scenario assumes that renewable electricity capacity is scaled up more rapidly, especially from 2020. It should be borne in mind that 10 GW of wind capacity is rated as equivalent to about 2 GW of base-load capacity, given its lower load factor arising from wind intermittency. The latter two scenarios are compatible with a levelling off in electricity demand growth after 2020, in line with a steady state economy.

[155] One exception is the Centre for Renewable and Sustainable Energy Studies based at Stellenbosch University.

[156] On the other hand, future demand for conventional nuclear power is uncertain following the Fukushima nuclear disaster in Japan; Germany and Switzerland subsequently decided to abandon nuclear power.

Figure 5-2: Electricity generation capacity scenarios, 2010-2030



Source: DoE (2011b) and author's calculations

Hydrogen

The National Department of Science and Technology (DST, 2011) has identified hydrogen as a strategic focus area and has allocated millions of rands to universities to conduct research into hydrogen energy and fuel cell technology. Hydrogen is the most abundant element in the universe and it can be burned as a fuel or used in fuel cells to generate electricity. However, hydrogen is not available freely in the physical environment, but has to be split from carbon atoms (bonded in hydrocarbons like natural gas or coal) or oxygen atoms (through electrolysis of water). Hydrogen, like electricity, therefore, is an energy carrier rather than an energy source. An advantage of hydrogen as an energy carrier is that many different primary sources can be used to make it, including hydrocarbons, nuclear and renewable energy. However, both methods of producing hydrogen require energy inputs and are less than 100 per cent efficient; i.e. more energy is needed as an input than is contained in the resulting hydrogen (Strahan, 2007).[157] On the demand or consumption side, hydrogen is also flexible. It can be burned in internal combustion engines, or combined with oxygen in fuel cells to produce an electric current.

However, hydrogen has several major drawbacks (Gilbert & Perl, 2008: 146). First, fuel cells are costly and unreliable. Second, hydrogen storage and distribution require specially designed and currently expensive infrastructure, which would probably take decades to roll out. Third, hydrogen poses safety risks since the gas is highly flammable and difficult to contain as the molecules are so small. Fourth, although the direct efficiency of a hydrogen fuel cell is more than twice that of a conventional internal combustion engine, overall some 75% of the energy is lost in the process of manufacture, distribution and final use of the hydrogen in the fuel cell so that it is actually less energy efficient than a petrol-electric hybrid car (Strahan, 2007: 87).[158] It would be more efficient to

[157] Most hydrogen produced in the world today is made from natural gas and other fossil fuels; only 4% is made via electrolysis (Strahan, 2007). This is because electrolysis requires a much higher energy input, amounting to 35% of the energy content of the hydrogen product.

[158] According to Gilbert and Perl (2008: 146), "The transition from electricity to hydrogen and then back to electricity involves energy losses of between 57 per cent and 80 per cent."

use electricity directly in electric vehicles, especially considering the costs involved in building hydrogen storage and distribution infrastructure.

In sum, hydrogen does not make sense as a vehicle fuel because of efficiency losses and storage problems. Hydrogen may play a role for storage of energy derived from renewable sources such as solar and wind power, but a number of technical challenges will have to be surmounted and the supporting infrastructure will be very costly and will likely take decades to construct.

Alternatives to non-energy uses of petroleum

Bitumen, a by-product of oil refining that is used for road surfacing, can be substituted by cement. Cement, however, like bitumen, is capital, transport and energy intensive (Zammataro, 2010), and it also carries large negative environmental externalities (Monbiot, 2006). Fortunately, there are several promising alternatives for "eco-road building" that use local, sustainable materials with lower carbon footprints and that require less mining and transport (Zammataro, 2010; Lennox & MacKenzie, 2008). These include: wood or palm lignin (by-products of paper production and palm oil, respectively); pine resin; drying oils (for example derived from the Jatropha plant); oil, resin and biomaterial blends; Geotextile and Biofibre Reinforcement; and Pozzolanas and cement substitutes (Lennox & MacKenzie, 2008). The development of such alternatives could boost local economies and create employment opportunities. The potential for wood lignin is significant given the large established wood and paper industry in South Africa, although other substitutes such as Jatropha oil would have to be established from scratch.

In South Africa, petrochemical products are currently produced by Sasol from natural gas that is imported from Mozambique. Petrochemical products such as plastics, pesticides and pharmaceuticals can alternatively be manufactured from biomass (Gonzalez-Gutierrez, Partal, Garcia-Morales, and Gallegos, 2010). However, the use of biomass for this purpose could be constrained by scarcity of water, arable land and soil fertility (see the discussion on biofuels above).

Table 5-2: Comparison of liquid fuel capital costs

Fuel type	**Capital cost** R million	**Capacity** litres/day	**Unit cost** R/litre/day	**Source**
CTL	160,000[c]	12,720,000	12,579	Donnelly (2010)
GTL	133,000[b,d]	22,260,000	5,975	Petroleum Economist (2011)
	58,800[b,e]	5,247,000	11,206	Engineering News (2011)
Ethanol	958[a]	473,000	2,024	Barradas (2007)
Biodiesel	0.085	600	142	Biodiesel Centre (2011)
	0.325	3,000	108	Biodiesel Centre (2011)
	0.025	113	221	NanoElf Biodiesel (2011)
	0.036	200	182	NanoElf Biodiesel (2011)
	164[a]	61,644	2,663	Nolte (2007)

Notes:

a. *Capital costs cited by Barradas (2007) and Nolte (2007) were for the year 2006; these values were updated to 2011 by using the GDP deflator, which increased them by a factor of 1.37.*
b. *Capital costs for the GTL plants were converted from US$ to Rands using an exchange rate of R7.00/$ (March 2011).*
c. *Sasol's proposed Mafutha project for the Waterberg in South Africa.*
d. *Shell's Pearl GTL plant in Qatar, due on stream in 2011.*
e. *Chevron/Sasol's GTL plant in Nigeria, under construction in 2011.*

5.1.2 *Cost comparisons for alternative energy sources*

Estimated capital costs for various liquid fuel alternatives are listed in Table 5-2 (above). It is clear that CTL and GTL plants are much more expensive than ethanol and biodiesel plants. Small-scale biodiesel plants have the lowest cost per litre of daily production. Feedstock costs for all types of plant are highly variable and can be expected to increase over time (as a result of depletion in the case of coal and gas, and due to land and water shortages in the case of biofuels crops).

Table 5.3 (below) displays estimates of capital costs, operation and maintenance costs, and several technological parameters (efficiency, availability, lifetime and average unit size) for a range of electricity generation technologies. The capital costs of existing coal-fired power stations are low because most date back to the 1970s and 1980s and the capital expenditures have largely been written down. No new large-scale hydro-electric plants are being considered, and capital costs of existing plants have been fully written down. Amongst the candidates for new power generation, wind has the lowest capital cost per kilowatt (kW), slightly less than supercritical coal. Solar power capital costs, especially for thermal central receivers (CSP) and photovoltaic panels, are considerably higher than other technologies. The variable operation and maintenance costs (mostly feedstock costs) are highest for new coal power plants, and zero for renewables like solar, wind and hydro.

Table 5-3: Costs and technical parameters of various electricity generation options

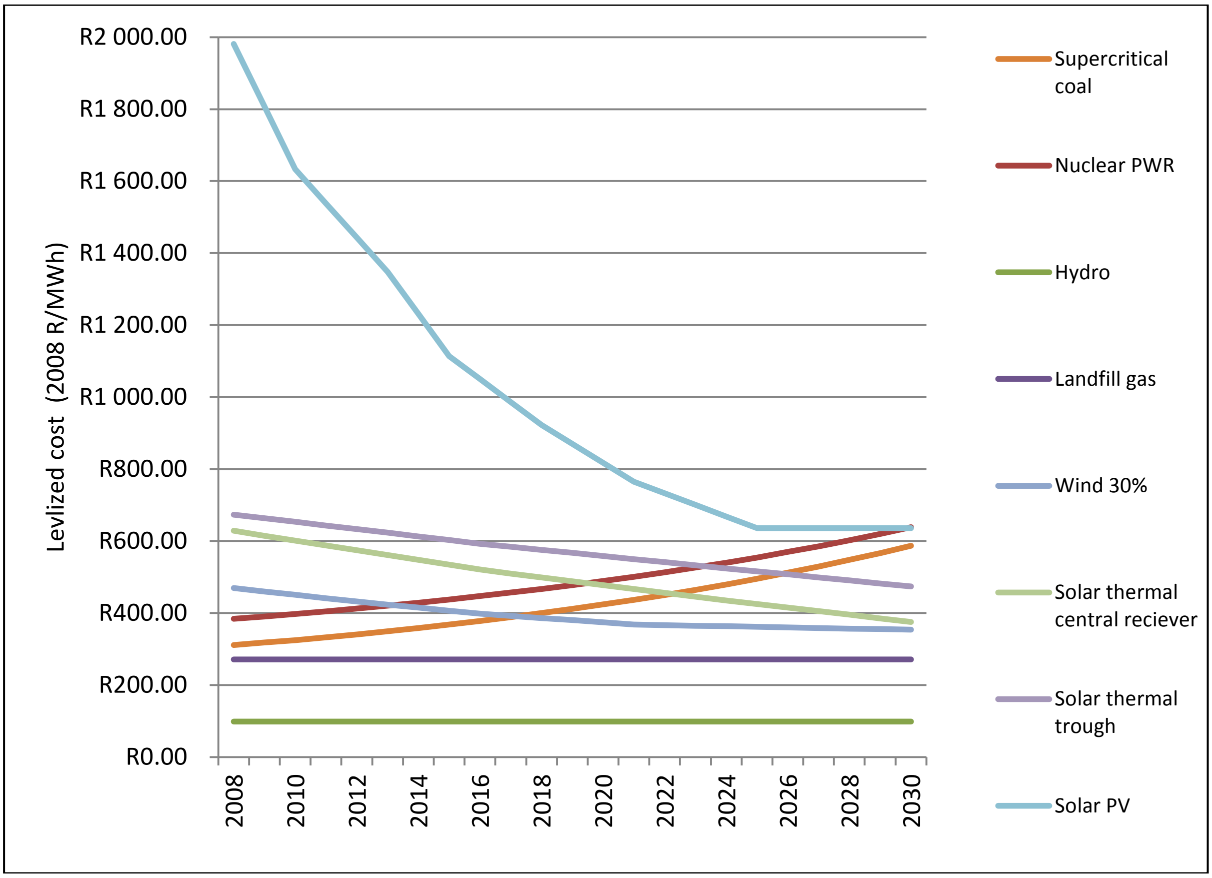
Plant description	Capital cost R/kW	Fixed O&M R/kW	Variable O&M R/kWh	Efficiency *fraction*	Availability *fraction*	Lifetime *years*	Unit Size *MW*
Coal - existing large	7,065	199	8.2	0.35	0.87	50	564
Coal - supercritical new	17,639	230	28.7	0.37	0.86	30	794
Nuclear - PWR	29,141	751	4.1	0.33	0.84	40	1,350
Hydro - existing	0	130	0.0	1.00	0.15	100	95
Landfill gas	21,076	953	0.1	0.25	0.86	25	30
Wind	16,033	253	0	1.00	0.30	20	1
Solar - thermal central receiver	63,370	474	0	1.00	0.60	30	100
Solar - thermal trough	42,247	474	0	1.00	0.40	30	100
Solar - PV	50,042	97	0	1.00	0.23	15	5

Source: Based on ERC (2010)[159]

Notes: O&M = operations and maintenance; kW = kilowatts; MW = megawatts; R = rands.

[159] These figures are derived from the SNAPP version 1.0 model, developed by the Energy Research Centre (ERC, 2010) at the University of Cape Town. SNAPP is a spreadsheet-based tool that includes technical parameters and cost estimates for a wide range of electricity generation technologies, but allows the user to select values for certain parameters, including the discount rate and future fuel (feedstock) prices.

Figure 5-3: Levelised costs of alternative electricity generation options



Source: Based on ERC (2010)

Notes:

- *The discount rate is set at 2%, reflecting an ethical favouring of inter-generation equity.*[160]
- *Fuel costs (coal and enriched uranium) are assumed to increase by 5% per annum, reflecting growing international demand and scarcity constraints (see Chapter 2 for details). Although prices are likely to be volatile over time, it is impossible to predict the cyclical fluctuations in prices; however a rising trend has a high probability of occurring. This growth rate results in roughly a trebling of fuel costs by 2030, which is not extreme considering that oil prices more than trebled between 2003 and 2008 when supply merely stagnated, rather than contracted.*
- *Cost-reducing technological learning is assumed to bring down capital costs for solar and wind energy technologies.*

Figure 5-3 (above) displays the levelised costs for the range of electricity generation technologies discussed above. The lowest costs are for hydro (R99 per MWh), followed by landfill gas (R271/MWh). Levelised costs for coal (R318/MWh) and nuclear (R390/MWh) power are the next cheapest in 2009, but rise over time owing to an assumed rise in feedstock prices, reaching R587 and R602 per MWh by 2030, respectively. The costs of wind (R460/MWh) and solar thermal (central receiver: R615/MWh; trough: R663/MWh) power are relatively high in 2009 but fall over time as a result of technological learning assumptions. Wind power becomes cheaper than nuclear power in

[160] This rate may still be considered high from an ethical point of view. For example, the Stern Review (2007) assumes a discount rate of 0.1% for evaluating the costs and benefits of climate change impacts and mitigation policies. Sensitivity analysis on the discount rate is shown in Appendix F.

2013 and coal power in 2017. Solar thermal (central receiver) technology becomes cheaper than nuclear power by 2020 and coal power by 2022. Solar PV starts out costing much more than all the other technologies (almost R2000/MWh), but becomes competitive with nuclear by 2030. It must be emphasized that the above costs for coal power exclude externalities such as environmental and health costs. Epstein et al. (2011) estimate that the hidden costs of coal mining and use in the USA amounts to approximately $345 billion a year, which is enough to nearly treble the price of coal-fired electricity. The negative externalities of coal are likely to be similar in South Africa. Furthermore, the nuclear power costs in the model exclude the costs of waste disposal and plant decommissioning. Thus when full life-cycle costs are included, renewable energy sources are considerably more competitive than the following figure suggests.

5.1.3 Demand side: conservation and efficiency

Given the limitations on alternative energy supplies, energy conservation and efficiency are essential to combat the future decline in oil availability. Since all energy sources are substitutes to some degree, a national programme to promote conservation and efficiency should apply to all energy sources. The most important area for oil conservation is transport, given that this sector consumes three quarters of oil products; measures to boost efficiency and curtailment of oil use in transport will be discussed in Section 6.1.2. Consumption of petrochemical products such as plastics can be reduced through improved recycling programmes. The need for bitumen will be reduced as road-based transport is shifted to railways (see Section 6.2). Efficiency improvements should be implemented at the point of energy generation (e.g. upgrading oil refineries and power plants to be as efficient as possible) as well as distribution (e.g. rationalising the logistics of fuel transport and/or using pipelines rather than trucks to carry fuel). Detailed discussion of efficiency measures in the electricity sector are beyond the scope of this research, but could include aspects and technologies such as the implementation of smart grids and the decentralisation of electricity generation to reduce distribution losses; the installation of solar water heaters; and cogeneration of heat and power (e.g. see Winkler, 2007; Greenpeace, 2011).

A national drive for energy efficiency and conservation should be led by central government and encouraged by a combination of awareness campaigns, statutory regulations (e.g. mandatory efficiency standards) and economic incentives (e.g. tax rebates for efficiency). Account must be taken of the rebound effect (see section 2.2.2), which can be counteracted by appropriate education and awareness campaigns (via media advertising and community engagement) and energy pricing (e.g. escalating block tariffs) (Davis et al., 2010). The programme would benefit from explicit national targets for oil demand reduction, similar to the efficiency targets adopted by the Chinese government (China Sustainable Energy Programme, 2011). National targets would best be aligned with international cooperation over oil resources.

Oil Depletion Protocol

Campbell (2006) and Heinberg (2006) outline an Oil Depletion Protocol as a cooperative response to declining oil supplies (see Appendix B for the full Protocol). The Protocol in essence requires all oil importing nations to agree to reduce their annual oil imports by a percentage equal to the World Oil Depletion Rate, which has been estimated by Campbell (2006) as approximately 2.6 per cent per annum. In addition, oil producing nations would agree to reduce their rate of production by their National Depletion Rate. The result will effectively be a global rationing system, which is intended to help stabilise oil prices and avoid wars over remaining oil, and thereby ensure that economic and social conditions are more conducive to the crash programme of mitigation required to avoid the worst potential economic impacts. Heinberg (2006) suggests that the Oil Depletion Protocol could operate along-side carbon emissions-based agreements such as a strengthened and extended Kyoto Protocol.

While the Oil Depletion Protocol has merits in theory, it would face similar obstacles to international adoption and implementation as have confounded climate treaty negotiations. In particular, there are likely to be conflicts between various groupings of countries, such as between developed and developing nations (the latter may argue that they have a right to a greater proportion of remaining oil reserves to compensate for their lower historical oil consumption), and between oil importing and oil exporting nations. The situation resembles a complex version of the Prisoner's Dilemma, in that the individually rational country strategies are likely to lead to a socially suboptimal outcome. The Protocol represents a mutually cooperative set of strategies that would be very difficult to achieve in practice.

5.1.4 Conclusions on energy mitigation

All of the potential substitutes for imported oil have advantages and limitations (see Table 5-4). The main advantages of CTLs and GTLs are that they are proven technologies which produce fuels that can be used in existing transport infrastructure. The disadvantages include a depleting resource base, low EROI, high capital costs, water scarcity, and pollution (including GHGs). Biogas has considerable potential as a sustainable, local replacement for LPG and wood fuel. Liquid biofuels might make a small contribution to liquid fuel needs, but will be severely constrained by scarcity of water and high quality arable land, and may undermine food security. The best prospects are for small-scale, decentralised biodiesel production, especially for use on farms. Electricity is a flexible energy carrier that can be used for multiple purposes including transport, although new generation, transmission and distribution infrastructure will need to be constructed. Nuclear energy provides a relatively reliable base-load power source, but faces very high capital investment and decommissioning costs, risks of contamination, and the as yet unsolved issue of long-term waste disposal. Electricity generated from renewable sources has several limitations that need to be overcome (e.g. intermittency and low power density), but shows the greatest promise for long-term sustainability. A rapid mobilisation of domestic capacity to produce renewable energy (especially solar CSP and PV, and wind turbines) is therefore recommended.

Owing to the constraints, costs, lead times and risks attached to developing alternative energy sources, a nation-wide programme of energy conservation and efficiency is imperative to address the oil supply challenge. In fact, conservation should be the first priority, since it offers opportunities to capture "low hanging fruit" that are cheaper and easier to implement, while constructing new infrastructure to deliver alternative energy sources is a longer term project. Such a conservation programme should ideally be guided by a South African commitment to an international Oil Depletion Protocol, whereby all signatories would commit to a targeted annual reduction in oil consumption.

The future balance between energy supply and consumption depends on many factors such as the rate and composition of economic growth, improvements in energy efficiency, the government's climate change response strategy, and not least of all the impact of the global oil peak (including its effect on the viability of new infrastructure developments and the prices and availability of primary energy sources, both domestic and imported). The additional electricity that would be required in a transport modal shift away from internal combustion engines will be considered in Section 5.2.

Table 5-4: Pros and cons of alternative energy sources in South Africa

Energy Source/Carrier	Advantages	Disadvantages & Constraints
Coal-to-liquids	proven technology can be used in existing vehicles	low EROI depleting coal reserves high capital cost rising feedstock costs pollution (CO_2, sulphur) water scarcity
Gas-to-liquids	proven technology can be used in existing vehicles possible new sources of gas (e.g. UCG)	depleting gas reserves high capital cost rising feedstock costs pollution (CO_2) water scarcity
Liquid biofuels	can be used in existing vehicles with minor modifications renewable relatively low CO_2 emissions small scale, local biodiesel possible	generally low EROI scarcity of water & arable land could compete with food production could accelerate soil degradation
Biogas	renewable substitute for LPG useful by-products	capital costs might inhibit low-income households and small-scale farmers
Renewable electricity	flexible usage for multiple purposes abundant sustainable sources (solar, wind, ocean) technological improvements raise efficiency over time low CO_2 emissions	intermittency low power density new infrastructure required (incl. transmission) solar relatively expensive now
Nuclear power	flexible usage for multiple purposes substantial domestic uranium reserves reliable base-load power	reliance on imported enriched uranium very high capital costs escalating feedstock costs risk of radioactive contamination no solution for long-term waste decommissioning costs pollution from uranium mining
Hydrogen	storage for renewable electricity	not a primary energy source inefficient conversion processes costly new infrastructure transport & storage difficulties

5.2 Transport

Mitigating global oil depletion in the transport sector amounts to reducing the overwhelming dependence on petroleum fuels of the various modes of passenger and freight transport, especially motorised road and air transport. The DoT is aware of the peak oil issue, although it is not yet fully and explicitly reflected in policy documents. The national Department of Transport (DoT, 1996) expressed its vision as to ''Provide safe, reliable, effective, efficient, and fully integrated transport operations and infrastructure which will best meet the needs of freight and passenger customers at improving levels of service and cost in a fashion which supports government strategies for economic and social development whilst being environmentally and economically sustainable''. The National Transport Master Plan, still under development in early 2011, incorporated a set of reports on the implications of global oil depletion for transport in South Africa (ASPO-SA et al., 2008a, 2008b, 2008c, 2008d). Encouragingly, the DoT has recently given renewed attention to railways, including investigations into the feasibility of constructing high-speed rail lines on major transport corridors and upgrading passenger rail infrastructure (Business Report, 2011a). Integrated (bus) rapid transit systems were already under construction in several major cities as of 2011, with more such systems planned. Nonetheless, very large amounts of money were spent in recent years on oil-related transport infrastructure such as roads and airports, especially in preparation for the 2010 FIFA Soccer World Cup tournament.

This section considers a wide range of options for reducing the transport system's dependence on oil. Broadly speaking, the options are: (1) to use the existing infrastructure more efficiently; and (2) to create new, less oil-dependent transport infrastructure.[161] Section 6.2.1 addresses demand side interventions aimed at improving energy efficiency and curtailing oil use in transport. Many of these measures can be implemented in the short to medium term. Section 6.2.2 discusses supply side responses, including improved vehicle design, alternatives to the internal combustion engine as a propulsion system for land-based transport, and shifts between transport modes. These are generally longer term strategies. In both demand and supply side cases, specific policy measures and constraints facing these are identified. Since road-based transport accounts for the bulk of oil demand, it is the primary focus for mitigation measures, although rail and air transport are also considered. The concluding subsection (6.2.3) summarises the numerous mitigation options and discusses the concept of a "transport revolution", and how it might be catalysed.

5.2.1 Demand side measures

To a certain extent, high oil prices will stimulate behavioural responses by transport users in ways that conserve fuel through improved efficiency and curtailment. However, it is well known that the short-term price elasticity of demand for transport is low (IEA, 2005: 14). Government can provide incentives and information, and promulgate regulations, that encourage fuel conservation, reduce wastage and enhance efficiency. The following measures apply in particular to private passenger vehicles, but to a large extent are also relevant for buses, MBTs and freight vehicles (light and heavy goods vehicles).

In the first place, economical driving ("ecodriving") behaviour can have a significant impact on vehicle fuel efficiency, saving up to 5% of fuel (IEA, 2005). Ways in which drivers can improve fuel efficiency include: appropriate use of gears; curtailment of unnecessary idling; reduced use of air-conditioning; driving with windows closed; and avoidance of excessive acceleration and braking (Vanderschuren et al., 2008: 25). Another source of increased fuel efficiency is improved vehicle

[161] A third strategy, namely to reduce the need for transport through appropriate land use policies, is considered in Section 6.5.

maintenance, which includes correct tuning of the engine, maintaining the correct tyre pressures, regular replacement of air filters, and use of appropriate motor oil (Vanderschuren et al., 2008: 25). Government authorities can encourage ecodriving through public education and awareness programmes, and including relevant questions in learner driver tests.

Second, traffic management systems can reduce fuel consumption by between 5-15% by helping to ensure that vehicles travel at more efficient speeds (Vanderschuren et al., 2008: 25). One of the most effective ways to reduce fuel consumption in road vehicles is to reduce maximum road speed limits (IEA, 2005), for example to 90 kilometres per hour for highways. Success, however, will depend on adequate enforcement, and require expenditure on new signage and possibly extra law enforcement personnel. In September 2011 the Minister of Transport, Sibusiso Ndebele, stated that he would request Cabinet to assess the possibility of reducing the national road speed limit from 120 km/h to 100 km/h (DoT, 2011).[162] Other management options that have been found to improve fuel efficiency include fleet tracking systems for freight vehicles and onboard navigation systems for passenger vehicles (Vanderschuren et al., 2008: 25-26).

Third, the greatest opportunity for achieving energy efficiencies in passenger transport lie in boosting vehicle occupancy rates (see Section 3.2). This applies mainly to private cars, but also to buses, trains and airplanes. Car-pooling (or ride-sharing) aims to reduce the prevalence of single-occupant private vehicles by encouraging drivers to take passengers. Authorities can promote car-pooling by establishing car-pool or high-occupancy vehicle lanes on urban freeways,[163] designating park-and-ride lots, introducing internet-based systems to match riders, and conducting awareness campaigns (IEA, 2005). The IEA (2005) found car-pooling to be the single most effective measure for rapid oil demand restraint in terms of quantity of fuel saved. However, widespread car-pooling could face obstacles in a South African context, for example because of high crime rates and fears of hijackings. Some cities in the northern hemisphere have introduced car sharing schemes, in which residents effectively share the use of vehicles (ASPO-SA et al., 2008c: 56; CarSharing.net, 2011). This option would require an even higher level of trust and cooperation among community members.

Fourth, there are several ways to reduce the need for commuting in cities. For example, telecommuting (working via the Internet) and tele-shopping (purchasing online with efficient delivery systems) rely on telecommunications to reduce the need for physical travel. However, the scope for telecommuting in South Africa is limited both by suitable types of employment and by the need for computer equipment and Internet connectivity. A fairly large percentage of those employees with jobs conducive to telecommuting probably own personal computers and have Internet connections already. Any additional costs of telecommuting should ideally be borne by employers, which could reduce company travel allowances to offset these costs. A similar option is for companies to be encouraged to introduce flexible work schedules, such as work weeks compressed into fewer, longer days, thus requiring fewer car trips (IEA, 2005), or staggered start and end times (to reduce traffic congestion).

Fifth, car ownership, and hence fuel consumption, can be dissuaded through fiscal incentives such as the imposition of higher taxes on new vehicle sales (Vanderschuren & Jobanputra, 2005). In 2010 the National Treasury introduced a carbon emissions tax on new vehicles sold in South Africa. Moreover, reduction or elimination of company car and travel allowances (which have been estimated to raise

[162] An official from the Department of Environmental Affairs subsequently told a parliamentary committee that such a speed limit reduction would help to reduce carbon emissions from transport (Hartley, 2011).

[163] High-occupancy vehicles (HOV) lanes have yet to be introduced in South Africa, apart from a short-term pilot project, but are under consideration for implementation as part of the Gauteng Freeway Improvement Project (de Vries, Bester and van Biljon, 2010). Public transport lanes were in operation on the N2 in Cape Town and N3 in Durban as of 2011. Adequate enforcement is critical to the success of HOV lanes.

fuel consumption by 8%) would also tend to reduce oil consumption (Vanderschuren et al., 2008: 26). Congestion charging (i.e. charging a levy on cars entering specific urban zones) in cities is another way to induce a reduction in private car use.

Six, another curtailment option is fuel rationing. This could take various forms, e.g. banning fuel purchases on certain days of the week or restricting hours of fuel sales; fuel allocation coupons (which should be tradable to improve efficiency); or selective driving bans (e.g. restricted entry to city centres based on odd/even vehicle licence plates). Fuel rationing would be particularly important if consumers react to high oil prices or shortages by panic and hoarding behaviour (IEA, 2005: 15). On the negative side, fuel rationing is often economically inefficient (IEA, 2005: 15), and is likely to be difficult to implement and face serious opposition from consumers, including (perhaps especially) taxi owners and drivers. However, from an equity point of view it might be a very important way to maintain social cohesion, as the alternative is price rationing, which impacts the poor most severely and exacerbates inequalities.[164]

Seventh, higher fuel taxes can be imposed as a way of encouraging lower fuel demand, while simultaneously raising revenue that can be spent on public transport systems and reducing negative externalities of road transport such as pollution and traffic accidents (Gilbert & Perl, 2008: 282; Litman, 2008). Raising fuel levies in advance of oil price spikes could provide some leeway for cushioning the impact of oil shocks by reducing the levy when prices are high, helping to stabilise price fluctuations. In the South African context, however, higher fuel taxes would likely be very unpopular and may be met with protest action. The taxi industry in particular would likely be vehemently opposed to such measures. At the least, however, the IEA (2005) recommends that authorities do not yield to any pressure by the public or lobby groups to reduce fuel taxes, so as to avoid distortionary impacts on price signals.

Air travel (international and domestic) accounts for approximately 11% of transport sector fuel consumption in South Africa (see Section 3.2.2). Demand for air travel may be managed through taxes (e.g. on jet fuel, which is not currently taxed, or on airline tickets). As air travel is the preserve of the relatively wealthy, such taxes would not have the same degree of equity considerations as taxes on road fuels. Telecommuting and video conferencing present especially attractive measures to reduce air travel demand and provide a prime example of “dematerialisation” through the use of advanced technology.

For road freight transport, several of the foregoing measures can be implemented, including improved driver behaviour and vehicle maintenance, the imposition of higher fuel and vehicle taxes, and appropriate traffic management. Road freight transport is effectively subsidised by government spending on road infrastructure; such subsidies could be terminated through the charging of appropriate road tolls. Policies that promote localisation of economic activities (see Section 5.4.3) will also help to reduce oil consumption by freight transport. Lane (2009) assessed a comprehensive range of measures to improve the sustainability and energy efficiency of freight transport. She found that the most promising measures are efficiency improvements, including vehicle maintenance, route optimisation and scheduling, and intelligent traffic management, while driving bans, tolling schemes and fuel rationing were considered to be unviable.

Cost-effectiveness estimates

Public awareness campaigns can involve the preparation and dissemination of fact sheets via digital and print media, including email, broadcast fax, radio and television, and press releases (IEA, 2005). In most cases, government can make use of public media services at little or no cost, although a cost of R100,000 is assumed. Information pamphlets (containing tips on eco-driving, vehicle

164 The issue of fuel rationing and social equity is discussed in greater detail in Section 5.5.1.

maintenance, car-pooling, etc.) could be produced, at an assumed cost of R1 per copy, and distributed to four million vehicle owners/drivers. Pamphlet preparation costs and personnel costs are assumed to be R100,000 each.

Table 5-5: Estimated costs of a public awareness campaign for fuel efficiency

Costs	**Rand**
Pamphlet preparation	100,000
Pamphlet printing	4,000,000
Personnel costs	100,000
Public announcement costs	100,000
Total costs	4,300,000

Source: Author's estimates

The cost-effectiveness of various demand side transport mitigation measures is shown in Table 5-6. As found by the IEA (2005: 128), "[t]he most cost-effective policies are clearly those that can be implemented mainly with a public information campaign", such as eco-driving, telecommuting and flexible work schedules. Measures that involve some infrastructure outlay, for instance restriping urban freeway lanes as car-pool lanes and providing signage for driving bans and speed limit reductions, are more costly. It should be noted, however, that some costs are not included in these calculations, such as loss of mobility and economic activity. By the same token, various additional benefits are excluded, such as safety, health and environmental benefits. It is likely that implementing the full range of mitigation measures will unleash synergies (e.g., a single information campaign can include the full range of measures) and lead to even greater fuel reductions (IEA, 2005: 132). Overall, all of these demand restraint measures promise substantial fuel savings at very low costs compared to the cost of fuel.

Table 5-6: Cost-effectiveness of fuel saving mitigation measures

Category	Measure	Total cost	Fuel saving	Fuel saving	Cost effectiveness
		Million Rands	%	Million litres	R/litre saved
Eco-driving	Information campaign	4.3	5%	566	0.01
Speed limit reduction	Total	50	3%	339	0.12
(90km/h)	*Signage*	*40*			
	Enforcement	*10*			
Car-pooling	Total	84.3	7%	792	0.11
	Information campaign	*4.3*	*1%*	*113*	*0.04*
	System to match riders	*0.3*			
	Restriping freeway lanes	*84*			
	Enforcement	*10*			
Telecommuting	Information campaign	4.3	4%	453	0.01
Flexible work schedules	Information campaign	4.3	3%	317	0.01
Driving ban (odd/even)	Total	34	20%	2263	0.02
	Signage	*20*			
	Enforcement	*10*			
	Information campaign	*4.3*			
Integrated response	*Information campaign*	*4.3*	*13%*	*1471*	*0.003*
	Enforcement, infrastructure, etc.	*164*	*29%*	*3281*	*0.05*
	Total	169	42%	4751	0.04

Source: IEA (2005) and author's estimates

Notes:

- *Percentage fuel saving estimates are drawn from the IEA (2005).*
- *Estimated actual fuel savings (in litres) are based on 2009 national petrol consumption of 11,313 million litres.*
- *The integrated response saves on publicity and enforcement costs.*

5.2.2 Supply side measures

Supply side mitigation responses address the types and design of transport infrastructure, especially motorised vehicles. Options include improving the design of existing oil-powered vehicles, developing alternative propulsion systems that rely less (or not at all) on oil, and shifting between transport modes to those that are more energy efficient and/or not reliant on oil.

Improving vehicle design

Internal combustion engine vehicle (ICEV) technology has not changed fundamentally in over a century. ICEVs are highly energy inefficient, using approximately 17% of the energy contained in the fuel to propel the vehicle and less than 1% to move a single occupant (Lovins et al., 2005: 46). This is because most of the energy is lost as heat and noise in transmission to the wheels, and because vehicles are very heavy compared to passenger weight. Further energy is lost through "aerodynamic drag" (air resistance), "rolling resistance" (heating the road and tyres) and "braking loss" (Lovins et al., 2005: 46).

Improvements in the design of vehicles, for example in terms of size, materials and engine configuration, can bring substantial fuel efficiency benefits (Lovins et al., 2005). In general, smaller vehicles are lighter and therefore more fuel efficient, since between 60% and 75% of fuel consumption is usually weight-dependent (Lovins et al., 2005: 47). According to Lovins et al. (2005: x), the largest opportunity for fuel saving is presented by ultra light vehicle design that uses "advanced composite or lightweight-steel materials", which can nearly double fuel efficiency. A switch from petrol to diesel vehicles would also bring substantial fuel savings, since diesel vehicles are typically up to 30-35% more fuel efficient than comparable petrol driven vehicles (Vandershuren & Jobanputra, 2005; Vanderschuren et al., 2008: 22). However, when fuel supplies become tight, the price of diesel may rise considerably higher than that of petrol since it is the predominant fuel for road freight transport.[165] Therefore a substantial expansion of the diesel passenger car fleet may be limited. Improvements in vehicle design (e.g. aerodynamics and friction management) can also boost fuel efficiency in other modes of transport, such as air and rail (ASPO-SA et al., 2008c: 52-53).

Government can influence vehicle design and the purchasing choices of consumers in several ways. First, the state can mandate higher fuel efficiency standards for vehicle manufacturers. As part of the National Climate Change Response Policy, the Department of Transport is to "create an Efficient Vehicles Programme with interventions that result in measurable improvements in the average efficiency of the South African vehicle fleet by 2020", including a specific Government Vehicle Efficiency Programme (RSA, 2011: 31). Second, so-called "feebates", i.e. combinations of taxes on inefficient vehicles and rebates on efficient models, are the most effective fiscal instruments for altering consumer incentives, and can be revenue neutral (Lovins et al., 2005: xi; Vanderschuren & Jobanputra, 2005). Such measures have been successfully implemented in other countries, such as the US and EU (Vanderschuren & Jobanputra, 2005; Heinberg, 2006). Third, scrappage policies, which provide financial incentives for consumers to replace their cars, can be used to boost the uptake of newer, more efficient vehicles. However, scrappage incentives would incur costs to the state that could be used more effectively for other purposes (Vanderschuren et al., 2008), and in any event rising fuel prices will provide a similar incentive. For freight vehicles, Lane (2009) assessed the viability of old vehicle replacement schemes to be doubtful. Fourth, government can implement a procurement policy aimed at boosting the number of efficient vehicles.

[165] In South Africa, the price of diesel rose above that of petrol for the first time during the price spike in 2008.

The main constraint on harnessing the benefits of improved vehicle design across all modes is likely to be the cost of purchasing new vehicles, airplanes and rolling stock. Although automobile manufacturers may initially oppose efficiency standards, in the longer term they will benefit from higher sales revenue as customers opt to buy more efficient models which enable them to offset the higher capital outlay with lower fuel expenditures.

Alternative fuels and vehicle propulsion systems

Although ICEVs have totally dominated road-based transport both globally and in South Africa for the past century, by 2011 several alternative fuels and vehicle propulsion systems were either already available or were under development and intended by manufacturers to be commercially available within a few years. For the most part, these new vehicles are for private passenger transport, although in some cases the technologies are being used for buses, MBTs and even trucks. These technologies include liquefied petroleum gas (LPG) vehicles, compressed natural gas (CNG) vehicles, compressed air vehicles (CAVs), hydrogen powered vehicles (HPVs), hybrid-electric vehicles (HEVs), plug-in hybrid vehicles (PHVs), battery electric vehicles (BEVs) and grid-connected vehicles (GCVs). The merits and limitations of each will be considered below, and policies described that can boost their market penetration.

ICEVs can be powered by LPG, which is one of the by-products of crude oil refining (accounting for approximately 5% of total refined product volume) and is also produced synthetically by Sasol and PetroSA from natural gas and coal, respectively. LPG can be used as a fuel for conventional petrol motor vehicles after minor modifications have been made (mainly involving the installation of a new tank to store the LPG). As a vehicle fuel it has two main advantages over petrol: (1) it is cleaner burning (i.e. it generates lower emissions of nitrogen oxide and carbon monoxide); and (2) engines running on LPG require less maintenance and last longer. However, LPG vehicles are slightly less energy efficient than petrol vehicles (Taylor, 2011). LPG vehicles, including automobiles, buses and trucks, are already fairly common in some parts of the world, such as Europe and the United States (Vandershuren et al., 2008: 23). However, in South Africa the Department of Energy does not support the use of LPG as a transport fuel (Vanderschuren et al., 2008: 23), mainly because it promotes the use of LPG for other purposes, especially as a household energy source for cooking (GCIS, 2007). Moreover, given that LPG is derived from crude oil, LPG vehicles do not represent a true alternative to oil-powered vehicles. Constraints on LPG supplies, and demand for other purposes, probably preclude its widespread use for transport (see Section 5.1 above).

Compressed natural gas (CNG), stored in an on-board cylinder, can be used to power a modified ICE (Kendall, 2008: 131). CNG vehicles are increasingly popular in some countries, but have yet to penetrate the South African market since natural gas is scarce (see Section 5.1). In any event, Kendall (2008: 132) notes that it is more efficient to convert gas into electricity in power plants and use this to run electrified mass transit, rather than to use the gas in many individual ICEs. Thus CNG vehicles do not present a viable alternative in South Africa in the foreseeable future.[166]

Compressed air vehicles (CAVs) have motors that are powered by compressed air stored in high pressure tanks. Advantages include a simpler design with fewer parts. Electricity is required to compress the air, and there are energy efficiency losses in the process of conversion from primary source to electricity to compressed air. Creutzig et al. (2009: 1) conclude that "[e]ven under highly optimistic assumptions the compressed-air car is significantly less efficient than a battery electric vehicle and produces more greenhouse gas emissions than a conventional [petrol]-powered car with a coal intensive power mix." CAVs were in a prototype phase of development by 2011, and had not

[166] If sufficient gas were found, the IEA (2010: 186) states that "[t]he biggest potential lies with heavy-duty vehicles (trucks and buses), as the costs of installing refuelling infrastructure for light-duty vehicles and adapting cars to run on gas are likely to limit the growth of CNG use in light vehicles."

yet been commercialised. By early 2011 there were indications that hybrid ICE-CAVs might help to increase energy efficiency and could be cheaper than HEVs (Guardian, 2011).

Prototype vehicles have been developed that run on hydrogen gas or hydrogen fuel cells. However, there are many serious obstacles to commercialisation, including the requirement for a new infrastructure for storage and distribution of hydrogen; safety concerns; and a very high cost for hydrogen powered vehicles. Perhaps most seriously, the energy efficiency of HPVs is very low because of efficiency losses in the conversion of primary sources into hydrogen (Strahan, 2007; see Section 5.1). BEVs have far superior energy efficiency (Gilbert & Perl, 2008). For these reasons, HPVs are unlikely to have any significant market penetration in the foreseeable future.

Hybrid-electric vehicles (HEVs) use a combination of a conventional ICE together with electrical motor technology. Several hybrid models are available or under development, the best known being the Toyota Prius. Hybrids can be up to twice as fuel efficient as comparable ICE cars (Vandershuren et al., 2008: 23),[167] but are still dependent on oil. Market penetration has been very slow in South Africa, partly due to the relatively high cost of hybrid vehicles.[168] A Toyota Prius was priced at R332,700 in early 2011, compared to approximately R200,000 for a comparable Corolla sedan. Nevertheless, hybrids offer a potentially significant source of fuel savings should they become more affordable as the technology matures and scale economies are harnessed.

Battery electric vehicles (BEVs), which use energy stored in on-board batteries to power electric motors, have several great advantages over ICEs: (1) they do not rely on liquid petroleum fuels; (2) they are substantially more energy efficient than ICEs; (3) they are quiet and provide rapid acceleration at low velocities; (4) their maintenance requirements are much lower; and (5) their 'tailpipe' emissions at the vehicle are negligible (Gilbert & Perl, 2010: 3). However, BEVs also have several drawbacks. First, the cost of batteries is still very high, and the materials currently used (e.g. lithium) could face supply constraints if production volumes increase significantly (Johnson, 2009). Second, BEVs have limited driving ranges between charges, which take several hours (Vandershuren et al., 2008: 23). Limited range is likely to be a greater obstacle for the use of EV trucks for freight haulage than for urban passenger travel; HEVs show greater promise for freight (Lane, 2009). Third, BEVs have to carry a high weight in batteries (up to several hundred kilograms), which utilise space and increase the vehicle's energy consumption. Energy losses also occur in charging and discharging batteries (Gilbert & Perl, 2010: 3). Major advances in battery technology are likely required for widespread deployment of BEVs on anything like the current scale of automobile usage.

Plug-in hybrid vehicles (PHVs) are similar to HEVs but have larger batteries that can be charged from their ICEs while in motion or from the electricity grid when stationary (Gilbert & Perl, 2008: 153). The first PHV, the Chevrolet Volt, became available for purchase in the United States in 2011. PHVs offer similar energy efficiency to HEVs and longer ranges than BEVs. The major drawback of PHVs is their greater cost, although this might fall as economies of scale are exploited.

Grid-connected vehicles (GCVs) are powered by electricity that "is generated remotely and delivered directly by wire or rail to the motor as the vehicle moves"; examples include heavy rail, light rail, trams, and trolley buses (Gilbert & Perl, 2010: 3). GCVs have some major advantages: they have a proven track record spanning over a century, being used for intra- and inter-city travel in many countries; they are the most energy efficient form of motorised transport; and they do not require

[167] The 2004 model Prius is more than twice as efficient in tonnes per km/litre than a modern non-hybrid car (Lovins et al., 2005: 48).

[168] In the Long-term Mitigation Scenarios (LTMS) published by the Department of Environmental Affairs and Tourism (DEAT, 2007), hybrids were identified as one of the most costly mitigation options per unit of emissions saved.

heavy and costly batteries as do BEVs. For example, trolley buses in the US consume on average 0.85 megajoules per person-kilometre (MJ/pkm), while diesel buses use 2.40 MJ/pkm (Gilbert & Perl, 2008: 156). Disadvantages include large infrastructure requirements (constructing the grid) and hence high initial capital costs, and the fact that mobility is limited to the grid's coverage (although in some instances batteries could be added to allow limited off-grid travel). Nevertheless, Gilbert and Perl (2008, 2010) see GVCs as forming the backbone of future land-based transport systems. The most energy efficient form of rail transport is "magnetic levitation" (maglev) trains, which also offer reduced maintenance costs, higher speeds and greater passenger comfort (Quain, 2007a; 2007b). However, as of 2011 there were only a few maglev systems in operation in the world (in Japan, China and Germany) mainly as a result of their very high construction costs (Quain, 2007b).

Left to themselves, markets will determine which alternative propulsion technologies are successfully commercialised, depending on both supply factors (e.g. technologies and costs) and demand patterns (e.g. consumer preferences).[169] Vested business interests and consumer resistance to change could thwart the transition to more sustainable transport systems (Kendall, 2008: 151). Nonetheless, certain specific policy interventions may be implemented to boost the uptake of the most energy efficient alternative vehicles (e.g. BEVs and GCVs), in order to mitigate future oil scarcity. These include: tax incentives for manufacturers (e.g. tax breaks for research and development into efficient design and battery technology); a feebate system to encourage purchases of efficient vehicles; government vehicle procurement programmes targeting efficient vehicles; providing supporting infrastructure such as public charging facilities for BEVs; allowing exemptions from toll road fees; and imposing regulations on vehicle emissions (e.g. mandating a certain percentage of zero emission vehicles) (Kendall, 2008).

A great advantage of alternative road vehicles is that they permit the use of existing road infrastructure, thus saving considerable costs that would be incurred for instance in building new railways. Another advantage is that BEVs, PHEVs and GCVs can be powered by electricity generated from renewable energy resources. However, there are two major constraints facing a large-scale replacement of ICEVs with alternative vehicle technologies. First, the vehicle manufacturers' production capacity for new technologies such as BEVs and PHVs will take several years to scale up significantly from negligible levels in 2011. Secondly, there is a substantial roll-out time for replacing an ICEV fleet because of affordability constraints.[170] Figure 5-4 shows the number of new passenger vehicles sold per annum between 2000 and 2009. Clearly, vehicle sales are influenced by broader economic conditions such as the rate of economic growth and interest rates. In 2009, when the economy was in recession, 224,754 new passenger vehicles and 129,216 new commercial vehicles were sold (353,970 vehicles in total). The total licensed passenger vehicle population in 2009 was 5,411,093 passenger cars and 2,596,054 commercial vehicles (see Table 3-7 in Section 3.2.1). At the 2009 rate of sales, it would take 24 (20) years to replace the passenger (commercial) vehicle fleet with more efficient models. Figure 5-5 shows that the growth rates in vehicle sales and real GDP have followed similar cyclical patterns between 1980 and 2010, although the fluctuations are much larger in the case of vehicle sales. Between 2007 and 2009 (inclusive), annual vehicle sales declined by an average of 18% per year, although the economy was in recession only in 2009.

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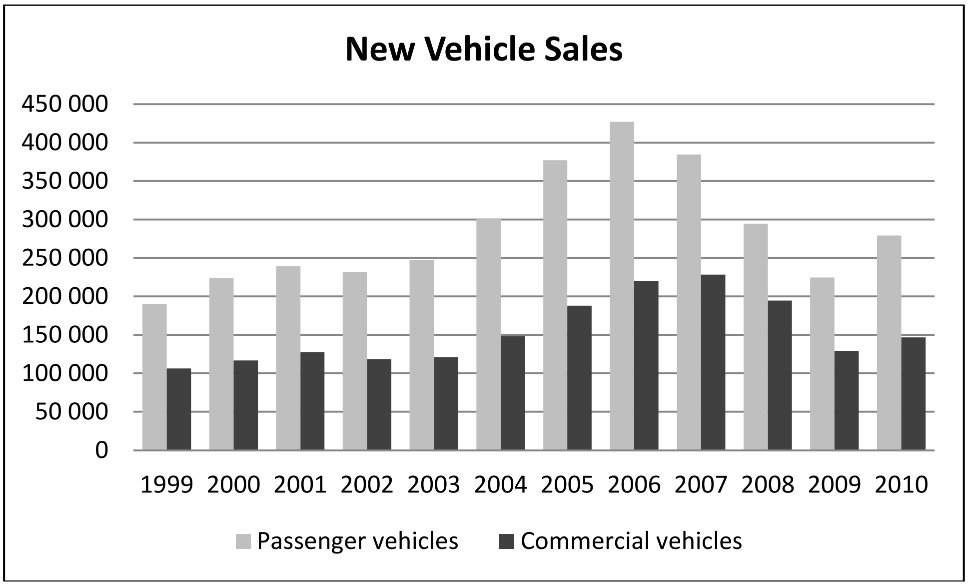
[169] South African vehicle manufacturers are generally followers of world developments in automotive technology (Vandershuren et al., 2008: 22). One exception is the local development of the "Joule" electric vehicle by a company called Optimal Energy. The Joule is expected to retail at a price of R240,000.

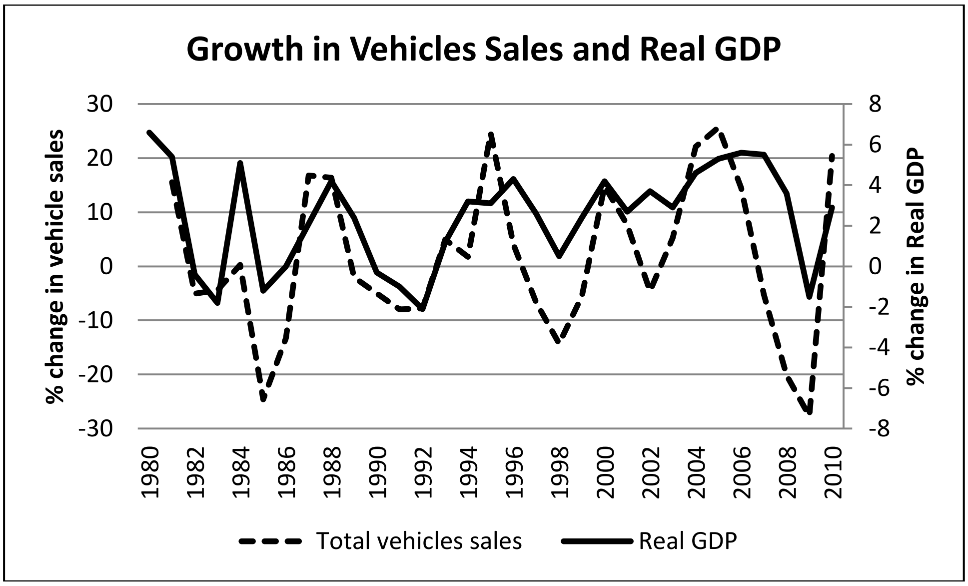
[170] The average ages of passenger and commercial vehicles in South Africa are approximately 10 and 12 years, respectively (DoT, 2004).

Figure 5-4: New passenger and commercial vehicle sales in South Africa, 1999 to 2010



Source: NAAMSA (2011)

Figure 5-5: Growth in passenger vehicle sales and real GDP, 1980 to 2010



Source: Author's calculations based on SARB (2011) and NAAMSA (2011)

Vehicles represent a very large expenditure item for households and businesses, which will likely be facing increasingly adverse economic circumstances and falling discretionary incomes and profits, respectively. Figure 5-6 projects the total passenger vehicle stock and the percentage replacement by new vehicles, assuming a 5% annual decline in vehicle sales. The decline in sales is based on the assumption that GDP and household income will contract, and/or fuel and vehicle prices will rise, as global oil supplies decline. Assuming 3% of the 2010 vehicle stock is scrapped every year, it would take 33 years to replace the entire passenger vehicle fleet with new (more efficient) vehicles.[171] The annual and cumulative costs of replacing the passenger vehicle fleet are presented in Figure 5-7, assuming sales units fall by 5% per annum. The annual replacement cost declines from R45 billion in

[171] In 2004, less than 0.5% of licensed vehicles were more than 40 years old; 2.7% were more than 30 years old.

2011 (approximately 1.5% of GDP) to R8.7 billion in 2043, by which time the entire vehicle stock has been replaced at a cumulative cost of almost R735 billion. If the decline in vehicle sales were 10% per annum, replacement would still take 33 years but would result in a smaller total fleet of 2.16 million vehicles with a cumulative replacement cost of R450 billion. Thus modal shifts away from private passenger (and freight road) transport are likely to be necessary, as discussed in the next subsection.

Figure 5-6: Replacement of passenger vehicle fleet with 5% annual decline in new vehicle sales

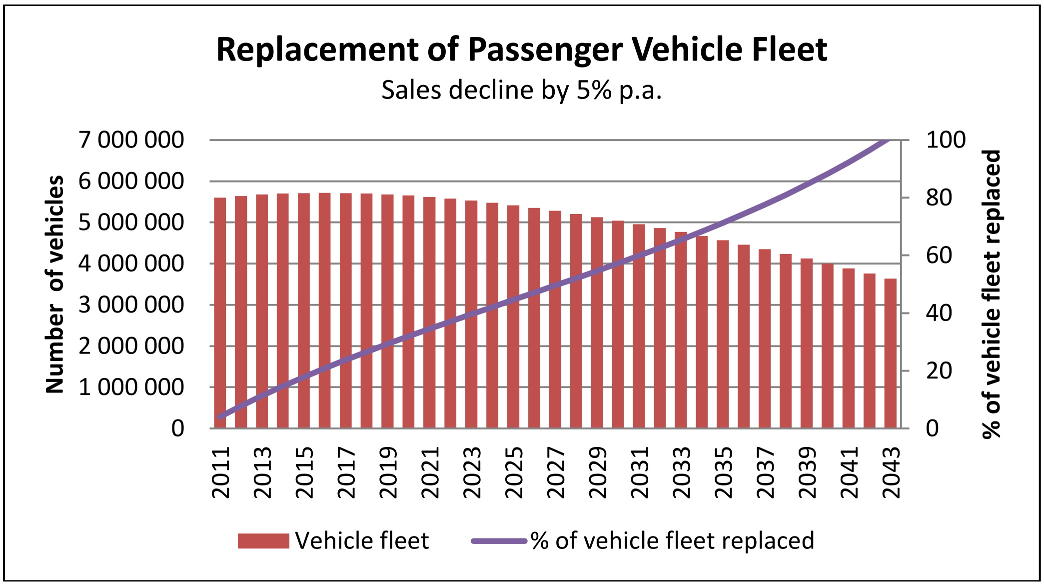
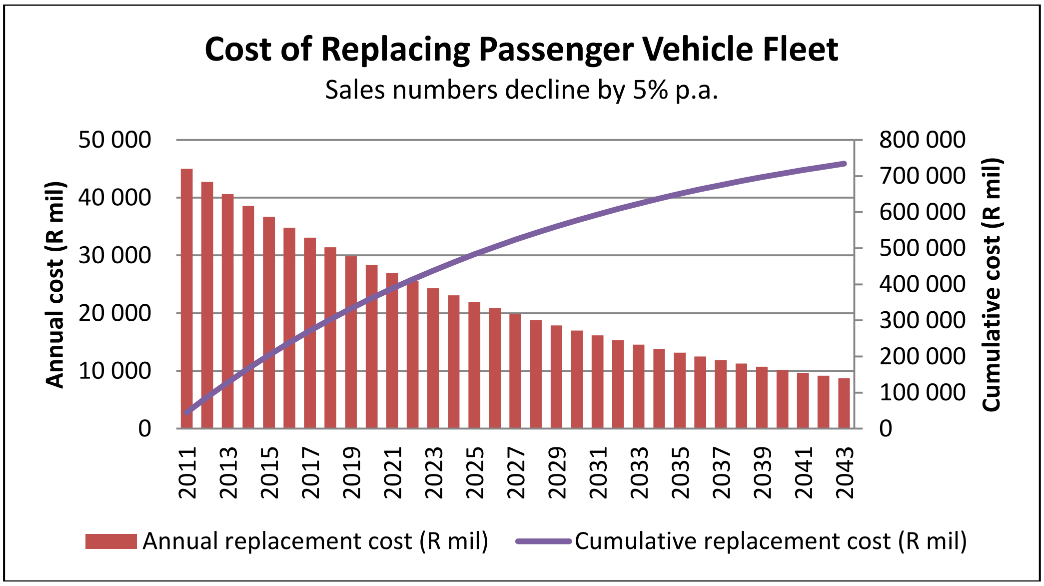


Figure 5-7: Cost of replacing passenger vehicle fleet



Source: Author's calculations based on NAAMSA (2010) and eNatis (2010)

Notes:

- *The assumed annual scrappage rate is 2.2% of the vehicle fleet, the average rate for 2007-10.*
- *The price of a new vehicle is assumed to be R200,000 (which assumes a 10% discount on the 2011 price of a Nissan Leaf BEV, allowing for future economies of scale in production). The costs are in 2010 terms and are not discounted.*

Gilbert and Perl (2010: 2, 4) argue that "[o]ver the next two or three decades motorized land transport will become mostly propelled by electric motors" and describe electricity as "the ideal transport fuel for an uncertain future."[172] This is because: (1) electricity can be derived from a wide range of primary energy sources, including renewables; (2) transport systems based on electricity can easily adapt to changing primary energy sources, and thus avoid the need for changing infrastructure that is dependent on a particular energy source (e.g. oil or natural gas); and (3) the transport system's energy requirements will not constrain innovation in energy production systems. Electrification of transport will involve the replacement of ICEVs with BEVs and GVCs, including a modal shift from road to rail. Remaining diesel and biodiesel should be prioritised for heavy uses with less flexible fuel options than personal transport, such as freight trucks and buses (City of Portland, 2007: 39), as well as air transport. Transport electrification will be time-consuming and costly (requiring enhanced/smarter electricity grids) but also provides a transition pathway for energy from oil to renewable electricity.

Modal shifts

The energy efficiency of different modes of both passenger and freight transport vary greatly (see Figure 3-16). Thus shifting passengers and freight between modes can potentially result in significant energy savings. In addition, some modes (e.g. electric vehicles and non-motorised transport) do not rely on petroleum fuels and therefore enhance energy security. For passengers, the primary modal shifts are from private road vehicles to non-motorised transport (NMT), electric bicycles, scooters and motorcycles, and collective public transport (which includes minibuses, buses and various grid-connected vehicles such as trams, trolley buses and trains). This applies to the relatively wealthy minority of the South African population who currently have access to private motor vehicles (25% in 2003, according to the DoT (2005)). In addition, some road-based public transport users (including MBT passengers) can in principle be shifted to GCV systems. Shifting from air travel to other modes (e.g. rail) is applicable to a numerically small but financially significant proportion of travellers. For freight, the main modal shifts to consider are from road and air to rail (which should be progressively electrified). In general, government can employ two strategies to encourage modal shifts: (1) use fiscal measures (e.g. congestion charges, vehicle taxes or fuel taxes) that make it more expensive for people to use road vehicles; and (2) provide alternatives modes of transport that are sufficiently attractive, e.g. invest in public transport and freight rail infrastructure. The benefits, constraints and specific policy measures to encourage these various modal shifts are considered below.

Non-motorised transport refers chiefly to walking and cycling, but also includes animal-powered transport, predominantly in rural areas. The main benefits of NMT are the absence of direct oil dependency and its low or negligible economic costs. Cycling and walking are the most energy efficient forms of passenger transport. Other benefits of NMT include reduced air pollution, health benefits associated with physical exercise, enhancement of community cohesion, and less use of land and road space (DoT, 2008: 10). NMT faces both practical and cultural constraints. Average travel distances in South African cities are high compared with international norms, thus placing severe constraints on the possibilities for NMT, which is only suitable for relatively short travel distances (Vanderschuren et al., 2009). The Department of Transport (2010) recognises that public resistance to a shift from private vehicles to NMT may present an obstacle. Another major challenge will be ensuring the safety and security of pedestrians and cyclists, especially in areas with high rates of traffic accidents and crime. Other challenges relate to geographic conditions and spatial infrastructure developments that inhibit movement (DoT, 2008). However, NMT can be promoted in urban areas by the construction of dedicated cycle lanes and pedestrian walk-ways, which should link to public transport facilities where possible. In addition, bicycle hire schemes have proven very

[172] Kendall (2008: 148) reaches a similar conclusion: "By far the most promising automotive platform is the grid-connected vehicle: depending on application, a high proportion of our future road-based mobility requirements may be satisfied with either BEVs or PHEVs."

popular in some cities, such as Copenhagen and Dublin (Daly, 2011). In rural areas, the majority of the population (lower income households) already relies on NMT, especially walking. Here the opportunity is to improve mobility, for example by subsidising bicycles for the poor or expanding public transport facilities (such as buses). The Shova Kalula (Ride Easy) programme of the Department of Transport aims to promote the use of bicycles in order to increase the mobility of low-income households, particularly amongst women, scholars and farm workers (DoT, 2010). The programme targeted a rollout of 1 million bicycles by 2010. The DoT (2010) is also considering ways to promote animal-drawn carts in deep rural areas; an example is the Kgalagadi model, in which community members construct the cart, boosting the local economy.

Electric bicycles (EBs) share the benefits of ordinary bicycles mentioned above, but are even more energy efficient and present an attractive option for commuting longer distances of up to 50 kilometres per day. As of 2010, the National Road Traffic Act classified electric bicycles along with motor vehicles, which presents something of an obstacle to widespread use. Another constraint, especially for low-income households, is the substantially higher costs of EBs relative to ordinary bicycles (see Table 5-7). Batteries need to be replaced after several years of use, but otherwise maintenance costs are low. Use of EBs could be encouraged through government subsidies, funded for example by higher road vehicle taxes.

Scooters and motorcycles have several advantages over cars, including higher fuel efficiency (compared to single-occupant cars),[173] lower capital costs, lower maintenance costs, and less usage of land and road space. They present an attractive alternative to cars for urban commuting and rural transport for individuals. Electric scooters offer higher speeds (up to 75 km/h) and longer ranges (70 kms) than EBs, and require no effort on the part of riders. At R16,600, an electric scooter is only 40% more expensive than an EB (see Table 5-7). The particular attraction of these vehicles is their complete lack of oil dependency. Although petrol scooters are oil dependent, their fuel efficiency (approximately 44 km/l) is much greater than that of passenger cars (17 km/l or lower) and also greater than that of motorcycles (approximately 30 km/l). Petrol-fuelled motorcycles permit higher speeds and longer ranges than scooters. At the end of 2009 there were 362,400 licensed motorcycles in South Africa, or 4.2% of all road vehicles, indicating much potential for growth in market share.[174] The main disadvantages of scooters and motorcycles relate to safety on roads, use in wet weather conditions, and their capacity to transport only one (or possibly two) person(s) and little luggage. A small-sized sedan car loaded with four passengers is actually more fuel efficient (in person kilometres per litre) than a scooter or motorcycle with one rider (see Figure 3-17). Use of scooters and motorcycles can be encouraged by fiscal measures, including taxes and congestion charges on (single-occupant) cars.

Minibus taxis (MBTs) provide the bulk of public transport in South Africa (see Section 3.2.1). At March 2011 diesel prices, a fully loaded diesel minibus outperformed almost all other forms of road transport in terms of cost per passenger kilometre (see Table 5-7). Such vehicles are flexible in terms of route and especially schedule, which allows them to maximise the number of passengers they carry and hence their energy efficiency. At the end of 2009 there were 282,941 licensed MBTs on South African roads, constituting 3.3% of all vehicles. The major constraint on shifting passengers from private vehicles to MBTs is arguably perceptions of safety. This could be addressed through stricter regulation of taxis, including vehicle maintenance and driver licences. Safety is being addressed to some extent through the government's taxi recapitalisation programme, which involves the scrapping of un-roadworthy vehicles and the introduction of slightly larger minibuses.

[173] This is mainly because the ratio of passenger weight to vehicle weight is much lower than for cars.
[174] Motorcycles are much more common in some other developing countries, especially in Asia.

The energy efficiency of buses is highly dependent on the load factor (number of passengers relative to maximum capacity). With low occupancy, buses are the least efficient mode of road transport, while with maximum occupancy they are the most efficient (see Figure 3-17). An efficient, well-utilised bus service would substantially reduce energy consumption, especially if the buses were hybrid-electric or fully-electric models. As of December 2009 there were 45,217 licensed buses in South Africa, accounting for just 0.5% of road vehicles (see Table 3-7). Bus services connect cities and operate within urban areas. The main obstacles to increasing bus transport are: (1) relatively high capital cost for buses; (2) passenger resistance due to real and/or perceived inaccessibility, unreliability, and lack of safety (DoT, 2005); and (3) opposition (sometimes violent) from the incumbent MBT and bus industries (Froschauer, 2010; Schalekamp, Behrens & Wilkinson, 2010). These hindrances could be addressed through government subsidies (again funded by vehicle taxes), improved service levels and more effective regulation of the MBT industry. Bus rapid transit (BRT) systems are currently favoured as a new form of mass transit in South Africa's main metropolitan centres, but entail significant infrastructure expenditures.[175] Nevertheless, the infrastructure costs of BRT systems are an order of magnitude cheaper than those of light rail (e.g. R14 million per kilometre compared to R140 million/km, respectively), can be built much faster, and are more flexible as buses need not stick to trunk routes (Hook, 2009). BRT systems can use battery-electric buses, as is the case in Bogota, Columbia (Hook, 2009).

The energy efficiency of trains, like buses, depends significantly on the load factor. For similar load factors, trains are more energy efficient than buses, cars and aeroplanes (Schiller et al., 2010). South Africa has both diesel and electric powered trains, with very little difference in energy efficiency between them (Vanderschuren et al., 2010: 6097). The national Department of Transport and state-owned enterprises such as Transnet and the Passenger Rail Agency of South Africa (PRASA) embarked on a large-scale recapitalisation of railways and rolling stock in 2005, with R170 billion allocated to transport by 2010. The Department of Transport (Mahlalela, 2010) announced a comprehensive rail investment programme in 2010 as part of the National Transport Master Plan, aimed at upgrading existing stock, acquiring new rolling stock and developing new rail corridors. One of the three major projects under consideration is a high-speed railway (HSR) linking Durban and Johannesburg.[176] A second is "to have fully-integrated transit systems in 12 urban centres and 6 rural districts by 2020" (Mahlalela, 2010). The primary obstacle to broader rail usage is capital cost. For example, the mooted Gauteng-Durban HSR was estimated to cost between R250 billion and R600 billion (Venter, 2011).[177] The DoT budgeted R97 billion for new rolling stock for passenger rail services from 2011. The DoT's vision included development of local manufacturing capacity for rolling stock. Urban light rail systems operating on existing roads would be considerably cheaper than new heavy railway lines, especially considering that land acquisition was cited as a major component of the cost of the Gautrain (Serino, 2010). Despite the high costs, the upgrading and extension of railway services represents a strategic investment in more sustainable mass public transport. Again, funding could be derived partly from higher taxes on private vehicles, at least in the short to medium term. When comparing rail to road-based transport, account must be taken of the costs of building and maintaining roads, which (as argued in Chapter 4) are expected to rise as oil and bitumen become progressively scarcer and more expensive. In addition, externality costs such as

[175] As of 2011, BRT systems were under construction in several cities including Johannesburg, Cape Town and Tshwane, with mixed results (see Froschauer, 2010).

[176] High-speed rail may have several additional benefits, including: invigorating economic geography; agglomeration economies; increased worker productivity; and the opportunity to guide spatial development (Van der Meulen & Moller, 2010).

[177] The Gautrain HSR linking Sandton, Tshwane the O.R. Tambo airport cost upwards of R25 billion (Ndebele, 2011). Based on average costs in Spain of $22 million per mile (James, 2009), a HSR line connecting Johannesburg and Durban could cost R180 billion as a low estimate, given that extensive tunnelling would be required through the Drakensberg mountains.

road accidents, traffic congestion, pollution and associated health costs also tilt the balance in favour of rail. Resistance on the part of vehicle owners to using rail services could be addressed in ways similar to those mentioned above for bus services. It should be noted that any subsidisation of public transport would benefit existing users and may attract additional ('latent') demand users who previously relied on non-motorised transport (ASPO-SA et al., 2008c: 78). A further obstacle to increased usage of rail transport is the lack of inter-modal facilities, which will require additional infrastructure outlays (Vanderschuren et al., 2009: 830).

Passenger rail services will also need to substitute for air travel as the latter becomes less affordable as a result of fuel price increases. In the medium to longer term this modal shift will happen naturally based on economic incentives, although it depends of course on the availability of reliable rail services. In the interim, higher taxes could be levied on air travel to assist in the funding of rail projects. The high-speed rail links proposed by the Department of Transport would attempt to replace air travel without a great increase in travel time, but based on the Gautrain experience rapid rail is likely to be too expensive (see Section 5.2.4 below). Passengers may have to adapt to longer travel times in the longer term.

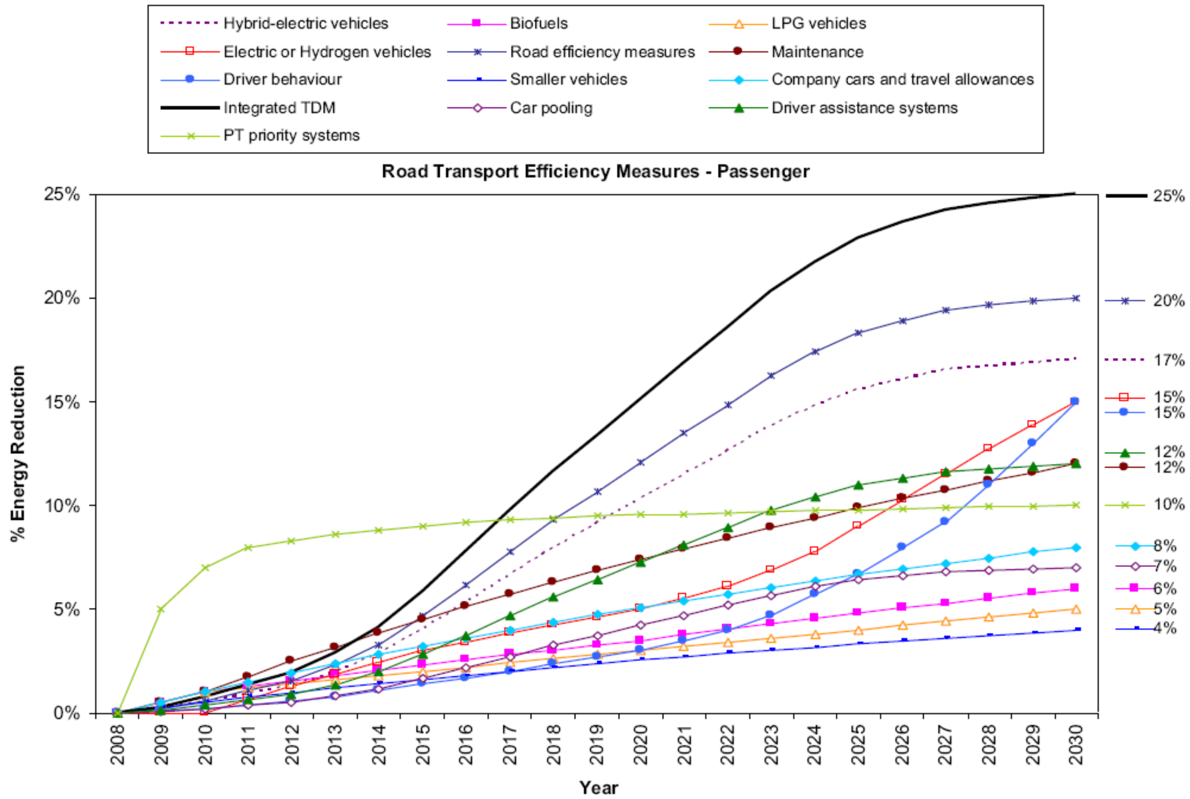
For land freight transport, energy efficiency is lowest for air, followed by road and highest for rail. For example, assuming payload utilisation rates that prevailed in 2008, rail transport fuel productivity over long distances was approximately 42% greater than that of road haulage (DoT, 2008: 30). Therefore the primary modal shifts required for freight are from air to road or rail and from road to rail. Transnet freight rail accounted for 31% of the country's land freight movement in 2009, measured in tonne-kilometres (CSIR, 2010), but consumed just 1.1% of the country's electricity and 2.1% of national diesel demand (Transnet, 2010). Transnet planned to spend R93 billion in the five year period from 2010 (Times Live, 2010), of which R52 billion was earmarked for freight rail, including R34 billion for general freight. Although most of this spending was geared towards expanding volumes of coal and iron ore exports, the new locomotives could be utilised at a later stage for transporting manufactured goods within the country. The constraints on freight rail are similar to those discussed in the case of passenger rail. Fortunately, Transnet is purchasing locomotives that can operate on diesel fuel or electricity, providing the greatest flexibility and possibilities for energy efficiency.

5.2.3 Quantifying fuel savings from mitigation measures

The potential fuel savings over a 20 year period for a wide range of demand and supply side transport mitigation measures have been estimated by ASPO-SA et al. (2008c) and Vanderschuren et al. (2010). In each case, the energy savings of different measures are not necessarily strictly additive. Figure 5-8 shows the estimated fuel savings for road passenger transport efficiency measures (percentage fuel saving after 20 years in parentheses): integrated travel demand management (TDM) (25%); driver behaviour (4%); maintenance (12%); driver assistance (navigation) programmes (12%); road efficiency measures (20%); car-pooling (7%); reducing company car and travel allowances (8%); smaller vehicles (15%); hybrid-electric vehicles (17%); electric vehicles (15%); biofuels (6%); and public transport priority systems (10%). The savings derived from HEVs and BEVs, which are amongst the largest, assume a gradual increase in market penetration.

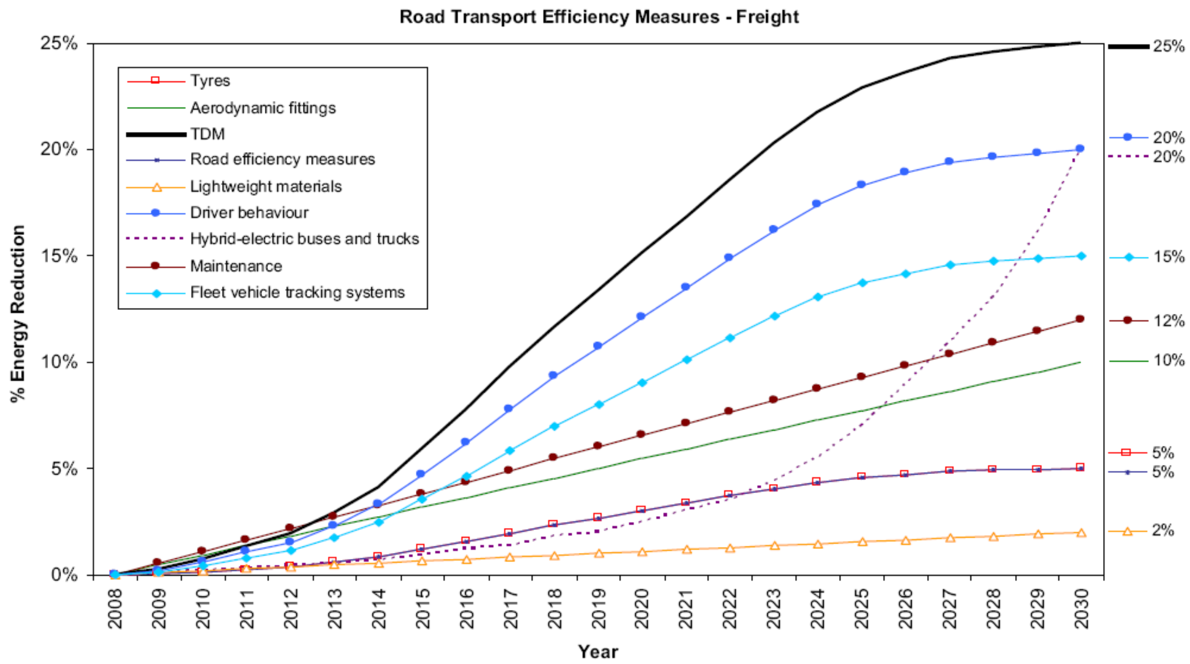
Figure 5-9 shows the estimated fuel savings for road freight transport efficiency measures (percentage fuel saving after 20 years in parentheses): driver behaviour (20%); correct tyre pressure (5%); road efficiency measures (5%); travel demand management (25%); maintenance (12%); fleet vehicle tracking systems (15%); aerodynamic fittings (10%); lightweight materials (2%); and hybrid-electric buses and trucks (20%).

Figure 5-8: Energy savings from road passenger transport efficiency measures



Source: Vanderschuren et al. (2010)

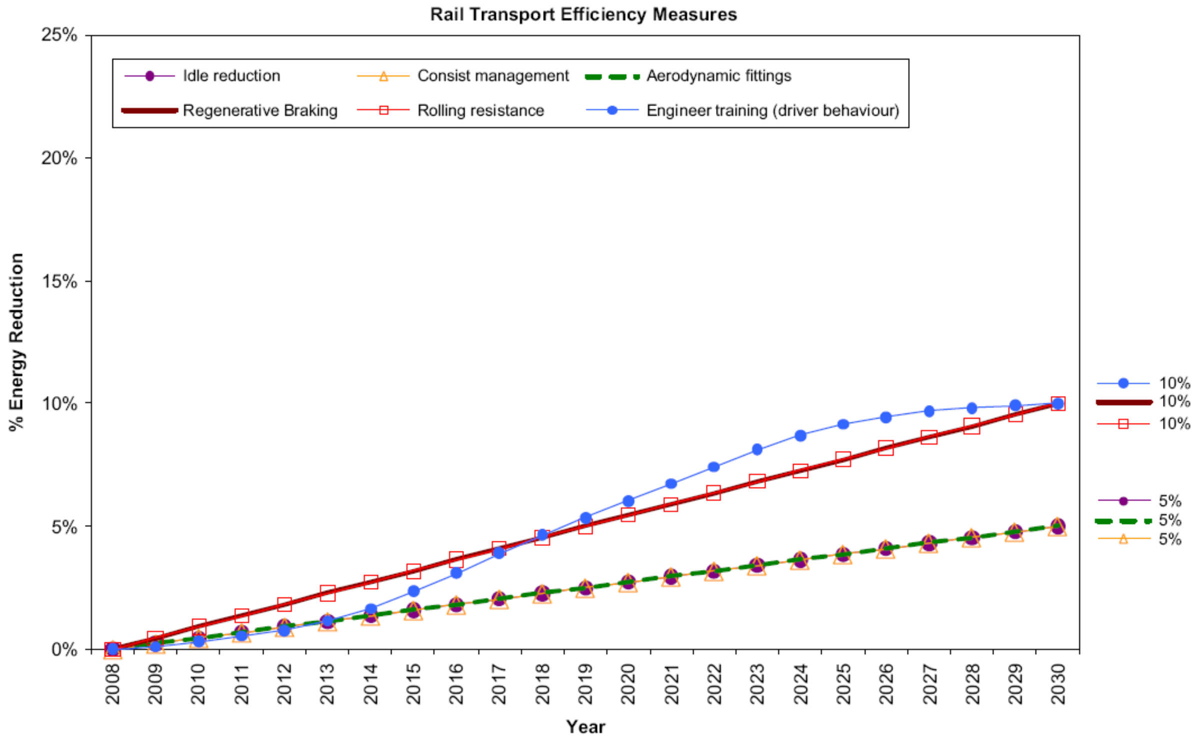
Figure 5-9: Energy savings from road freight transport efficiency measures



Source: Vanderschuren et al. (2010)

Figure 5-10 shows the estimated fuel savings for rail transport efficiency measures (percentage fuel saving after 20 years in parentheses): idle reduction (5%); consist management (10%); aerodynamic fittings (5%); regenerative braking (10%); rolling resistance (10%); and driver training (5%).

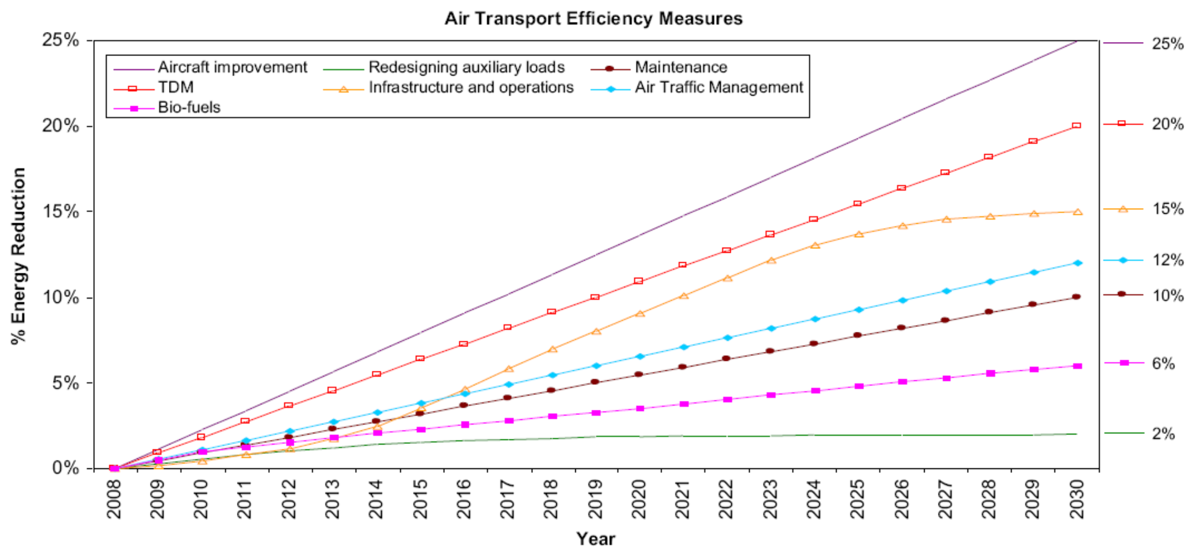
Figure 5-10: Energy savings from rail transport efficiency measures



Source: Vanderschuren et al. (2010)

Figure 5-11 shows the estimated fuel savings for air transport efficiency measures (percentage fuel saving after 20 years in parentheses): travel demand management (20%); improved design of aircraft (25%) and auxiliary loads (2%); better maintenance (10%); enhanced air traffic management (12%); improved infrastructure and operations (15%); and the substitution of biofuels (6%) for jet kerosene.

Figure 5-11: Energy savings from air transport efficiency measures



Source: Vanderschuren et al. (2010)

Table 5-7: Comparison of capital, energy and maintenance costs for various modes

Mode	Capital cost R	Energy efficiency km/l	Energy efficiency km/kWh	Energy cost R/km	Maximum loading number	Energy efficiency p-km/l	Energy cost R/p-km	Maint. cost R/km	Max range km	Max speed km/h	Make/Model
Walking	300	-	-	0.00	1		0.00	0.00	10	5	Shoes
Bicycle	1,000	-	-	0.00	1		0.00	0.01	30+	25	Raleigh Blade Twenty
Electric bicycle	12,000	1064.2	120.0	0.00	1	1064	0.00	0.08	40+	25	eZee Liv
Electric scooter	16,623	66.2	7.5	0.01	1	66	0.01	0.21	70	75	Scooti 3000 (lead acid)
Petrol scooter	12,500	43.5	-	0.22	2	43	0.22	0.30	196	80	Loncin LX150-T6
Petrol motorcycle	14,000	30.0	-	0.31	2	60	0.16	0.07	360	100	Honda XR125
Hybrid-electric car	240,000	22.7	-	0.41	4	91	0.10	0.24	1,135	120	Honda Jazz hybrid
Plug-in hybrid car	282,000	22.5	4.4	0.42	4	90	0.10	0.24	500	120	Chevrolet Volt 1.4L
Battery-electric car	225,000	41.8	4.7	0.20	4	167	0.05	0.12	150	120	Nissan Leaf
Petrol car	154,900	17.2	-	0.55	4	69	0.14	0.24	862	120	Honda Jazz Trend 1.4 L
Diesel car	211,000	23.8	-	0.37	4	95	0.09	0.41	1,190	120	VW Polo 1.6 Tdi
Petrol minibus	277,500	7.2	-	1.30	15	109	0.09	0.79	507	120	Toyota Sesfikile 2.7
Diesel minibus	291,500	9.1	-	0.97	15	136	0.06	0.83	634	120	Toyota Sesfikile 2.5D
Hybrid-electric bus	1,400,000	5.5	-	1.60	81	446	0.02	0.83	2063	100	Daimler Saf-T-Liner Hybrid
Battery-electric bus	1,540,000	14.3	1.6	0.58	80	1144	0.01	0.27	130	80	Jinghua Coach
Diesel bus	770,000	3.4	-	2.58	81	275	0.03	0.83	1275	100	Daimler Saf-T-Liner
Electric trolley bus		4.2	0.5	1.98	77	320	0.03				New Flyer low floor
Light rail train		5.8	0.7	1.42	180	1047	0.01				Seimans combino
Intercity train		1.4	0.2	5.80	167	238	0.03				Swedish Railways Regina
High-speed train		0.7	0.1	12.29	485	326	0.03				TGV Atlantique train-set
Small private airplane		5.3		1.6	4	21	0.41				Cessna 172
Regional turboprop		0.5		17.4	50	25	0.35				DHC 8-300
Short/med range airliner		0.2		48.0	137	25	0.35				Boeing 737
Med/long range airliner		0.2		46.2	156	30	0.30				Airbus 320
Very long range airliner		0.1		81.9	301	32	0.27				Boeing 777

Sources: Same as Figure 5-12 (below).

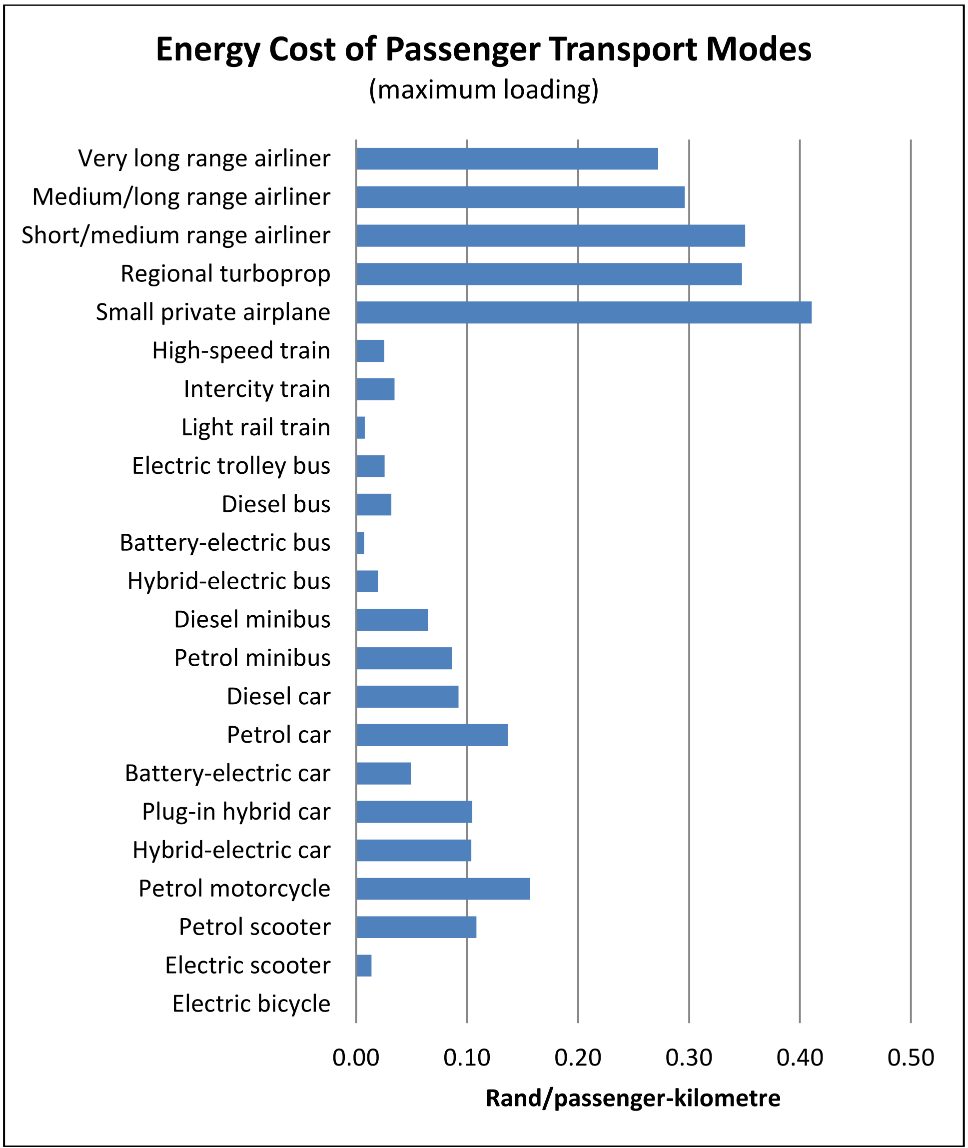
a. Energy costs: petrol = R 9.42/l (Gauteng Unleaded 95, 11/03/2011); diesel = R8.78/l (Gauteng 0.005 Sulphur, 11/03/2011); electricity = 0.93 R/kWh (Eskom 2011 tariff rate for consumption > 600 kWh/month; incl. VAT); jet fuel = diesel cost (assumed). b. Kilometres per litre equivalent in the case of electric powered vehicles.

5.2.4 Cost comparisons for alternative transport modes and efficiency measures

Table 5-7 (above) and Figure 5-12 (below) provide a comparison of capital, energy and maintenance costs for a wide range of transport modes and vehicles.[178] Electric bicycles have the lowest energy cost per passenger kilometre (p-km), followed by light rail trains and battery-electric buses. Other types of rail, as well as diesel and hybrid-electric buses, also have very low energy costs when fully loaded. The energy costs of air transport are much higher than for all other transport modes. It is important to note that the relative energy cost discrepancies will be exaggerated should liquid fuel prices rise faster than electricity prices.

[178] The Long Term Mitigation Scenarios (SBT, 2007) estimated the cost effectiveness of a wide range of climate mitigation initiatives, including ways to reduce carbon emissions in the transport sector. They found that improved vehicle efficiency is very cost effective, as it actually results in a net economic benefit (R269 per ton of CO_2 equivalent), mainly because smaller, more efficient vehicles are cheaper than less efficient, larger vehicles. By contrast, HEVs are the most expensive mitigation option, costing R1,987/ton of CO_2e, while mitigation by way of BEVs costs R607/ton. A passenger modal shift is the most cost effective transport mitigation measure, as it results in a net saving of R1,131/ton. The relative costs per unit of petroleum fuel saved would be similar, except that BEVs would save proportionately more fuel than emissions if the electricity to run them is derived from hydrocarbons.

Figure 5-12: Energy cost of various passenger transport modes [a, b]



Sources:

- Airplanes: Schiller et al. (2010)
- Trains & trolley bus: Schiller et al. (2010)
- Diesel bus; hybrid-electric bus: Thomas Built Buses (2011)
- Battery-electric bus: Xinhua News (2008)
- Petrol & diesel minibus: Toyota (2011)
- Diesel car: Volkswagen (2011)
- Battery-electric car: Independent News (2011)
- Plug-in-hybrid: United States Government (2011)
- Petrol motorcycle; hybrid-electric car; petrol car: Honda (2011)
- Electric scooter; petrol scooter: Scooti (2011); Electric bicycle: Eezebike (2011)

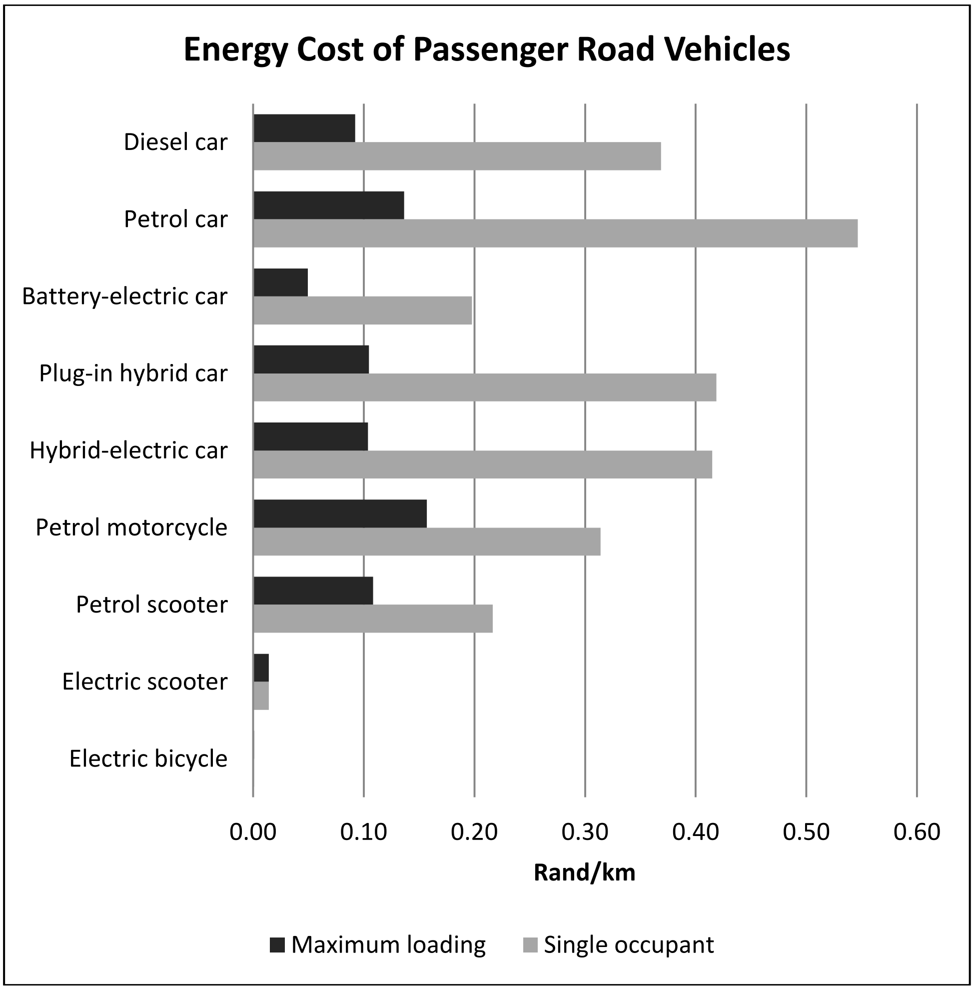
Notes:

a. Energy costs: petrol = R 9.42/l (Gauteng Unleaded 95, 11/03/2011); diesel = R8.78/l (Gauteng 0.005 Sulphur, 11/03/2011); electricity = 0.93 R/kWh (Eskom 2011 tariff rate for consumption > 600 kWh/month; incl. VAT); jet fuel = diesel cost (assumed).

b. Maximum loading for a motorcycle and an electric scooter is assumed to be two.

Figure 5-13 highlights the importance of loading vehicles with close to the maximum number of occupants. For example, a petrol car carrying four people has a lower energy cost per passenger kilometre than a petrol scooter carrying one person, but is far less efficient if the car has a single occupant.

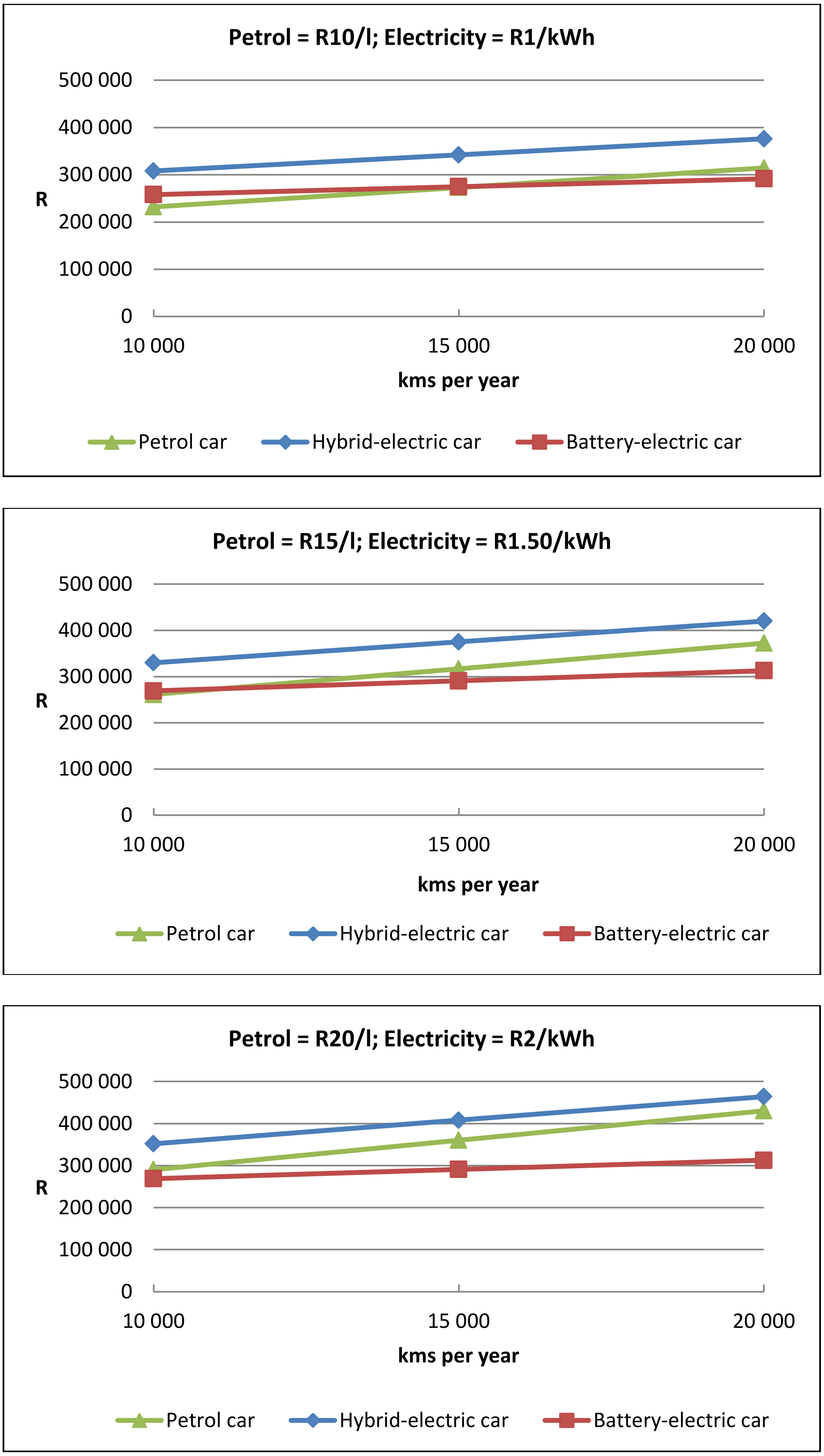
Figure 5-13: Energy cost of road vehicles: maximum loading versus single occupancy



Sources: See previous figure

Capital costs for BEVs and HEVs are substantially higher than for comparable sized petrol or diesel vehicles, although this premium can be expected to decline over time as production volumes grow, yielding economies of scale. Assuming a ten year vehicle lifespan, the total costs of owning and operating a BEV are lower than those of a comparable petrol car as long as the average distance travelled is greater than 15,000 kilometres per annum, or if energy prices rise by more than 20% from March 2011 levels (see Figure 5-14 below). The total lifetime costs of hybrid-electric cars are greater than petrol and battery-electric cars no matter what the annual mileage or energy prices are. This explains the very small consumer demand for hybrid-electric vehicles thus far.

Figure 5-14: Lifetime costs of petrol, hybrid-electric and battery-electric cars



Source: Author's calculations.

Infrastructure costs: road versus rail

It is important to compare the costs of new infrastructure, maintenance and rolling stock for road and rail based transport. The cost of a new regional railway line could be in the region of R23m to R42m per kilometre.[179] The Gautrain high-speed railway cost R25 billion for 80 kilometres, or R313m per kilometre. In 2009/10, SANRAL's capital expenditure was R8,147 million for 748 kilometres of national toll roads, i.e. R10.9 million per kilometre (SANRAL, 2010). Thus capital costs for new infrastructure are considerably higher for rail than for road. In 2009/10, SANRAL spent R608 million maintaining 1,900 kms of national toll roads, i.e. R0.32 million per kilometre (SANRAL, 2010). Similarly, the CSIR (2010: 33) estimated road maintenance costs for 2009 at R150,000 per lane per kilometre, or R300,000 per kilometre for a dual carriage way. The annual maintenance cost for the 16,750 kilometres of national roads could thus amount to over R5 billion.[180] In contrast, Transnet Rail Engineering spent R149 million on rail maintenance in the 2010 financial year, but did not reveal the distance of track this involved (Transnet, 2010). The cost of acquiring new rolling stock to modernise the passenger rail system was budgeted at R97 billion over a period of 18 years (Ndebele, 2011). Annually this amounts to just 8% of the R67 billion that was spent by households on passenger motor vehicles in 2010 (SARB, 2011). Similarly, Transnet budgeted R34 billion for new rolling stock for its general freight business for the period 2011-2015; annually this is just 16% of the approximately R43 billion that was spent on new commercial vehicles in 2010.[181] These figures (summarised in Table 5-8) make it clear that while capital expenditure for rail rolling stock is significant, it would be considerably less than what is currently spent on road vehicles. In addition, a shift from ICEVs to BEVs and PHVs will likely require the installation of new electricity charging networks, whose cost must be factored in.

Table 5-8: Capital and maintenance costs for road and rail transport

	Capital cost R million/km	**Maintenance cost** R million/km/annum	**Rolling stock cost** R million/annum
Bus rapid transit	14		
Rail – regional	33		5,400
Rail – high speed	313		
Road – national	11	0.3	67,000

Source: SANRAL (2010), Transnet (2010), Hook (2009), Ndebele (2011)

5.2.5 Conclusions on transport mitigation

Global oil depletion implies that all transport planning decisions should be based on expectations of higher oil prices and growing oil scarcity in the future. From a short term perspective, "pre-planning is essential in order for transport demand restraint measures to succeed during an emergency" (IEA, 2005: 15). Effective communication of clear information to the public is vital to ensure greater co-operation and participation in fuel saving measures. In respect of long term planning, the expansion of infrastructure for aircraft and internal combustion engine vehicles should be terminated, and resources redirected towards electric powered mass transit and freight (Gilbert & Perl, 2008: 335). The wide range of both demand and supply side policies and measures that can substantially reduce oil consumption and dependence are summarised in Table 5-9. Ideally, a comparative evaluation of

[179] The projected cost for a planned 1 500 km Trans-Kalahari railway linking Botswana's Mmamabula coal field to Walvis Bay in Namibia was projected to cost between $5 billion and $9 billion (between R35 bn and R63 bn) (van den Bosch, 2011).

[180] This figure is probably an overestimate, since the cost figure related to the high-traffic Johannesburg-Durban corridor.

[181] This approximation is based on vehicle sales figures from NAAMSA (2010).

alternative mitigation measures should be based on economic, social and environmental costs and benefits over the full life-cycle. However, such an evaluation is beyond the scope of this dissertation. Given the extreme level of current oil dependence, and the speed at which global oil supplies are likely to decline, the government is advised to use a combination of all these measures, subject to cost-effectiveness and affordability criteria.

In general, the most cost effective option for reducing oil consumption is curtailment, followed by efficiency improvements to existing infrastructure, and then investment in new infrastructure. However, there could be a trade-off between cost effectiveness and volumetric effectiveness; i.e. measures that save the most oil tend to be more expensive and have more embodied energy. Also, curtailment will generally reduce mobility and can impose non-energy economic costs. In terms of infrastructure, another important consideration is the energy (mostly derived from fossil fuels) that is embodied in transport infrastructure via the manufacturing process, both as raw energy inputs (e.g. for steel production) and as petrochemical materials (e.g. plastics, rubber, etc.). For example, approximately half of the oil consumed in the lifetime of a typical automobile is used in its manufacture (Heinberg, 2003). Thus the cost of vehicles and other infrastructure that have a high degree of embodied energy will rise faster than those with lower embodied energy. This provides added motivation for non-motorised transport and the use of smaller, lighter vehicles.

Transport mitigation measures will face a variety of constraints and risks. First, fuel efficiency measures are likely to induce some level of the rebound effect, although rising fuel prices will ameliorate this. Second, some measures, such as fuel levies, vehicle taxes, toll roads and congestion charges, are likely to be politically unpopular, especially in a time of high and escalating fuel prices. Third, effective state capacity for enforcement of regulations will require adequate training and deployment of traffic officers. Fourth, most of the transport mitigation measures will take several years to be implemented and scaled up, especially those requiring investments in new infrastructure. Fifth, replacement of ICEVs will have to overcome technological lock-in, in that ICEVs evolved along with an extensive infrastructural and industrial network (roads, parts, filling stations, dealerships, service centres, etc.) and also benefited from economies of scale, subsidies and entrenched consumer preferences (Kendall, 2008: 68). However, rising oil prices present an opportunity to challenge the dominance of inefficient ICEVs with alternatives that are better in many respects. Sixth, recessionary economic conditions resulting from oil price shocks is likely to reduce private and public funds available for spending on desired mitigation strategies. Seventh, cost escalations driven by rising energy costs could result in delays to projects, or even render certain projects unaffordable. On the upside, there is a possibility of unforeseen technological breakthroughs that substantially improve energy efficiency. Nonetheless, new technologies usually take several years or even decades to reach market saturation.

With regard to passenger transport, travel demand management measures are generally relatively cheap since they mostly do not require much or any new infrastructure. Amongst short-term demand restraint measures, information campaigns encouraging eco-driving, car-pooling, driving bans, telecommuting, and compressed work weeks are the most cost effective. More costly alternatives include the implementation of high-occupancy vehicle lanes and subsidised public transport. The quantitatively largest opportunities for reducing oil dependence are presented by a modal shift from road-based passenger movement to public transport infrastructure, especially grid-connected electric vehicles such as trains and trams.[182] Vanderschuren and Jobanputra (2005) estimated that the combination of fuel displacement and efficiency measures they propose could

[182] Vanderschuren et al. (2008: 28) estimate that the use of alternative propulsion systems will likely bring about the largest reduction in oil consumption, relative to road efficiency, driver behavioural changes, travel demand management and modal shifts.

result in a 55% saving of fuel consumption within five years. However, behavioural changes are not easy to achieve in practice (Vanderschuren, 2008), and will often need to be regulated and enforced. Measures that require substantial financial outlays by consumers (drivers) may be problematic in a post-peak oil situation, as household incomes are likely to be under considerable pressure. Probably the largest constraint on expansion of public transit will be the extensive funds required for major infrastructure. Moreover, successfully attracting passengers from cars to public transport will depend on improving the provision of public transport services, in terms of speed, reliability, regularity, safety and security, convenience, comfort and costs (Wright & Hook, 2007).

The most cost-effective measures for reducing oil dependency in freight transport are those requiring little new infrastructure and which can be implemented relatively easily in the short to medium term, such as improved vehicle maintenance, optimised routing and scheduling, and intelligent traffic management solutions. In the longer term, the greatest potential for reducing oil dependency lies in shifting freight from road and air to electrified railways, although this will require substantial investment in upgrading railway infrastructure, as well as additional electrical generation and grid capacity.

Table 5-9: Summary of transport mitigation policies and measures

Demand management, efficiency & conservation			
Category	**Policies & Measures**	**Benefits**	**Constraints**
Eco-driving & vehicle maintenance	• information campaign • vehicle road-worthy inspections	• greater efficiency • improved road safety	• driver culture & apathy • affordability of maintenance • enforcement capacity
Traffic management	• reduced speed limits • fleet tracking • onboard navigation	• greater efficiency • energy conservation • reduced congestion • improved road safety	• enforcement capacity • technology & equipment costs
Car-pooling & car sharing	• information campaign • car pool lanes • congestion charges	• energy conservation • reduced congestion	• driver willingness • coordination challenges • safety & security concerns
Telecommuting	• information campaign • investment in telecoms	• energy conservation • reduced congestion	• Internet access • suitable occupations
Flexible work schedules	• information campaign • legislation	• energy conservation • reduced congestion	• employer resistance
Fiscal instruments	• vehicle taxes • fuel taxes • congestion charges	• energy conservation • raise revenue	• administration costs • unpopular
Fuel rationing	• fuel coupons • selective driving bans	• energy conservation • reduced congestion • greater equity	• unpopular? • black market trade
Improved vehicle design			
Category	**Policies & Measures**	**Benefits**	**Constraints**
Vehicle efficiency (smaller; lighter materials)	• efficiency standards • information campaign • government procurement • feebates	• improved fuel efficiency • lower emissions	• enforcement capacity • entrenched consumer preferences • still oil dependent
Shift to diesel vehicles	• information campaign • government procurement	• improved fuel efficiency • lower emissions	• competing with freight • higher diesel prices • still oil dependent

Alternative propulsion systems			
Category	**Policies & Measures**	**Benefits**	**Constraints**
Compressed natural gas vehicles	• feebates • emissions regulations	• oil independent	• imported gas • new refuelling stations
Compressed air vehicles	• feebates • emissions regulations	• oil independent	• rely on electricity • limited range
Hydrogen vehicles	• feebates • emissions regulations	• diversity of primary energy sources	• energy inefficient • design challenges • infrastructure costs • safety concerns
Hybrid-electric vehicles	• feebates • emissions regulations	• greater efficiency	• not cost-effective
Battery electric vehicles	• feebates • emissions regulations • recharge infrastructure • government procurement	• highly efficient • diversity of primary energy sources • low maintenance cost • oil independent	• relatively high cost • limited range
Grid-connected vehicles	• feebates • emissions regulations • provision of grid infrastructure	• highly efficient • diversity of primary energy sources	• high cost of infrastructure • accessibility of grid • electricity supply
Modal shifts			
Category	**Policies & Measures**	**Benefits**	**Constraints**
Non-motorised transport	• vehicle taxes • congestion charges • provision of cycle lanes & pedestrian walkways • bicycle subsidies	• energy conservation • reduced pollution • improved health • space efficient	• limited range • safety & security • animal feed
Electric bicycles	• vehicle taxes • congestion charges • provision of cycle lanes • subsidies	• very fuel efficient • reduced pollution • improved health • space efficient	• limited range • limited capacity • safety & security • too costly for low-income households
Scooters & motorcycles	• vehicle taxes • congestion charges	• fuel efficient • space efficient	• limited capacity • safety & security
Public transit - cars to buses - road to rail - air to rail	• vehicle taxes • infrastructure provision • subsidies • improved services	• greater energy efficiency • improved energy security • improved safety	• large capital investments • accessibility • reliability • security
Freight - road to rail - air to rail	• road & fuel taxes • air transport & fuel taxes • improved rail infrastructure & service	• greater energy efficiency • improved energy security • improved safety	• large capital investments • accessibility • reliability • slower speed

5.3 Agriculture

As argued in Chapter 4, leaving the adjustment of commercial agriculture to increasing oil scarcity to occur through market forces could be highly destructive to the sector, with wide-scale bankruptcies and loss of output. Thus there is a clear role for mitigation and adaptation policies. In the context of global oil depletion, there are several important objectives for national agricultural policy. The short- to medium-term goal should be to develop the resilience of agriculture to oil price and supply shocks. In particular, farmers should be protected from severe oil price shocks so that they do not become bankrupt, as this would compromise agricultural output and national food security for the long term. In addition, it is essential that the distribution of food products to markets be maintained. The longer term goals should be to systematically reduce oil dependency, to enhance food sovereignty, and most broadly to effect a transition to sustainable agriculture. Food sovereignty has been defined as "the right of each nation to maintain and develop their own capacity to produce foods that are crucial to national and community food security, respecting cultural diversity and diversity of production methods" (Pimbert, 2008: 43). Sustainable agricultural systems may be defined as those that efficiently utilise environmental goods and services whilst preserving natural, human, social, physical and financial capital (Hine et al., 2008: 6).

There are two core strategies for improving the resilience and sustainability of the commercial agriculture and food system. Section 5.3.1 explores ways in which the use of petroleum fuels can be reduced in the food production system, together with specific policy measures and likely constraints. Section 5.3.2 considers the distributional efficiency of food distribution systems and advocates a general reduction of distances between producers and consumers, i.e. a relocalisation of the food system. Section 5.3.3 concludes the discussion on boosting the resilience of the agricultural system.

5.3.1 Reducing oil use in agricultural production

The main use of oil in agriculture in South Africa is in the form of diesel fuel for tractors, harvesters and other machinery. However a wide range of other inputs are derived from crude or synthetic oil, including irrigation piping and fittings, pesticides, packaging materials, etc. In addition, rising crude oil prices will put upward pressure on the price of natural gas, which is the primary feedstock for synthetic nitrogen fertilisers.

Agroecological farming

Agroecology is "the science of applying ecological concepts and principles to the design, development and management of sustainable agricultural systems" (Pfeiffer, 2006: 59). Practically, an agroecological approach involves "enhancing the habitat so that it promotes healthy plant growth, stresses pests, and encourages beneficial organisms while using labor and local resources more efficiently" (Altieri, 2009: 109). Organic agriculture may be defined as a "system of agricultural production that seeks to promote and enhance an ecosystem's health while minimizing adverse effects on natural resources" (Hine et al., 2008: 6). It aims to use locally available and natural materials as far as possible, and thus inherently minimises the use of fossil fuel inputs, including oil. According to Pfeiffer (2006: 68), "organic farming is the most practical method of reducing fossil fuel input at the level of production." Clearly, the definitions of agroecological and organic farming are very similar, and will thus be used interchangeably in what follows.

The use of tractors can be reduced through the implementation of no-till or low-till agriculture. Conservation agriculture, which is based on a principle of minimal soil disturbance, reduces the need for tractor usage and therefore diesel fuel (FAO, 2010). However, weed management becomes more challenging, which given the unsustainability of herbicides implies greater demand for labour (Giller et al., 2009). Another option is to utilise alternative energy sources for farm machinery. Biodiesel can be manufactured on a small, local scale from crops produced on a portion of a farmer's land.[183] Solar-powered electric tractors have been designed that can be recharged from the grid or from tractor-mounted photovoltaic panels (Heckeroth, 2009). Alternatively, draft animals can be substituted for tractors, bringing additional advantages of less compaction of soils and the generation of manure for fertilising. However, both biodiesel and animal power imply a reduced land area available for food production and could therefore compromise food security.

Another important aspect of organic agriculture is soil rehabilitation to restore soil fertility without inorganic fertilisers (Heinberg & Bomford, 2009: 22). This can be achieved through appropriate crop rotation, incorporating nitrogen-fixing crops, and recycling of critical nutrients (including phosphorus) through the use of composting, animal manures, green manures (Pfeiffer, 2006: 58) and even 'humanure' (Greer, 2010). Animal and human manures were the chief sources of fertiliser before the fossil fuel era. However, using animal manure implies allocating more arable land to grazing and therefore less to growing food crops. Rehabilitating depleted soils takes several years of sustained effort (Heinberg & Bomford, 2009: 22). In addition, oil-based pesticides should be replaced with integrated pest management, utilising biopesticides, microbes and natural pest control, intercropping to reduce losses to pests, and cover cropping to counteract weeds (Pfeiffer, 2006; Heinberg & Bomford, 2009: 11).

Most commercially available seeds are produced through energy-intensive, centralised production and distribution systems, and for some staple crops such as maize and soya include an increasing percentage that is genetically modified (GM), which typically are tied to chemical fertilisers and pesticides (Heinberg & Bomford, 2009: 30). Rather, programmes to identify and distribute seeds of locally adapted, open-pollinated food crops, and training in seed saving techniques, are required (Heinberg & Bomford, 2009: 30). Government could also sponsor the development of regional heirloom seed banks.

A shift to agroecological farming methods would bring additional benefits beyond reduced oil dependency and lower production costs (Hine, Twarog & Pretty, 2008). They can boost stocks of natural, social, human, physical and financial capital in rural communities and thus have a lasting impact on food security and well-being. Where organic farmers are able to produce surpluses for export, their products command premium prices and can therefore boost incomes and alleviate poverty amongst small farmers (Hine et al., 2008). Environmental benefits include reduced pollution (e.g. from pesticides, fertilisers and greenhouse gas emissions) and enhanced soil fertility, water quality and biodiversity.

As argued in the previous chapter, a reversal of the trend towards integration of farms into larger units is a very likely consequence of increasing oil scarcity. If this process is to unfold beneficially, it will need to be coordinated and supported by government policies. Fortunately, organic farming is more efficient on a small scale and is inherently more labour intensive than industrial agriculture, and therefore has the potential to create numerous livelihood opportunities. Furthermore, small farms have "multiple functions which benefit both society and the biosphere" (Rosset, 1999: 452). Potential benefits of small farms include greater diversity, improved natural resource management, community empowerment and responsibility, and development of the local economy through multiplier effects (Rosset, 1999). Rosset (1999) argues that the productivity of small farms, which usually have multiple crops, is generally greater than that of large farms when taking into account total yield as opposed to the yield from a single crop. Traditional agriculture involved small-scale farms with high levels of genetic and biological diversity, and reliance on local resources and knowledge, all of which made farming resilient to changing conditions (Altieri, 2009: 103). Altieri

[183] According to Heinberg and Bomford (2009: 19), in the United States approximately one fifth of a typical farmer's arable land could produce sufficient biofuel energy for most of the farm's requirements.

(2009) suggests that this form of farming can provide a model for the future, as it does not rely on oil and chemicals and is more ecologically and socially sustainable than industrial agriculture.

Constraints and challenges

The transition to sustainable agriculture will involve several challenges (see Chapter 3). First, good quality land and water are both scarce in South Africa. Second, the current dearth of farming skills implies that considerable time would be needed to train new farmers in agroecological methods. Third, the agroecological model of farming requires more land than industrial farming as part of the land has to be set aside for animals to produce manure for fertilising (Pfeiffer, 2006: 63). Agroecological farming also has greater labour requirements, but this can be seen as an opportunity to create sustainable livelihoods. Fourth, farmers who convert from conventional to organic farming will face transition costs in the form of initially reduced output and revenues (to some extent offset by reduced input costs) and human capital investment costs (Hine et al., 2008: 34). Nevertheless, Hine et al. (2008: 11) state that while farms that convert from industrial to organic methods generally experience a decrease in yield initially, yields increase notably once the agro-ecosystem recovers.[184] On the other hand, large-scale, mechanised farms are able to reap economies of scale and thus produce at lower prices, although some costs are externalised to the environment. In addition, fertilizers and pesticides have allowed the cultivation of more marginal soils, which might not be suitable for organic production. Thus total output could decline significantly, as it did in the early 1980s after fertilizer subsidies were reduced (FAO, 2005).

Policies and measures to support sustainable agriculture

The successful diffusion of agroecological innovations require specific policy support and institutions (Altieri, 2009), rather than being sidelined in favour of high-input farming approaches (Hine et al., 2008). The National Resources Institute (2008: 268) identified two key strategies for developing an organic sector, namely “(1) the establishment of an effective Sector Body and National Organic Commission with broadbased support and (2) the establishment of a clear and inclusive policy and regulatory environment.” Scientific and research budgets need to give greater priority to agroecological farming (Hine et al., 2008). Moreover, various networks need to be strengthened, for example those involving scientists, agricultural extension providers and farmers, and connections between farmers, civil society organisations and government departments (Hine et al., 2008).

In Cuba, the establishment of thousands of private cooperatives, managed and owned by farm workers, helped the transition to sustainable agriculture following a drastic fall in Cuba’s oil imports after the collapse of the Soviet Union (Pfeiffer, 2006). Co-operatives reward individual members for their productivity and yet offer the benefits of economies of scale. Through the Cooperatives Act of 2005, the South African government has sought to promote the horizontal integration of emerging farmers to help improve their access to markets and to share resources (Lyne & Collins, 2008). However, Lyne and Collins (2008) note that the historical experience of development-oriented cooperatives in South Africa has been very poor. They argue that the Cooperatives Act should be amended to allow for non-patron members of ‘emerging’ cooperatives, in order to facilitate the transfer of knowledge and capital from private agribusinesses. Buscher and Atkinson (2006) suggest that a commonage approach to farming could be a useful “step-up” for small-scale farmers.

Access to land and water are key to achieving food sovereignty and food security (Altieri, 2009), while the transition to organic agriculture will require an increase in the number of farmers and farm workers due to its small-scale and labour-intensive nature. Thus effective land reform will be an essential component of reducing oil dependency and vulnerability. Vink and van Rooyen (2009: 34) argue that land reform should be targeted at small-scale commercial farmers, since they contribute

[184] “Organic agriculture can increase agricultural productivity and can raise incomes with low-cost, locally available and appropriate technologies, without causing environmental damage” (Hine et al., 2008: x).

a relatively small share of agricultural output, while large-scale farmers produce the bulk of agricultural value and are thus important for maintaining national food security. However, this perspective assumes the continued viability of large-scale, oil-intensive farming. Vink and van Rooyen (2009: 36) argue further that the land reform process be managed in a way that "affords greater priority to currently successful small farmers as beneficiaries". In addition, land reform must be accompanied by adequate training and skill acquisition for the new farmers; otherwise the result can be unsuccessful (National Resources Institute (NRI), 2008). Admittedly, land reform is very costly: government required on the order of R40 billion to meet its target of redistributing 40% of agricultural land by 2014 (Business Report, 2011b).

Various other farmer support services will also assist the move to sustainable agriculture. Financial support may be needed to enable new farmers to start up. This could be provided in the form of subsidies or low-interest credit. Any subsidies provided to farmers should be targeted to those who are progressively implementing more sustainable (e.g. organic) agricultural methods; otherwise, unsustainable practices and petrochemical dependency will be perpetuated. Subsidies would reflect the priority of agriculture and national food security in ensuring social welfare and cohesion. In addition, the knowledge-intensive nature of organic farming means that learning capabilities and cooperation need to be enhanced, for example through investments in local social capital (Hine et al., 2008: xi). The dissemination of knowledge, skills and training should be "targeted at those who need it most, especially farmers in remote rural areas" (Vink & van Rooyen, 2009: 36). Other forms of support include "assistance in accessing commercial supply chains", including support for collective action and access to alternative markets not dominated by large processors and supermarket chains (Vink & van Rooyen, 2009: 36).

5.3.2 Distributional efficiency and localisation

The vulnerabilities of the agricultural and food distribution systems to rising oil prices and fuel shortages can be addressed in two main ways. In the first instance, targeted interventions should be made to enhance logistical efficiencies of supply chains operating between input suppliers and farms, and between farms and consumers (Vink & van Rooyen, 2009: 37). Resilience to fuel supply shortages can be increased by building in redundancies and increasing inventories (Heinberg & Bomford, 2009: 33). Second, given the overwhelming dependence of the current distribution systems on road based transport infrastructure, for the longer term a fundamentally new orientation is required: a relocalisation and decentralisation of food economies that reduces distances been producers and consumers. Relocalisation implies production of a greater proportion of necessary foodstuffs occurs locally, while longer-distance trade is reserved mainly for luxury items (Heinberg & Bomford, 2009: 15). In order to promote food security, each area should produce regionally-adapted staple crops as far as possible. For food processing, relocalisation would involve the establishment of smaller scale facilities rather than large, centralised processing plants.

Localisation of food economies may bring several benefits beyond fuel saving. First, food availability is more seasonal and often of better quality, with less processing required (Heinberg & Bomford, 2009: 16). Second, localisation has been shown to build community networks and promote resilience (Feenstra, 2007; McKibben, 2007). Third, local food economies "tend to promote greater sustainability by shifting the decision making around the food system back to the communities in which they are embedded" (Schulschenk, 2010: 122). Fourth, greater prioritisation of import replacement and production for local needs would reduce exposure to fluctuations in foreign demand and exchange rates, while promoting diversity and strengthening the regional economy (Shuman, 1997). On the other hand, local food economies may be limited in their capacity to meet diverse nutritional needs of some communities and constrained by environmental conditions such as extreme climates or degraded ecosystems (Schulschenk, 2010: 59-61).

Localisation will require a major redirection of national agricultural policy, which currently favours an export-led path. At the micro level, government can help to establish localised agricultural markets and to promote farmers' markets, for example by making public spaces available in urban areas and rural towns. Such local markets help to reduce the power of giant wholesalers and retailers, and strengthen community bonds (Pfeiffer, 2006). Governments can also support "buy local" campaigns and insist that government institutions source a minimum portion of their food needs locally (Heinberg & Bomford, 2009: 17). Building local food economies initially may depend on civil society participation to be competitive with the current food system, although over time rising oil prices will assist the process (Schulschenk, 2010: 122).

The development of urban agriculture (UA) represents a specific form of localisation with significant opportunities to foster the resilience of urban communities (Hopkins, 2000). Local governments can promote urban food production by allocating under-utilised land for food gardens and leasing allotments to residents. Local by-laws can foster rooftop and backyard food gardens and laws could be enacted to require urban agricultural produce to be organic, as in Cuba (Pfeiffer, 2006: 61). Municipalities can either organise their waste systems to process food waste into compost or biogas (Heinberg & Bomford, 2009: 17), or incentivise residents to do so themselves. Thornton (2008) recommends that the Department of Agriculture widen its extension services to cover urban townships and informal settlements. Yields from bio-intensive urban agriculture have been shown to be higher than those of conventional farming in the US (Hopkins, 2000: 206). Nevertheless, it is recognised that the development of urban agriculture would face significant challenges and constraints, such as the availability of suitable land, water, and organic materials for composting, as well as security. Evidence suggests that cultural attitudes about the 'backwardness' of food production and the availability of social welfare grants can also hinder the growth of UA (Thornton, 2008).

5.3.3 Conclusions on agriculture mitigation

It is imperative to view the agriculture and food distribution system holistically. Efforts to mitigate declining oil availability need to take cognisance of the various additional vulnerabilities of the agriculture system mentioned in Chapter 3, such as poor soils, water scarcity and climate change. Thus reducing oil dependency should form part of an overall transition to sustainable agriculture. It should also be managed as a phased transition, since "[r]emoving fossil fuels from the food system too quickly, before alternative systems are in place, would be catastrophic" (Heinberg & Bomford, 2009: 12). The transition will take time, as soils will need to be rebuilt after years or decades of application of chemical inputs. Thus mitigation efforts should begin immediately. The scale of the challenge is immense, given the current dominance of industrialised agriculture.

Reducing oil dependency specifically, and fossil fuel dependency more broadly, implies a conversion over time to more sustainable agricultural practices, such as agroecological, organic and permaculture farming principles and techniques. Evidence shows that yields of small-scale and organic farming can be at least as good as those of conventional, large-scale farming, for at least some environmental conditions. It is also more labour-intensive than current industrial farming, and would therefore assist in the creation of sustainable livelihoods. The transition to sustainable agriculture will require institutions that support new farmers with appropriate knowledge and skill acquisition. It will also depend on improvements in the land reform process. Farmers will need to invest in renewable energy and adopt farming practices that rely less on mechanisation, such as conservation tillage. More broadly, there is a need to relocalise the agriculture and food distribution system so as to reduce vulnerabilities to fuel supply disruptions and rising transport costs. The main costs involved in mitigating the impact of oil depletion on agriculture are temporary subsidies for farming inputs, training and institutional support for emerging farmers and for conversion to agro-ecological practices, and funds for land reform. Government should recognise the strategic importance of the agricultural sector in maintaining social welfare and cohesion, and prioritise its expenditures accordingly, reallocating funds to agriculture from other sectors if necessary.

5.4 Macro-economy

Macroeconomic policy is a vital component of a strategy for mitigating the impact of global oil depletion on South Africa's socio-economy. In this context, the short- to medium-term goal of macroeconomic policy should be to promote resilience to oil price shocks and physical oil shortages. The longer term objective should be to decouple economic development from oil consumption and to improve the sustainability of the macro-economy. On a pragmatic level, macroeconomic policies and planning should be formulated with due cognizance of global oil depletion and its probable effects. This implies recognition of the likely reversal of globalisation in the trade of physical goods and some services (i.e. a relocalisation of economic production and consumption) and possible long-term global economic stagnation or contraction.

This section begins with an overview of the existing macroeconomic policy framework (as of 2011) and an evaluation of its compatibility with oil mitigation. Subsequent subsections focus on particular areas within macroeconomic policy, namely fiscal policy, monetary and exchange rate policy, industrial policy, trade policy, and labour market policy. The final subsection offers concluding thoughts on constraints and opportunities in the quest for improved economic sustainability.

5.4.1 Macroeconomic policy framework

In November 2010 the Minister of Economic Development, Ebrahim Patel, announced a new overarching macroeconomic policy framework called the New Growth Path (NGP). The NGP aims to enhance growth, employment creation and equity, with a chief target of creating five million jobs over the ensuing decade. The NGP identifies five principal "jobs drivers," namely: (1) investments in energy, transport, communication, water and housing infrastructure for employment and development; (2) improving job creation in specific economic sectors (agriculture, mining, manufacturing, tourism and other high-level services); (3) seizing the potential of new economies, e.g. the green economy and the knowledge economy; (4) investing in social capital; and (5) fostering rural development and regional integration (EDD, 2010). These five jobs drivers are evaluated in turn.

South Africa clearly needs improved infrastructure (especially housing, water, sewage and electricity for poor communities which currently lack these services), but the type and location of investments must be compatible with mitigation of oil depletion. The emphasis in the NGP on revitalised and expanded passenger and freight rail infrastructure is very welcome, as is the expansion of communications infrastructure, which to some extent can substitute for physical travel. However, the planned expansion of roads will in most instances constitute a misallocation of resources. Other aspects of infrastructure investment are relatively neglected, such as renewable energy in general and decentralised energy production using solar photovoltaic technology in particular.

In terms of priority sectors for employment creation, the NGP proposals for support for the agricultural sector are broadly consistent with the oil mitigation strategies discussed in Section 5.3. Of particular value are the NGP's targeting of opportunities for 300,000 households in agricultural smallholder schemes, as well as follow-up support to beneficiaries of land restitution. The proposed intention to boost local beneficiation of minerals higher up the value chain is compatible with future increases in transport costs; it is more energy efficient to export higher-value, lower-weight products. However, increasing employment creation in primary mining activities, and even beneficiation, could be constrained to some extent by higher fuel and electricity prices and energy shortages. In terms of manufacturing, support for knowledge intensive industries are consistent with the need for dematerialisation. Other manufacturing sectors will benefit from import substitution once international transport costs rise significantly. In general, services that rely heavily on road or air transport will suffer more than those that do not. The medium to long-term prospects for tourism are unfortunately poor as this sector depends so heavily on affordable air and road transport (see Atkinson, 2008). However, there are opportunities for different kinds of tourism, e.g. more local tour-bus operations as opposed to longer distance touring by individuals or families in private motor vehicles.

Both of the "new economy" sectors targeted in the NGP, namely the "green economy" and the "knowledge economy", are consistent with mitigation of oil depletion.[185] However, renewable energy needs even more support and more ambitious targets. Efforts to "reduce the cost of and improve access to broadband" (EDD, 2010) are important for assisting telecommuting and thus reducing the need for personal travel.

The NGP's proposals for investments in social capital and public services are important for enhancing social cohesion in a future context of economic shocks, and will assist the move toward sustainability by mobilising local resources. However, this aspect of the NGP will hinge critically on state capacity for implementation. The NGP emphasis on rural development, such as investment in public infrastructure and housing in rural areas, is laudable. However, it should be aligned with the principle of economic localisation and cannot rely heavily upon road-based transport. Regional integration will be important to the extent that it fosters cooperation amongst governments in Southern Africa and helps countries cope with pressures such as regional migration. On the other hand, the desire for regional trade integration will likely have to be tempered in the light of increasing transport costs.

In summary, many, although not all, of the strategies and priorities elucidated in the NGP are consistent with mitigating the impact of global oil depletion. However, in some cases they do not go far enough, and there are areas (e.g. tourism) where the NGP is out of alignment with the future of oil.[186] Implementation of the NGP will face significant challenges. First, the NGP assumes that the global economy will recover from the 2008-9 recession and will continue to grow indefinitely thereafter, aside from possible cyclical downturns. As discussed in Chapters 2 and 4, this assumption is unlikely to hold, in which case the South African economy – and state coffers – will grow more slowly, or possibly shrink. Second, there is a risk that financing rates for NGP projects could rise considerably as inflationary pressures mount.[187] Third, the true test of the NGP will be at the policy implementation stage, where effective state capacity is required, but has often been lacking in the

[185] The NGP draws substantially on concepts raised in a national "Green Economy Summit" that was held in May 2010, involving government, business, labour and civil society organisations (RSA, 2010). Key government departments included the Economic Development Department (EDD), Department of Environmental Affairs (DEA), Science and Technology (DST) and Trade and Industry (DTI). The "Draft Statement of Conclusion" stated that the stakeholders aspire "to develop a sustainable, resilient, economically prosperous and self-reliant nation state..." The 'green economy' also features in the Industrial Policy Action Plan (IPAP2), which will be discussed in Section 5.3.5.

[186] Trollip and Tyler (2011) argue that the NGP is weakly aligned with the government's climate mitigation policies, in that it includes mitigation in its intent but does not engage quantitatively with emissions reduction targets. This means that the NGP does not adequately tackle the need for structural transformation of the economy.

[187] Much of the funding for implementing the NGP has been earmarked to come from the Industrial Development Corporation (IDC), namely R102 billion for the five-year period from 2011 to 2015.

past. Fourth, the restructuring of the economy envisaged in the NGP will encounter strong resistance from vested interests, not least of which is the minerals-energy complex (Fine, 2011).[188]

5.4.2 Fiscal policy

The key challenge for fiscal policy presented by the impacts of global oil depletion consists in maintaining fiscal sustainability. The budget deficit and therefore the level of public debt increased during the 2009 recession, but the National Treasury announced in its 2011/12 budget plans to reduce the deficit to 4.8% in 2011/12 and 3.8% in 2013/14, assuming an increase in the rate of economic (real GDP) growth to 4.4% by 2013 (National Treasury, 2011). As discussed in the previous chapter, there is a strong likelihood that the onset of declining global oil production will result in world-wide economic contraction and recession in South Africa. This would increase social pressure on government relief spending, but at the same time tax revenues would likely shrink. Resorting to increased borrowing in the short term would be self-defeating in the longer run since the economic shocks will persist and possibly worsen. Thus in order to avoid larger budget deficits and an increasing borrowing requirement, which over time could take the country towards the level of a debt trap, the National Treasury will have to ensure that spending is in line with tax revenues. In addition, the Treasury should set an example for the broader economy by maintaining public sector wage restraint so as to avoid a potential wage-price spiral, as occurred in many countries following the oils shocks of the 1970s.

Within a stance of fiscal prudence, there is considerable scope for expenditure switching in order to mitigate the impacts of global oil depletion. In general, given the constraints on government revenues noted above, mitigation strategies should wherever possible aim to be revenue neutral. For example, fiscal incentives can be realigned to encourage firms and consumers to invest in more sustainable, less oil-dependent capital stock (durable and semi-durable goods).

On the expenditure side of the budget, the priority should be to eliminate spending on infrastructure that would be imprudent in the context of high oil prices and fuel shortages (cf. City of Portland, 2007). As discussed in earlier sections of this chapter, government spending should be prioritised on more sustainable infrastructure and services such as electrified public transport, renewable energy and telecommunication networks. In addition, government procurement policy should aim to stimulate local production, as mentioned in the New Growth Path (EDD, 2010), for example in agriculture and light manufacturing (Fofana et al., 2008: 13). In the context of severe budgetary constraints, subsidies would in general be unsustainable, except to the extent that they provide an initial boost to green industries and activities that need initial assistance to achieve economies of scale in production. Subsidies to the automotive industry, which totalled R51 billion in the three years to 2011 (Donnelly, 2011), should be reduced and tied to more vehicle efficiency improvements and the production of BEVs and PHVs, if allocated at all. Tax rebates for energy efficiency and renewable energy have been discussed earlier. Any broad liquid fuel subsidy would be fiscally unsustainable and would encourage continued petroleum dependency. However, the fuel price stabilisation fund could be used to limit extreme short-term fuel price fluctuations (both increases and decreases), although the degree of uncertainty surrounding future prices would make its administration difficult. While there is a strong temptation for government to protect vulnerable sectors with temporary subsidies, these would in most cases be unsustainable in the face of repeated oil shocks. The exceptions would be industries that in the long run would benefit from the import substituting impact of higher transport costs and would promote greater sustainability. For example, subsidies for the automotive industry would be ill-advised unless specifically earmarked for highly energy efficient and less oil dependent vehicles (e.g. electric vehicles).

[188] The issues of state capacity and vested interests are discussed in more detail in Chapter 6.

On the revenue side of the budget, various taxes can be used to boost the greening of the economy. The National Treasury has already introduced carbon taxation, albeit at very modest rates, on coal-fired electricity and on vehicle emissions; such a tax could in principle be levied on liquid petroleum fuels as well. While carbon taxes can be effective in shifting incentives for energy efficiency and 'clean energy', they may become increasingly unpopular as oil and other fossil fuel prices continue their upward trajectory. Furthermore, blanket carbon taxes provide no guarantee of fairness in the distribution of an increasingly scarce resource; that is, while richer consumers will be able to absorb the increased cost of fuels, poorer households may not. There might, however, be a case for gradual, predictable increases in liquid fuel taxes in the short term (before the next major oil price spike) in order to incentivise fuel economy initiatives while generating greater revenues for public transit infrastructure (Litman, 2008). The Equalisation Fund, which historically was used to smooth out fluctuations in petroleum fuel prices, could be used again for this purpose.

The fact that consumption of petroleum fuels will decline in the future implies that the National Treasury should plan for falling fuel tax revenues, which amounted to approximately R48 billion (7.2% of total government revenue) in 2010 (see Table 5-10). The Treasury will therefore need to formulate alternative ways of generating revenue from transportation to fund transport infrastructure, including maintenance of existing roads (City of Portland, 2007: 39).

Table 5-10: Fuel levies and tax revenues estimated for 2010

		Petrol	Diesel	Total
Fuel sales volumes (2009)*	million litres	11,311	9,109	
95 unleaded petrol in DSML area	million litres	509		
Levies (June 2010)				
Fuel levy	cents/litre	167.5	152.5	
Customs & excise duty	cents/litre	4.0	4.0	
Road accident fund levy	cents/litre	72.0	72.0	
Petroleum products levy	cents/litre	0.15	0.15	
IP marker levy	cents/litre	0.0	0.01	
Demand side management levy	cents/litre	10.0	0.0	
Tax revenues				
Fuel levy	R million	18,946	13,891	32,837
Customs & excise duty	R million	452	364	817
Road accident fund levy	R million	8,144	6,558	14,702
Petroleum products levy	R million	17	14	31
IP marker levy	R million	0	1	1
Demand side management levy	R million	51	0	51
Total	R million	**27,610**	**20,829**	**48,439**

Source: SAPIA (2010)

*Note: * Fuel sales volumes for 2010 were not available.*

One option for additional taxation is a "windfall tax" on the profits of local synthetic fuel producers, i.e. Sasol and PetroSA. These companies are producing synthetic fuels from non-crude oil, indigenous feedstocks (coal and natural gas), but benefit by way of increased revenues and profits when international crude oil prices rise since retail fuel prices are based on import parity pricing. A task team appointed by the National Treasury in 2006 recommended the imposition of a windfall tax on synthetic fuel producers (Rustomjee et al., 2007), as did a report compiled for the Fiscal and Financial Commission (Fofana et al., 2008). However, the Finance Minister at the time, Trevor Manuel, opted not to follow this recommendation, out of fear that it would undermine further investment in the synfuel industry, which he saw as necessary for bolstering energy security. As discussed in Section 5.1.1, however, there are strong arguments against the construction of a new CTL plant. In essence, a windfall tax would transfer increasing resource rents from a (partially foreign-owned) private company to the country as a whole (providing the tax revenue is used beneficially).

5.4.3 Monetary policy

The South African Reserve Bank (SARB) is mandated to maintain price stability in support of economic growth and development. The primary policy framework, which is determined by the government, is inflation targeting. The major implementation tool is the repurchase rate of interest charged on overnight loans to commercial banks, which determines short-term market interest rates. Inflation targeting goes hand-in-hand with a free-floating exchange rate. As of 2011, the inflation target, which is set by the National Treasury, was a range between 3 to 6% for headline inflation (annual percentage change in the consumer price index). The NGP calls for "somewhat looser monetary policy" which is intended to "support a competitive exchange rate while continuing to target low and stable inflation" (EDD, 2010). The NGP recognises that these goals are to some extent conflicting, and thus identifies the need for additional policy tools to combat inflation, such as effective competition policy and probes into anti-competitive pricing, and restraints on administered price increases (EDD, 2010).

Global oil depletion presents a significant challenge to monetary policy, since oil price increases generally lead to higher rates of producer and consumer price inflation for many goods and services. Critically, the SARB must recognise that (1) the inflationary pressures are largely cost-push in nature, and (2) that these cost push forces will likely continue for many years. Since consumer demand will come under increasing pressure from rising costs of basic commodities (electricity, fuel, transport and food), the SARB should avoid excessively high interest rates that destroy demand and dampen investment in mitigating alternatives. It is probably advisable to allow relative prices to change through moderately higher inflation, rather than risk serious deflation (Feasta, 2005; Douthwaite, 2010). As far as the exchange rate is concerned, the SARB should refrain from attempting to intervene directly in the foreign exchange markets to influence the rand exchange rate, as historical experience (e.g. in 1996 and 1998) has shown this to be ineffective and costly. A far more preferable option would be to introduce a financial transactions tax (a type of "Tobin tax") to stabilise portfolio inflows, and raise much-needed revenues at the same time.[189]

The policy measures discussed above assume that the international and national financial and monetary architecture remain intact. However, as explained in Chapter 4, a possible scenario is that the current system experiences systemic collapse to one degree or another. If such an event were to occur, and arguably even if it did not, a national mitigation strategy could involve "monetary reform", i.e. a restructuring of the national monetary system. This could take the form of government-created money at very low interest rates, either by way of state-owned banks lending money into existence or the South African Reserve Bank being nationalised and performing the same function.[190] The advantage of monetary reform along these lines is that sustainable investments (e.g. in renewable energy and mass public transport) could be financed at low or negligible interest rates. Critically, the long-term success of this approach would depend on a responsible state that does not create too much money relative to the goods and services available, otherwise it could follow the

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[189] Brazil introduced a 1.5% tax on portfolio inflows in 2008, and subsequently raised this to 6% by 2011. Although there appeared to be little impact on the country's exchange rate, the tax did garner a significant amount of revenue for the state: equivalent to R3.36 billion in 2010 (Romano, 2011).

[190] The dti (2011) shows that South Africa's long-term and short-term real interest rates are higher than most of its trading partners, indicating a higher cost of capital, which militates against productive investment.

path to hyperinflation (e.g. as experience in Zimbabwe in the 2000s). While this type of monetary reform is anathema to the dominant ideological paradigm and vested financial interests (i.e. corporate banking), it has been implemented successfully at a state level (e.g. in North Dakota, USA) (Harkinson, 2009). An alternative approach to monetary reform at the local level will be discussed in Section 5.5.

5.4.4 Industrial policy

South Africa's industrial policy as of 2011 was summarised in the Industrial Policy Action Plan 2011/12 – 13/4 (IPAP2), introduced by the Department of Trade and Industry (DTI) in February 2011 (DTI, 2011). The IPAP2 elaborates on and supports the sectoral strategies delineated in the New Growth Path. IPAP2 (DTI, 2011: 79) prioritises three clusters of sectors, namely: (1) "qualitatively new areas of focus" (metal fabrication; capital and transport equipment; oil and gas; green industries; agro-processing and boat-building); (2) "scaled-up and broadened interventions in existing IPAP sectors" (automotive; petrochemicals; clothing and textiles; biofuels; forestry; paper and pulp; tourism; and business process outsourcing (BPO); and (3) "sectors with potential for long-term advanced capabilities" (nuclear; advanced materials; and aerospace). All of the Cluster 1 sectors are consistent with mitigation of global oil depletion, with the possible exception of boat-building.[191] The green industries included in the IPAP2 are solar water heaters, wind turbines, solar PV panels, concentrated solar thermal, biomass energy, energy- and water-efficient materials, appliances and motors, waste management, and energy-efficient vehicles. These are all commendable initiatives, but need to be supplemented with sustainable transport infrastructure and vehicles, including bicycles and electric bicycles and scooters. In Cluster 2, the prospects for export-oriented sectors such as automotive and tourism are not bright; sectors with potential for import substitution such as petrochemicals (derived from coal and gas feedstock) and clothing have better potential. In terms of Cluster 3, the nuclear value chain is highly contentious, while aerospace will likely be an unaffordable luxury; advanced materials could become a niche area for innovation.

There are several broad policy tools that can be used to stimulate green industries. First, regulations can be imposed, such as building regulations mandating solar water heaters and energy efficiency standards for vehicles and appliances. Second, policies to support innovation are critical to the success of the mitigation programme. The NGP targets a doubling of South Africa's research and development (R&D) investment to 2% of GDP by 2018, although the framework does not spell out how this is to be achieved. R&D can be promoted by subsidies (justified by the social benefits outweighing the private benefits) and other fiscal incentives. Key areas for technological innovation include renewable energy technologies, energy storage technologies and more efficient vehicle designs.[192] Third, IPAP2 correctly identifies the need for procurement policies to stimulate local production capacities (DTI, 2011: 47). However, its list of "strategic procurement fleets" excludes bicycles, fuel-efficient vehicles (for government use) and solar PV panels.

The IPAP2 contends that a "continual ramp up of renewables capacity at the ambitious level of around 1–3 GW per year, would build up towards the generally acknowledged potential of at least 15% of the electricity grid by 2020-2025" (DTI, 2011: 110). Green industries are well known to have a relatively high employment creation potential and will thus contribute to multiple socioeconomic goals (DTI, 2011). However, the DTI (2011: 111) states that "[n]ational funding sources alone are insufficient to achieve a critical mass of renewable investment", and concludes that "international

[191] As maritime oil becomes more expensive, international trade and therefore demand for freight ships is likely to decline. However, demand for passenger transport ships might increase.
[192] The topic of innovation will be addressed in more detail in Chapter 6.

cooperation is required to secure the necessary concessionary finance and risk guarantee instruments."

There are several probable constraints on the implementation of industrial mitigation strategies. First, the historical trend towards increasing financialisation of the South African economy, which has diverted capital away from productive investments, will need to change (Mohammed, 2010). Second, the minerals-energy complex dominates the economy and channels much of the available capital into resource, energy and capital intensive sectors (Mohammed, 2010; Fine, 2011).[193] Third, the high degree of economic concentration in the economy results in monopolistic or oligopolistic pricing for many intermediate and final products (DTI, 2011: 22). Fourth, financial capital for businesses to retool will become increasingly scarce and expensive in the era of declining world oil production. Fifth, green industries will face input bottlenecks, for example in raw materials such as rare earth metals that are used in renewable energy technologies. Sixth, there is a chronic shortage of high-skilled workers (Adcorp, 2011).[194] Where possible, these constraints will need to be addressed directly as part of the mitigation strategy, for example through the application of competition policy and skills development programmes. Competition policy is one of the central microeconomic tools identified in the NGP, and will be aimed at ensuring more competitive pricing, particularly of intermediate products and basic necessities. The NGP also correctly identifies the need for new types of education and training to support newly emerging industries, such as green technologies and knowledge-intensive sectors.

5.4.5 Trade policy

Since 1994, South Africa's economy has become increasingly integrated with the global economy, as evidenced by increasing shares of both exports and imports in GDP. The main thrust in trade policy, at least until recently, has been towards export-led growth.[195] Given the future context of rising oil prices, however, trade policy authorities should anticipate the dampening effect that rising transport costs will have on both exports and imports (Rubin, 2009). Thus they should plan for and facilitate import substitution and reduced reliance on exports, which is counter to the prevailing wisdom. In particular, subsidies to the automotive sector represent a misallocation of resources, considering that the global demand for new (ICE) vehicles is likely to contract rapidly once oil supplies begin to shrink. Such a re-orientation of trade policy will have to overcome resistance both ideologically and from vested interests that stand to lose in the short term. It is therefore essential that the scientific basis of oil depletion be properly communicated so that businesses understand the real context for future trade.

5.4.6 Labour market policy

Labour market policy in South Africa has typically been highly contested by different ideological persuasions, especially on the issue of "flexibility" versus the protection of workers' rights and decent working conditions. Four areas of labour market policy should be included in the oil mitigation strategy. First, while recognising the need to protect the interests of workers, it might be advisable for government to introduce greater flexibility in hiring and firing to facilitate the shift of labour out of declining sectors and into growth sectors as the economy restructures in response to

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[193] This issue, together with the related issue of technological lock-in, will be elaborated in Chapter 6.

[194] Adcorp (2011: 3) estimated that there were nearly 830,000 "unfilled positions for high-skilled workers across a wide range of occupations, including senior management, the professions (medicine, engineering, accounting and the law), technical occupations (specialized technicians and artisans), and agriculture."

[195] There is an unresolved debate in the literature over the actual extent of trade liberalisation in South Africa (Edwards, 2004).

rising transport costs. Otherwise, mass retrenchments might be the norm as companies are liquidated as a result of declining global and local demand. Second, given inflationary pressures from oil prices there is a strong argument for public and private sector wage restraint, which should ideally occur within a social compact involving business, labour and government (see NPC, 2011). Third, education and training programmes should be aligned with the likely impacts of oil depletion, such as the decline of certain industries and the rise of others. The NGP's emphasis on artisanal and technical skills is very welcome.[196] In addition to renewable energy, another sector that will see rapid growth is bicycle manufacture and repair. More generally, repair and maintenance skills will experience a rapid growth in demand as the "salvage economy" unfolds (Greer, 2010). Fourth, employment creation could be stimulated by employment subsidies in green sectors like renewable energy and the manufacture of sustainable electric transport infrastructure. However, ever-tightening budget constraints might render subsidies unaffordable in the medium to long term. Given the long battle to improve workers' rights, some of these suggested policy changes might be fiercely resisted by trade unions if they are not fully apprised of the reasoning. Essentially, the sustainability of formal sector jobs is the critical issue.

5.4.7 Conclusions on macroeconomic mitigation

Given the broad and deep dependence on petroleum fuels, peak oil presents an immense challenge to the entire economy and to macroeconomic policy in particular. At the same time, there are many opportunities for both incremental and fundamental shifts in macroeconomic policy that can both mitigate the impending decline in world oil production and improve economic sustainability. Some recent government policies, especially the New Growth Path and the Industrial Policy Action Plan 2, have made important strides towards mainstreaming sustainability imperatives. However, in these policy documents the 'green economy' is still interpreted as a subsector of the overall economy, incorporating energy efficiency and renewable energy investments. The conceptual synthesis developed in Chapter 1, however, regards the project of 'greening the economy' as all-encompassing measures to make *all* sectors of the economy more sustainable. Thus there remains a disjuncture between the NGP and IPAP2 on the one hand, and the vision expressed in the National Framework for Sustainable Development on the other. To a large degree, this probably reflects the different theoretical and/or ideological paradigms underpinning these sets of policy documents: the NGP and IPAP2 were formulated mainly from a conventional economics perspective (albeit influenced by the 'developmental state' literature), while the NFSD reflects a broader understanding of the economy-ecology relationship as developed within the ecological economics paradigm and the social-ecological systems approach.

Some of the main macroeconomic mitigation policies and measures, together with the various financial and institutional constraints they will face, are summarised in Table 5-11. Some constraints will apply to all of the policy categories. One is that there will be increasing demand for government expenditure but falling tax revenues. This will result in difficult trade-offs, of both an inter-sectoral and an inter-temporal nature. For example, there will be pressures for short-term support (e.g. for employment in negatively affected industries) but a need for long-term restructuring for sustainability. Second, the financing of projects is likely to become more costly as interest rates rise in response to oil-price induced inflation in the coming years. Third, the success of many of the policies will require a social compact between government, business and labour, but this might be even more difficult to achieve in a context of economic shocks and social stress. A fourth constraint is the managerial and administrative capacity of state institutions; South Africa does not have a particularly good record of policy implementation and delivery, especially at the local level (NPC,

[196] The NGP correctly notes that "[i]mprovements in education and skill levels are a fundamental prerequisite for achieving many of the goals in this growth path" (EDD, 2010: 19).

2011). An additional mitigation strategy which has not yet been discussed at the macroeconomic level, but is no less important, is an education and awareness programme about the nature and implications of global oil depletion to inform appropriate planning decisions by businesses and consumers. This will help to reduce investments in enterprises and developments that would likely face a significant future reduction in demand, while signalling opportunities in more sustainable sectors.

Table 5-11: Summary of macroeconomic mitigation policies and constraints

	Mitigation strategies, policies and measures	**Constraints**
Fiscal	• fiscal prudence • expenditure switching • prioritise sustainable human & physical capital • green taxes & subsidies • windfall tax on synthetic fuels	• falling tax revenues but rising demands on state resources • increasing borrowing costs
Monetary	• low real interest rates • state-owned development banks • tax on international financial transactions	• inflation control versus competitive exchange rate • balancing inflationary/deflationary pressures • opposition from banking sector • reaction of international capital markets to monetary reform
Industrial	• incentive support for green industries • regulations for efficiency standards • support for innovation • local procurement • competition policy	• financialisation of the economy • minerals/energy complex • economic concentration • scarcity & expense of financial capital • input bottlenecks • skills shortages
Trade	• support for import substitution • selective (initial) tariff protection • elimination of export subsidies for unsustainable sectors (e.g. automotive)	• WTO commitments • sectoral interest groups
Labour market	• greater hiring/firing flexibility • social compact on wages • (re)training and skills acquisition • employment or wage subsidies in green sectors	• coordination of interest groups • fiscal constraints

5.5 Society

In the social domain, the main goals for a mitigation strategy for oil depletion must be to protect the most vulnerable members of society and to promote equity. More specific objectives include: promoting fairness in access to fuels; building community resilience to socioeconomic shocks; enhancing household food security; strengthening social cohesion; and planning to ensure sustainable spatial development in the long term and an ability to cope with emergency situations brought about by fuel supply disruptions.

Increasing oil prices and fuel scarcity will add pressure to existing socioeconomic challenges such as poverty and inequality. As such, existing programmes designed to alleviate these conditions will need to remain in place and even be strengthened, subject to budget and capacity constraints. South Africa already has in place a broad social safety net. As of 2010, state grants were given monthly to 14 million recipients, i.e. 28% of the population, and accounted for 3.5% of GDP (Presidency, 2010). It is unlikely that this expenditure can be raised in the medium/long term; in fact it is more likely that the amounts spent on social assistance will have to decline as a result of falling tax revenues. Thus other measures will need to be adopted to advance the goals listed above.

This section begins with an evaluation of several administrative alternatives for rationing fuel in the interests of maintaining equity. It then discusses local economic development and local food security initiatives as tools to build resilience at the community level. This is followed by a consideration of long-range human settlement planning and emergency planning for sudden shocks. The last section concludes that social cohesion must be fostered through effective leadership.

5.5.1 Social protection systems

Allowing market prices to determine who in society gains access to fuels brings no guarantee of fairness. The wealthy will still be able to afford fuel for their private automobiles, while poorer people may not be able to afford higher public transit fares. This inequality could precipitate serious social strife. To ensure fairness in access to and/or affordability of fuels and energy services, some form of administrative system should therefore be implemented. The pros and cons of four options are considered below, namely price controls, liquid fuel coupons, tradable energy quotas, and a “cap and share” system.

Fuel price controls

Government can in principle impose domestic fuel price controls to limit the rise in fuel prices to international levels (see Hirsch et al., 2010: 87). In effect this means imposing price ceilings on domestic oil producers (Sasol and PetroSA). Since approximately 70% of petroleum products are refined from imported crude oil, the government would also have to introduce an entitlements system for oil refiners that averaged the prices of domestic and imported oil. Thus refined fuel prices would still rise, albeit not to the world level. This system requires additional price controls on the mark-ups of downstream operators such as refiners, wholesalers and retailers; in South Africa these are already part of the existing regulatory regime. In the absence of allocation controls (rationing), price controls would result in long queues at filling stations since prices would not be high enough to reduce demand to the lower level of supply. On the plus side, all fuel consumers would benefit from the attenuation of fuel price increases, while domestic producers would not capture excessive scarcity rents. However, price controls have several major disadvantages. First, queuing for fuel is highly inefficient and results in a net welfare loss to society (Hirsch et al., 2010: 91). Second, the poorest members of society would still face price increases that would render fuel or transport increasingly unaffordable. Third, price control systems are administratively onerous, requiring refiners to submit detailed information to the authorities on quantities of oil bought and sold, and a large team of government personnel to administer the system. Fourth, such a system lacks the flexibility to cope efficiently with fluctuating oil prices. Finally, fuel price controls could potentially undermine the economic viability of the domestic producers, if their operational costs rise as a consequence of rising world oil prices.

Liquid fuel coupons

In order to overcome the queuing problems discussed above, price controls can be accompanied by a rationing system. Rationing systems have been adopted in many countries in the past, both for oil and for other essential commodities. The most basic rationing system involves booklets of coupons issued to citizens on the basis of registered vehicle ownership, historical consumption patterns, and/or priority users (Hirsch et al., 2010: 88). Citizens would have to relinquish their coupons (e.g. denominated in litre units) every time they purchased petrol or diesel; retailers would pass on coupons to refiners; and refiners would transfer the coupons to the government. Such a rationing system would have to be complemented with domestic oil price and refined fuel price controls as above, else petrol and diesel prices would rise to market-clearing levels. A secondary market for fuel coupons would develop, so that citizens requiring (and being able to afford) more fuel could purchase ration coupons from those needing less. The main advantages of a rationing system are its fairness, the elimination of queuing, and the opportunity for government to allocate coupons to priority users such as emergency services and those with particular hardships or high fuel dependency. However, such simple systems have many drawbacks, including: high administrative costs and human capacity requirements; interest groups exerting pressure on government officials responsible for coupon allocation; possible forgery of coupons; greater complexity if companies and state institutions are included; economic inefficiencies associated with price controls and allocation; and a limitation of ration trading opportunities to local areas (Hirsch et al., 2010; Fleming, 2007: 25).

Tradable Energy Quotas[197]

The concept of Tradable Energy Quotas (TEQs) was developed specifically to address the twin challenges of climate change and fossil fuel depletion, while ensuring social equity in access to energy.[198] The TEQs model aligns individual incentives with the collective requirement to reduce fossil fuel dependency (APPGOPO, 2009: 5). TEQs function as follows. To begin with, a Climate Committee determines a national "Carbon Budget" for total annual carbon dioxide emissions, which decrease each year over a twenty-year period. The annual budget is then divided into individual TEQ units, a unit being "defined as one "carbon unit" – that is, allowing the purchase of sufficient fuel or energy to produce one kilogram of carbon dioxide over its lifecycle" (APPGOPO, 2009: 9). TEQs are required for all energy purchases, with each energy type being rated according to its carbon content. A Registrar issues equal entitlements (summing to approximately 40% of units) to each adult citizen and maintains carbon accounts for all participants. In addition, TEQs are sold on a weekly tender via financial intermediaries to other energy users, including businesses and government. Once issued, TEQs can be traded by all energy users in a single market, allowing low-energy consumers to derive income while high-energy users obtain sufficient units to cover their energy needs. The entire system is electronic, making use of direct debits and cards. The price of TEQs is determined in this market and depends on efforts to reduce energy demand. It is not necessary to measure emissions at their exit point ("exhaust pipe"); rather, the carbon accounting is done at the point of sale. When individuals or entities purchase energy, they surrender the appropriate number of units to the retailer, who surrenders to wholesalers, etc. Primary energy producers surrender units to the Registrar. Each successive year, the total Carbon Budget is reduced and thus fewer TEQs are issued.

[197] This section is based on Fleming (2007) and APPGOPO (2009).
[198] The TEQ concept was pioneered by Fleming (2007).

TEQs have a number of benefits. First, they guarantee a certain annual reduction in fossil fuel use and carbon emissions. Second, TEQs promote fairness in access to energy, while providing strong incentives for individuals to reduce their energy consumption. Third, a rolling carbon budget is set for a twenty-year period, which creates a much greater degree of certainty for business and personal planning decisions. Fourth, the system is administratively simple, using modern, automated electronic systems that make it largely “hands free” (Fleming, 2007).

Nonetheless, TEQs do have certain limitations in the South African context. For one, TEQs require a single national market for carbon-based fuels, but this is not necessarily simple; for example, the incorporation of electricity generated from fossil fuels is complicated when renewable primary energy sources are also used. Second, TEQs do not directly protect individuals against high oil prices, which are still determined on international markets. Thus there is no guarantee that poorer people will actually be able to afford the fuel that their TEQs entitle them to. Nonetheless, they will be guaranteed a basic income through their right to sell their TEQs. Third, implementation of the TEQ system would face challenges in a developing country context such as South Africa, where in the region of 40% of the population does not participate in the formal banking system (African Loft, 2008), and 23.5% of adults were illiterate in 2008 (The Presidency, 2010: 48).

Cap and Share

A similar scheme, known, as Cap and Share (C&S), has been developed by the Ireland-based Foundation for the Economics of Sustainability (Feasta, 2008; Cap & Share, 2011). Like TEQs, C&S was designed to address the related challenges of global oil depletion and climate change. It can in principle be applied on a global or national scale. Under a national C&S scheme, an independent scientific body determines annually a maximum ceiling (cap) on carbon dioxide emissions from the combustion of fossil fuels. The total amount of emissions is divided equally among the adult population; each citizen is allocated a “pollution authorisation permit” (PAP), i.e. a certificate entitling the owner to emit a certain tonnage of CO_2 per year. Individuals are then free to sell their PAPs through financial institutions (e.g. banks and the post office) in a national market for PAPs. Fossil fuel producers and suppliers (e.g. coal miners, oil companies and gas importers) must buy sufficient PAPs to cover the emissions from the coal, oil or gas they sell into the economy. These companies then surrender these PAPs to an independent agency that monitors the actual CO_2 content of the fuels. Each year the cap is reduced by a percentage determined by the scientific panel (or faster than the rate at which global oil production declines). The fossil fuel suppliers will pass on the additional cost of the PAPs to consumers (ultimately to consumers of final energy products like petrol and electricity), but consumers will be at least partially compensated by the income they derive from selling their PAPs. Individuals who consume less than average fossil fuel based energy might benefit in net terms, while those consuming more energy will pay more in net terms.

In a variant of C&S, known as Cap and Dividend (C&D), an independent agency conducts auctions to sell the PAPs to fossil fuel suppliers, and distributes the monetary proceeds on an equal per adult basis. This variant would be better suited to the South African context of relatively high rates of illiteracy and lack of education, as individuals would not have to make complicated decisions about when to sell their PAPs. A portion of the auction dividends could be earmarked for specific community or social investments, such as renewable energy production or public transport systems.

C&S is designed to transfer the scarcity rents on fossil fuels from producers to all adult citizens in an equitable manner.[199] It also incentivises people to reduce their consumption of fossil fuels both directly (as fuels) and indirectly (embodied in goods), and simultaneously boosts the competitiveness of renewable energy sources. The diminishing annual cap means it would be

[199] C&S can be viewed as a special case within a broader discussion on the allocation of rights to the use of ‘environmental space’, in terms of both resources and sinks (see Buhrs, 2007).

effective in reducing CO_2 emissions. Since there are few fossil fuel companies bringing their products into the economy, the system would be simple to administer. Monthly dividends could be distributed in a manner similar to existing social grants, i.e. through post offices. In fact, these dividends would effectively constitute a "basic income guarantee" for all adult citizens, and thereby provide a measure of social protection against the negative socioeconomic impacts of global oil depletion. On the other hand, C&S would not function as desired if there were rapid declines in oil imports, and therefore other emergency rationing schemes would be required under such circumstances.

Comparison

The major drawbacks to all rationing systems are the administrative costs and human capacity required, and the risk of corruption. Of the schemes discussed above, Cap & Dividend is the simplest and cheapest. TEQs, being a downstream system, are more complicated and expensive to administer than C&S or C&D, which are upstream systems (Cap & Share, 2011). TEQs and C&S (or C&D) have other advantages over fuel rationing, in that they serve a wider range of purposes (e.g. climate mitigation). They are also more flexible, for example by including non-fuel energy such as electricity derived from coal, which is also likely to become increasingly expensive as coal reserves deplete. However, fuel rationing has the advantage that specific quotas can be distributed to priority users such as essential services (e.g. police, fire brigades and other emergency services), public transport vehicles such as buses and diesel trains, and farmers. It is also more effective in the event of sudden, large fuel shortages (e.g. triggered by geopolitical events in oil producing nations that shut in large amounts of supply). At a theoretical level, schemes such as TEQs and C&S reflect the fundamental role that energy plays in sustaining economic activity, by bringing energy closer to the centre of economic transactions. Fuel rations, TEQs or PAPs effectively become alternative currencies that could help to mobilise resources when the supply of conventional money is scarce, a topic discussed further in the following section.

5.5.2 Building community resilience through economic localisation

Although national economic policies and conditions affect economic development throughout the country, all development actually takes place at the local level. Furthermore, as discussed in Chapters 2 and 4, global oil depletion will in all likelihood result in a gradual reversal of globalisation in respect of trade in physical goods and transport-dependent services such as tourism. Thus any mitigation strategy must include a strong local dimension, the specific goals of which are to: (1) improve community resilience to economic shocks and facilitate sustainable development at a local level; (2) boost the number of sustainable livelihoods; and (3) enhance household food security. Local economic development (LED) strategies and policies operate at the local (municipal) level of government, in both urban and rural areas, and complement national economic policies. Municipal Integrated Development Plans (IDPs) (five-year strategic plans) must be aligned with the national oil mitigation strategy. This section explores instruments that can be used to achieve the above goals.

The Department of Cooperative Governance and Traditional Affairs (DCoGTA, 2011a) runs an LED programme guided by the National Framework for Local Economic Development (NFLED), the overarching aim of which is to "support the development of sustainable local economies through integrated government action" (DPLG, 2006: 3).[200] In this framework, LED is understood to be "about creating a platform and environment to engage stakeholders in implementing strategies and programmes", and involves "the provision of infrastructure and quality services" by municipalities with the aim of improving competitiveness of local economies (DPLG, 2006: 9). The NFLED identifies

[200] The DCoGTA was preceded until 2009 by the Department of Provincial and Local Government (DPLG), which authored the LED Framework.

two main policy thrusts. The first is "sound public sector leadership and governance" (DPLG, 2006: 19). The second is "sustainable developmental community investment", which aims to boost "the circulation of income in local economies" (DPLG, 2006: 20). This is to be achieved via community trusts that will accumulate both public and private investment capital and spend these on community projects via cooperative enterprises. The NFLED also calls for increased spending on "adult basic education and training aimed at improving literacy and numeracy as a basis for participating in local economic opportunities", particularly in rural areas (DPLG, 2006: 14). Local government can further assist LED through development marketing bodies and investment incentives (DPLG, 2005: 39).

For the most part, LED strategies in the past have assumed that the forces of globalisation will be maintained or even increase in the future, and seek to counter-balance these forces or adapt to them. Eco-localisation (or "relocalisation") calls for a proactive strategy to reduce reliance on a globalised economy that is expected to 'de-globalise' as a consequence of rising transport costs as world oil production declines (Heinberg, 2004; Hopkins, 2008; North, 2010).[201] Localisation implies "producing as much as possible as locally as possible, then within the shortest possible distance, with international trade only as a last resort for goods and services that really cannot be produced more locally" (North, 2010: 587); intra-industry trade would largely disappear. Since global value chains are highly susceptible to dislocation from liquid fuel shortages, businesses that are currently embedded in global and even national value chains should, wherever possible, seek to localise their sources of inputs and expand their local markets. Regional and local multipliers can be boosted by measures such as 'buy local' campaigns (e.g. Proudly South African). Further than this, intentional localisation "means developing community-owned local economic institutions like worker-owned and run co-operatives, communal gardens and restaurants, local power generation, local money, and communal forms of land ownership" (North, 2010: 587). Proponents of localisation advocate local economies that are resilient through diversity and interdependence. Authors such as Hopkins (2008) foresee that relocalisation will be driven primarily by communities, although working in partnership with local government authorities.[202] The doctrine of "eco-localism" holds that "[t]he road to environmental sustainability lies in the creation of local, self-reliant, community economies" (Curtis, 2003: 83).[203] In addition to conventional markets, local economies are "equally constituted by collectives and cooperatives, buying clubs, community enterprises, not-for-profits, barters and skills exchanges, mutual aid, volunteer activity, household and subsistence production, and what is variously termed the informal sector or the underground economy" (Curtis, 2003: 86).

The second major goal of an LED or relocalisation strategy is to create sustainable livelihoods. The NSSD (DEA, 2010: 18) identifies opportunities for sustainable livelihoods in eco-tourism, aquaculture, small-scale organic agriculture, ecosystem rehabilitation, renewable energy generation and wildlife management. The NSSD further proposes that the Public Works Programme be extended into the environmental sector. To some extent this has been achieved through the Expanded Public Works Programme (EPWP), which includes four sectors, namely: infrastructure; environment (including the Working for Water, Working for Wetlands, Working on Fire, and Working for Energy programmes); non-state sector; and social sector (DPW, 2011). The EPWP creates temporary work for unemployed

[201] North (2010: 589) distinguishes between "'immanent' localisation that just 'happens' as a market economy changes over time as a result of decisions made by individual businesspeople for business reasons; and 'intentional' localisation as a normative political project, something which someone 'makes' happen."
[202] The "Transition Town" movement, inspired by Rob Hopkins (2008), is testament to this idea. Communities formulate "energy descent action plans" in order to manage the forthcoming decline in energy availability.
[203] According to Curtis (2003: 83), eco-localism "is the perspective embodied in local currency systems, food co-ops, micro-enterprise, farmers' markets, permaculture, community supported agriculture (CSA) farms, car sharing schemes, barter systems, co-housing and eco-villages, mutual aid, home-based production, community corporations and banks, and localist business alliances."

citizens, but aims to build skills that will help individuals to find sustainable work opportunities. The EPWP Phase 2, launched in April 2009, aimed to generate two million full time equivalent jobs over the ensuing five-year period. The EPWP has successfully created short-term work opportunities but has been less successful in creating sustainable livelihoods, and is a relatively costly programme (Philip, 2010: 25). Another livelihood area that needs to be massively expanded is the training of artisans (see DPLG, 2005: 35).

The DCoGTA (2011b) runs a Community Work Programme (CWP), which aims to provide an "employment safety net" to improve the quality of life of people living in marginalised areas. The CWP is implemented in specific sites (in wards or municipalities) using a community participation approach to determine what constitutes 'useful work', defined as "work that contributes to the public good and improves the quality of life in communities" (TIPS, 2010: 5). Practical examples of useful work include home-based care, food gardens, community parks and gardens, rehabilitation of ecosystems, road maintenance, early childhood development programmes, and community safety. The CWP had 55 582 participants by March 2010 and the DCoGTA's "target is to implement the CWP countrywide in at least two wards per municipality to reach 237 000 people by 2013/2014" (TIPS, 2010). The budget for year 2009/10 was R159.6 million, of which 98% was spent, including 65% on wages. This first, expansion phase of the CWP was considered to be very successful in meeting its objectives, and could serve as basis for a national employment guarantee (Philip, 2010), which in turn could prove to be a vital tool for mitigating the socioeconomic impacts of oil depletion. As Philip (2010: 27) argues, "an employment guarantee doesn't only contribute to raising aggregate demand at local level: it also invests in human capital development, in public/community goods and services, and in natural capital, in ways that further enhance the potential for sustained social and economic development." Philip (2010: 24) estimates that an expanded CWP would cost about R10 billion per million participants, less than half as much as the EPWP. The key issue is a sustainable funding model, which is explored at the end of this section.

The third goal of boosting food security can be addressed by the expansion of small-scale sustainable agriculture, which can simultaneously assist in the creation of sustainable livelihoods.[204] According to TIPS (2010: 6), "[t]housands of food gardens have been established through the CWP, making a huge difference to food security at a household level, and providing free food for feeding schemes and vulnerable households." Hine et al. (2008: 12) report that the adoption of organic farming techniques amongst small-holder African farmers is associated with improving food security. Rundgren (2002, cited by the Institute of Natural Resources, INR, 2008) argues that organic farming can boost food security by raising productivity, generating safer food, attenuating production costs, reducing risks through diversification, supporting innovation and enhancing long term sustainability.
A critical pre-condition for the success of sustainable (e.g. organic) small-holder agriculture is the acquisition of appropriate knowledge and skills by emerging farmers; here the state has an important role to play. Furthermore, international evidence suggests that land redistribution can be an effective way of improving the welfare of landless rural dwellers, provided the land is of sufficient quality (Rosset, 1999). Department of Rural Development and Land Reform's Comprehensive Rural Development Programme (CRDP), published in July 2009, "is aimed at being an effective response against poverty and food insecurity by maximizing the use and management of natural resources to create vibrant, equitable and sustainable rural communities" (DRDLF, 2009: 3). The CRDP strategy involves three elements, namely: agrarian transformation; rural development (stimulated by strategic investment in economic and social infrastructure); and land reform. In practice, however, the CRDP was limited to approximately 56,700 households residing in 21 wards in 2009/10, and envisages expansion to include 121,500 households in 45 wards by 2013/14. The land reform process in South Africa is lagging far behind targets (DRDLF, 2009). The success of this process will be even more important in the future context of fuel scarcity, which as noted earlier is likely to reverse

[204] Since urban agriculture was discussed in Section 5.3, the discussion here focuses on rural farming.

the trend towards mechanisation of farming and consolidation of farms into larger units; i.e., more labour will be required in the future.

Effective mitigation and transformation strategies and policies face both institutional and resource constraints. Firstly, the policies discussed above fall under overlapping ambit of several national government departments, namely DAFF (which focuses mainly on commercial agriculture), DRDLF (primarily focused on rural communities) and CoGTA (dealing mostly with municipal governments), as well as local authorities. To be most effective, strategies require cooperation and integration among these various departments and spheres of government, which has historically proven difficult to achieve. Second, appropriate managerial capacity and skills has often been lacking at the provincial and local level (especially in rural areas and smaller towns), hampering policy implementation (NPC, 2011c). Third, financial resources are usually scarce, again especially in rural districts.

A crucial element of an effective LED or relocalisation strategy concerns ways to boost the local money supply, stimulate local money multipliers, and stem monetary leakages. Funds for LED could in principle be sourced from loans from national financial institutions or grants from national government and donors, but these sources will tend to be increasingly unsustainable in the era of declining world oil production. Three local approaches to ensuring a sufficient supply of money have much better prospects. The first option is the formation of state-owned municipal banks, which would be able to award low- or zero-interest loans to individual citizens and for community investment projects.[205] The second option is the formation of credit unions, which are cooperative, community-owned financial intermediaries. These institutions essentially pool the financial resources of citizens and make loans on favourable terms for projects adjudged by the governing board of directors to be sustainable and beneficial to the community (see Douthwaite, 1996). The third option is the use of local or community currencies, which are complementary to the national currency (Douthwaite, 1996). An effective network of community currencies is already operated by the Community Exchange System, a non-profit organisation. As of June 2011, the CES network included 294 local exchanges in 34 countries, including 29 exchanges in South Africa (CES, 2011). Essentially, all of these mechanisms would facilitate the mobilisation of otherwise idle natural and human resources (labour and skills) on an ongoing basis to produce goods and services that are needed by the community but that might not otherwise be produced as a result of lack of access to (externally originating) money. They also help to stem leakages of money outside of the local area, and hence boost local economic multipliers.

5.5.3 Spatial development planning for sustainable human settlements

Spatial development planning by national government as of 2011 is reflected primarily in two policy documents. The first is the National Spatial Development Perspective (NSDP), whose objective "is to fundamentally reconfigure apartheid spatial relations and to implement spatial priorities that meet the constitutional imperative of providing basic services to all and alleviating poverty and inequality" (The Presidency, 2006b: ii). Second, spatial development is one of the five 'jobs drivers' in the New Growth Path, according to which the government commits itself to "step up its efforts to provide public infrastructure and housing in rural areas" and increase support for small-scale agriculture, and also to boost regional development mainly by improving logistics, including "an integrated road and rail system across the continent" (EDD, 2010: 22-23). Neither of these policy documents takes into account the implications of global oil depletion, which suggests that three key principles should inform spatial development planning. First, all new housing, commercial and infrastructural

[205] A good example is the Bank of North Dakota, the only state-owned bank in the United States, which helped North Dakota weather the financial crisis of 2008 better than any other state (Harkinson, 2009).

developments should assume increasing prices and scarcity of transport fuels in the foreseeable future (e.g. a 20 to 30 year time horizon). Second, spatial development planning must be integrated with transport planning as well as with industrial and trade policies (as already discussed in Section 5.4). Third, planning should be based on an assumption that urbanisation will continue (and possibly accelerate) in the short- to medium-term, but is likely to be replaced by re-ruralisation in the longer term.[206]

A number of specific policies and measures should be adopted in urban planning. First of all, the phenomenon of urban sprawl should be halted in order to avoid further entrenching dependency on automobile transportation and to limit encroachment on agricultural land surrounding urban settlements. Rather, urban densification "in well-located areas" and "more intense development of vacant and under-used land" should be a major policy focus (Turok et al., 2011: 19). Mixed-use zoning and allocation of existing open spaces should be applied to facilitate localisation of food production. More generally, agriculture should be integrated with urban development planning, based on an ecosystem approach (Thornton, 2008: 259). Local government authorities should allow and encourage small commercial outlets, which might be termed "neighbourhood centres", within residential areas (City of Portland, 2007: 37). Planning should encourage housing of sufficient density near public transport routes that will generate adequate fare revenues to sustain the mass transit services (City of Portland, 2007: 37), foster developments along public transport corridors, and provide public spaces accessible to pedestrians in urban centres. Special efforts should be made in the short to medium term to maintain existing industrial areas, especially those that are near rail lines, to facilitate local economic diversification in the event that globalisation unwinds in the longer term (City of Portland, 2007: 38).

Given the large housing delivery backlog in cities and towns, evidenced by the number of people living in informal settlements, a critical question is where to build new, low-cost housing and associated infrastructure. Continuing the practice of upgrading existing townships or constructing new housing settlements on urban peripheries is likely to exacerbate the problems that will be associated with rising transport costs. In addition, in the long term oil depletion might force a substantial proportion of urban dwellers to return to rural areas to pursue subsistence agricultural activities. This suggests that the priority should be land reform (and associated training in organic farming methods) so that compact new housing developments can be built in more sustainable locations, i.e. in areas with agricultural potential. It also underscores the importance of rural development programmes that stem the tide of rural-urban migration. A further challenge for spatial development planners will be a choice between providing public transport infrastructure to service existing fixed (immovable) capital stock (e.g. houses, factories, and commercial buildings) and building new capital stock in locations close to existing mass transport infrastructure.

In summary, global oil depletion presents major challenges for spatial development planning by overturning certain prevailing assumptions that are based on historical trends and creating significant uncertainty regarding future migration patterns and the viability of the existing stock of residential, industrial and commercial buildings.

5.5.4 National climate change response policy

In October 2011 the South African government (RSA, 2011) promulgated a National Climate Change Response White Paper (NCCRWP). This document sets out in broad terms a range of adaptation policies to help the country cope with the likely impacts of climate change, and mitigation strategies

[206] Heinberg (2006d) contends that "re-ruralization will be the dominant social trend of the twenty-first century."

aimed at reducing greenhouse gas (GHG) emissions. The White Paper specifies that South Africa will pursue a "peak, plateau and decline" GHG emission trajectory, whereby GHG emissions peak between 2020 and 2025 in a range between 398 and 614 megatonnes (Mt) CO_2-equivalent per annum, plateau for approximately a decade (within that range), and from 2036 begin to decline in absolute terms towards a range between 212 and 428 Mt CO_2-eq p.a. by 2050.

The NCCRWP identifies a variety of policy measures and instruments that will be implemented in pursuit of the goals and targets. Key amongst these is "the use of incentives and disincentives, including regulatory, economic and fiscal measures, to promote behaviour change towards a lower-carbon society and economy." (RSA, 2011: 14). These measures are to be supported by "education, training and public awareness programmes to build the general public's awareness of climate change so as to empower all South Africans to make informed choices that contribute to an economy and society that is resilient to climate change" (RSA, 2011: 14). The White Paper stipulates that "each significantly emitting economic sector or sub-sector will be required to formulate mitigation and lower-carbon development strategies" (RSA, 2011: 29); this is exactly what is recommended in this chapter for mitigation of peak oil. The NCCRWP makes provision for a set of "near-term priority flagship projects", which on the mitigation side include renewable energy, energy efficiency and energy demand management, and transport. The latter involves vehicle efficiency standards, modal shifts and public transport investments. On the adaptation side, a Public Works Flagship Programme aims to boost the Expanded Public Works Programme, including the Community Work Programme and environmental sector programmes.

The White Paper also notes that South Africa's economy is potentially vulnerable to climate mitigation measures undertaken by other countries. "The sectors that are particularly vulnerable are those that are emissions-intensive, and trade-exposed, and may include iron and steel, non-ferrous metals, chemicals and petrochemicals, mining and quarrying, machinery and manufacturing, some agricultural exports, as well as transport services and tourism" (RSA, 2011: 29). These sectors are also highly vulnerable to the impacts of global oil depletion (e.g. rising fuel and transport costs).

For the most part, it is clear that the climate mitigation and adaptation policies delineated in the NCCRWP are consistent with policies to lessen the impacts of global oil depletion on South Africa. However, the NCCRWP by itself is not an adequate response to 'peak oil'. For one thing, there is not enough emphasis on threats to and security of liquid fuel supplies and their significance for the mobility of people and goods and the socioeconomic system more generally. Secondly, while the agriculture sector is rightly recognised as being especially vulnerable to the impacts of climate change, the NCCRWP does not address the particular threats to this sector (and national food security) posed by peak oil. Thirdly, while the 'greening' of the economy envisaged in the NCCRWP is in line with peak oil mitigation, the White Paper does not adequately take into account the socioeconomic impacts of future oil price shocks and supply shortages, including notably the integrity of the financial system. These impacts will make the funding of climate adaptation and mitigation considerably more difficult. On the positive side, however, the decline of world oil production could help South Africa to reduce its CO_2 emissions, at least from the transport sector and likely from a decline in energy-intensive activities resulting from rising fuel costs.

On the other hand, it is important for a peak oil mitigation strategy to take due cognisance of climate mitigation imperatives and the possible restrictions posed by climate change impacts. In particular, as mentioned in Section 5.1, the need to reduce GHG emissions places constraints on the development of certain substitutes for imported oil, notably CTL and GTL synthetic fuels, which are carbon-intensive. Furthermore, the effect of climate change on water availability will have highly significant implications for the potential of sustainable agriculture and biofuel production. In sum, South African government and society need to adopt a dual, synergistic strategy for dealing with climate change and peak oil.

5.5.5 Conclusions on social mitigation

There is a broad range of policies, measures and programmes that can be implemented to mitigate the social impacts of global oil depletion. Some form of fuel or energy rationing system will be essential to promote equity in access to fuels and transport. A Cap and Dividend scheme appears to be the simplest, while potentially meeting a broad range of objectives, including climate mitigation. Economic localisation can and should be promoted in order to strengthen community resilience to oil-related shocks. There are opportunities for sustainable livelihoods to be created in small-scale organic agriculture and localised manufacturing. Long-range planning for human settlements must be properly informed by the reality of declining oil supplies. The main obstacles facing these particular measures are political and institutional, rather than financial constraints.

5.6 Conclusions

The need for an oil depletion mitigation programme is motivated theoretically and practically by the need and desire for sustainable development, the building of resilience and adaptability, the precautionary principle, and the government's commitment to being a developmental state. As far as existing policy documents are concerned (as of October 2011 and reflected in Table 5-12), only the National Transport Master Plan and the National Framework for Sustainable Development explicitly recognise the phenomenon of global oil depletion and its potential impacts on South Africa. The *Energy Security Master Plan – Liquid Fuels* gives oblique references to future oil scarcity but does not directly or comprehensively address the looming decline in world oil production. Given the crucial role that petroleum plays in the socioeconomic system, the mitigation strategy should be one of the strategic priorities for all of these major policy and strategy documents, and should inform policy decisions across all spheres and sectors of government.

Table 5-12: Recognition of global oil depletion in major policy documents

Policy Document	Year	Recognises global oil depletion
Medium Term Strategic Framework	2009	No
New Growth Path	2010	No
Industrial Policy Action Plan 2	2011	No
National Framework for Sustainable Development	2008	Yes
National Framework for Local Economic Development	2006	No
Energy Security Master Plan – Liquid Fuels	2007	Obliquely (long term)
Integrated Resource Plan 2010	2010	No
National Transport Master Plan	2010	Yes
Comprehensive Rural Development Programme	2009	No
National Spatial Development Perspective	2006	No

This chapter has provided details of a wide range of mitigation strategies, policies and measures that could be adopted in the various key subsystems of the socio-economy. In terms of alternative energy supply, the most sustainable option is to massively scale up renewable energy investments, especially in solar and wind power. Biodiesel may play a small but critical role in providing fuel mainly for agricultural machinery. In addition, energy conservation and improved efficiency are vital for energy security and sustainability reasons. For the transport sector, curtailment and efficiency are the quickest and cheapest options for reducing oil dependency. However these will need to be supplemented by supply side alternatives to ensure sustainable mobility for the long term, which will involve electrification of the transport system and in particular the use of grid-connected vehicles, powered increasingly with renewable electricity. Mass public transport and freight rail are both critically important areas for expansion, as is safe non-motorised transport. Agriculture and food distribution should in the short term receive priority for the allocation of scarce fuels, and possibly be subsidised. In the longer term, the need to progressively phase out the use of petroleum fuels in agriculture implies a gradual transition to agroecological farming practices, involving smaller scale farms and higher labour intensity of production. Oil mitigation has wide ranging implications for macroeconomic policy. A windfall tax on domestically produced synthetic fuels would enable a transfer of resource rents from private hands to society at large. The Reserve Bank should allow moderate inflation as a way of enabling relative prices to adjust less painfully, and for debts to be drawn down, and to prevent high interest rates from causing a collapse in property values and a rise in business liquidations. Trade and industrial policy should assume a reversal of the process of globalisation (as applied to trade in physical goods) and hence support sustainable local industries and import substitution. Labour market policy should focus on re-skilling the workforce for sunrise industries like renewable energy, electric vehicles, bicycles, etc. At the societal level, community resilience and social cohesion can be bolstered through the adoption of fuel rationing systems, economic localisation initiatives, community banks and local currencies, densification around public transport networks in urban areas, and sustainable rural development based on land reform and skill acquisition.

These various policies and measures will be most effective if they are integrated into an overall strategy for reducing oil dependence throughout the socioeconomic system. The national government should take the lead in formulating a vision for a future post-oil society and adopt a national strategy and action plan for attaining this vision. The next chapter addresses these issues, as well as the likely challenges and risks, on the basis of a more holistic view of mitigation responses to global oil depletion that is informed by the literature on societal transition to sustainability.

CHAPTER SIX

6. Transition to Sustainability

"To make sense of the world, and to inform our actions, we must both look backward to our history and look forward to our potential futures."

Proops (1989: 65)

"A transition cannot be limited to technical corrections to the current economic and social model but will rather be similarly fundamental as the Neolithic and Industrial revolutions. It requires a third Great Transformation."

Haberl et al. (2011: 8)

The previous three chapters have presented empirically the vulnerabilities of South African society to global oil depletion, the likely impacts if no pro-active responses are forthcoming, and a wide range of desirable mitigation policies. This chapter seeks to explore the broader meaning of the mitigation policies and to collate them within a coherent theoretical framework that sheds light on their role in societal change and a transition to a more sustainable socioeconomic system. The obvious point of departure is to refer back to the three theoretical approaches discussed in Chapter 1, to determine whether they provide an adequate analytical framework for understanding the notion of a transition to sustainability.

Neoclassical economics assumes that the current economic system will continue to progress incrementally and indefinitely, in terms of continual growth in gross domestic product (aside from brief cyclical recessions) and technological innovation. The limited ideas about phases of socioeconomic development that have surfaced on the fringes of mainstream economics, such as the agricultural and industrial "revolutions" described by North (1990) and Rostow's (1960) "stages of economic growth", do not foresee a radically different post-industrial economic system. Neoclassical economics does not regard resource depletion or environmental degradation as fundamental threats to the current economy. Hence mainstream economic theory has very little if anything to say about a 'sustainable economy', let alone about a process of transition from the current economic system to a fundamentally different (sustainable) one.

By contrast, ecological economics places great emphasis on the unsustainability of the current economy and presents a (partial) vision of where society should be moving. In particular, it envisages a transition from a growth economy, based on a linear throughput of large quantities of energy and materials, to a steady-state economy that meets the conditions for environmental sustainability (Daly & Farley, 2004). However, ecological economics has less to say about *how* societies are to get to this ideal state, i.e. there is less emphasis on the transition *process*, at least at a societal level.

In the socio-ecological systems (SES) perspective, the depletion of oil (and other fossil fuels), together with the need to reduce environmental impacts of material and energy use, implies that the industrial socio-metabolic regime (which is rooted in fossil fuels) must inevitably undergo a transition to a sustainable socio-metabolic regime that is based on renewable energy sources and exhibits a reduced metabolic rate (Haberl et al., 2011; Fischer-Kowalski & Haberl, 2007a; Fischer-Kowalski, 2011). The SES view posits that a regime change will be driven either unintentionally as a consequence of resource depletion and/or pollution, or as an intentional change chosen by society (Fischer-Kowalski, 2011). The outcome could either be systemic collapse, or a successful transition to sustainability, depending in large part on whether alternative resources and opportunities are available in time. Nonetheless, as noted in Section 1.3, the SES literature has not as yet spelled out in any great detail a vision for a sustainable regime, nor has it yet elaborated possible transition pathways.

The literature on the implications of global oil depletion discussed in Chapter 2 (which is largely informed by an ecological economics perspective) does to an extent address the transition issue explicitly. This literature views the current industrial economy and financial system as dependent on ever-expanding quantities of energy-dense fossil fuel resources, and hence unsustainable due to the depletion of these finite fuels and the (current and foreseeable) absence of better-quality, high-density energy alternatives. Hence, a transition to a post-fossil fuelled socioeconomic system is seen as inevitable. Many contributors to the oil depletion literature reject the techno-optimist vision of a more complex post-industrial society emerging as they do not foresee sufficient energy being available to support this (e.g. Heinberg, 2003, 2004, 2009a; Kunstler, 2005; Greer, 2009; Tainter, 2011; Martenson, 2011). Some writers advocate instead a "managed contraction" (Heinberg, 2011) and simplification of society based on significantly reduced energy and material flows, resulting eventually in a steady state economy, provided nations and communities take active steps to reduce their dependency on oil (e.g. Heinberg, 2003, 2006; Hopkins, 2008; New Economics Foundation (NEF), 2008). If this pro-active response is not forthcoming, the alternative is a more radical collapse (Korowicz, 2011), in line with the experience of numerous previous complex societies (Diamond, 2005; Tainter, 1988).

Thus none of the three schools of thought reviewed in Chapter 1 provide an adequate treatment of the transition to a sustainable socioeconomic system. The "peak oil" literature addresses the issue, but in an under-theorised manner. However, there is a relatively new body of literature focused specifically on "societal transitions", which *inter alia* seeks to understand the nature, drivers, requirements and dynamics of major changes in socioeconomic systems at various scales. Some key strands of this literature will be drawn upon in this chapter to reinterpret the oil mitigation policies from a transition perspective, in so doing exploring the role of various agents (in particular the developmental state) and various types of innovation in the transition process. This will provide an analytical basis for determining the necessary and/or sufficient conditions (e.g. institutional, political, economic, and cultural) for a successful transition to a post-oil, sustainable society. More specifically, the chapter seeks to answer the following questions:

- What might a sustainable, post-oil socioeconomic system look like? (i.e., where do we want to go?)
- Is there a feasible transition action plan that allows South Africa to steadily reduce its petroleum consumption while maintaining economic activity and reducing poverty and inequality? (i.e., how do we get there?)
- What are the barriers and risks to the implementation of such a transition strategy? (i.e., what might stop us?)

The chapter is structured as follows. In the first section, the literature on societal transitions is interrogated in order to provide an analytical reframing of the discussion on mitigation of global oil depletion. The next three sections apply this transition perspective in concrete terms for South Africa. Section 6.2 presents a vision of a sustainable, post-oil social-ecological system based on the policies and measures discussed in Chapter 5. Section 6.3 develops a practical transition action plan for attaining this vision. Section 6.4 considers a range of obstacles and risks that could impede the realisation of the transition plan. The final section concludes with some observations on the implications of the South African case study for the wider global discussion on a transition to sustainability.

6.1 Societal transition

Increasing recognition of the ecological implications of (industrial) economic growth and development, including both resource depletion and environmental impacts, has fostered a growing amount of attention from researchers in a number of fields on the concept of "transition". Various schools of thought or research traditions have defined or interpreted "transition" in different ways. According to van den Bergh et al. (2011: 1), a "socio-technical transition" involves "a combination of technical, organizational, economic, institutional, social–cultural and political changes." A special case is a transition from the current, industrial economy to an "environmentally sustainable economy". According to Geels (2011: 25), "sustainability transitions are necessarily about interactions between technology, policy/power/politics, economics/business/markets, and culture/discourse/public opinion." The following subsections provide a brief discussion of several general theoretical approaches to societal transition, the governance of transitions, the major role-players in the transition process (businesses, government and communities), and various modes of innovation as mechanisms for realising transition.

6.1.1 Theoretical approaches to transition research

Van den Bergh et al. (2011) provide an overview of four strands of research on societal transitions. First, an *innovation systems* (IS) approach takes the view that "technological and institutional characteristics of socio-technical systems should be analyzed jointly because they co-determine each other" (Van den Bergh et al., 2011: 9). Jacobsson and Bergek (2011: 41) see the value of IS analysis as being that it "allows policy makers to identify the processes and components in a system where intervention is likely to matter most." However, the IS approach is mostly applied to environmental innovations driven by environmental impact concerns (such as climate change), rather than resource depletion, and is also generally focused on smaller scales, such as particular technologies, rather than on socioeconomic systems more broadly. The topic of innovation will be discussed in greater detail in Section 6.1.3 below. The second strand of research understands transitions as changes in *complex adaptive systems*, of which socioeconomic systems are a special case (Van den Bergh et al., 2011: 10). This field advocates purposeful transition management, a perspective which partly informs the construction of a transition action plan for South Africa in Section 6.3. The third strand interprets transitions in terms of *evolutionary theory*, which regards complex systems as being subject to an evolutionary process characterised *inter alia* by path dependence and lock-in. The latter issues are expanded upon in Section 6.4, which deals with barriers to transition. The fourth approach, called the *multi-level perspective* (MLP) on socio-technical transitions, provides a particularly useful framework for enhancing the understanding of global oil depletion in the context of transition; the MLP is discussed in greater detail in the following subsection. A fifth perspective on transitions, concerning *techno-economic paradigms*, is dealt with in the last part of Section 6.1.1.

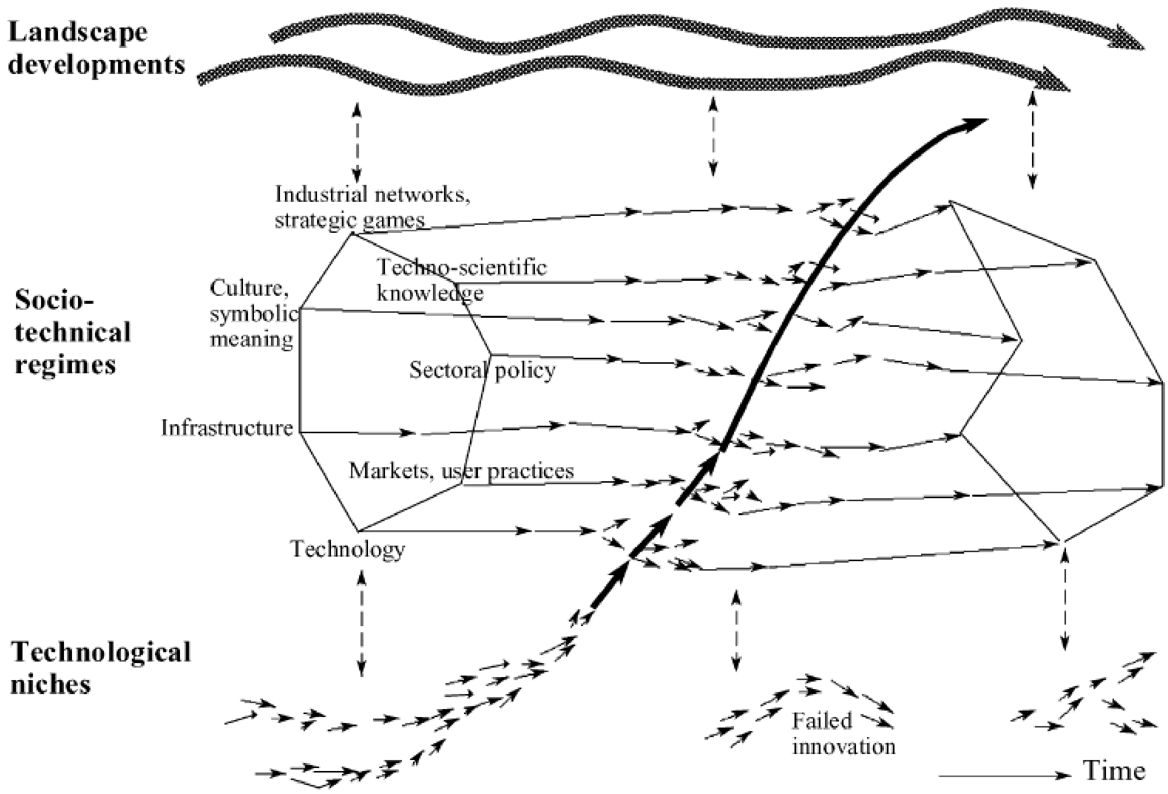
The multi-level perspective

The multi-level perspective on socio-technical transitions has been developed largely by a group of Dutch researchers (e.g. Geels, 2002; Geels, 2004; Smith, Stirling & Berkhout, 2005; Smith, Voss & Grin, 2010; Geels, 2011) over the past decade. Over time, the framework has evolved from a narrower focus on technological transitions to a broader treatment of socio-technical transitions, with an emphasis on sustainability (Lawhon & Murphy, 2010). The framework comprises three structural 'levels' and the dynamic interactions between them. At the broadest level, a socio-technical *landscape* consists in "cultural and normative values, broad political coalitions, long-term economic developments, accumulating environmental problems" and demographic trends, that together form the contextual structure within which actors interact and technologies develop

(Geels, 2004: 34; Geels, 2002: 1260). Secondly, socio-technical *regimes* are "relatively stable configurations of institutions, techniques and artefacts, as well as rules, practices and networks that determine the 'normal' development and use of technologies" (Smith, Stirling & Berkhout, 2005: 1493) by participants in the regime, such as "producers, workers, consumers, state agencies, scientists, societal groups, and business people" (Lawhon & Murphy, 2010: 7). At the smallest scale, socio-technical *niches* are "where innovation and learning occur and where social networks are built by firms, entrepreneurs, scientists, policymakers, etc." (Lawhon & Murphy, 2010: 7). Practical examples include "R&D laboratories, subsidised demonstration projects, or small market niches" (Geels, 2011: 27). Niches "act as 'incubation rooms' for radical novelties" (Geels, 2002: 1261), providing the "seeds for systemic change" (Geels, 2011: 27). The dynamic relations among the three levels are represented in Figure 6-1.

In the MLP framework, transitions are defined as shifts from one regime to another (Geels, 2011: 26). These occur when a destabilisation of an incumbent regime resulting from *selection pressures* (which can be specific to the regime or emanate from broader landscape pressures) opens windows of opportunity for niche innovations (Geels, 2011). The evolutionary interpretation sees variation occuring at the niche level, selection at the niche and regime levels, and retention at the regime level (Geels, 2002). Socio-technical transitions occur in a "stepwise process of reconfiguration" (Geels, 2002: 1272) which can span several decades and may not complete at all (Lawhon & Murphy, 2010: 6). Although landscapes do change (e.g. demographic, political and cultural trends), they do so more slowly than regimes (Geels, 2002).

Figure 6-1: Multi-level perspective on socio-technical transitions



Source: Geels (2002)

The MLP framework has been criticised on a range of issues (see Geels, 2011 for an overview and responses[207]). First, the definition of 'regime' suffers from boundary fuzziness, since different regimes may be overlapping or nested (Genus & Coles, 2008). Smith et al. (2005: 1493) caution that "there is a need carefully to distinguish in any given context between what constitutes the 'nested' and the 'spanning' regime, and to be precise in the empirical application of the concept of the socio-technical regime". Second, the 'landscape level' has been said to be a "residual analytical category" that is under-theorised (Geels, 2011: 36). An allied point (that will be elaborated upon below from the perspective of this dissertation's topic) is that the landscape level is perhaps accorded less significance than is warranted (relative to the regime level), especially in the context of sustainability transitions. Third, it has been claimed that the MLP is biased in favour of bottom-up models of change, giving too much weight to niche innovations relative to landscape pressures (Berkhout et al., 2004). However, this has to some extent been addressed by a refinement of the MLP which allows for variations in the nature (reinforcing or disruptive) and timing (niches are undeveloped or fully developed) of landscape and niche interactions with the prevailing regime (Geels & Schot, 2007). Fourth, the MLP has paid insufficient attention to geographic scale and other spatial dimensions of transition (Lawhon & Murphy, 2010). These authors point out that most case studies emanate from Europe, which may not necessarily be of direct relevance to other geographical areas (countries or regions). Fifth, the MLP has been criticised for an inadequate treatment of agency and power relations in determining transition pathways and distributional outcomes (Smith et al., 2005; Lawhon & Murphy, 2010). Meadowcroft (2011: 72) points out that "politics plays a potentially powerful role (defining the landscape, propping up or destabilising regimes, protecting or exposing niches)". Finally, at least in earlier MLP studies, there was more focus on *technological* innovations at the expense of *institutional* innovations. In this vein, Kemp and van Lente (2011) note that a change in cultural values and behaviours (e.g. "consumer criteria") is an important requirement of sustainability transitions in addition to technological and infrastructural changes. As an example, these authors suggest that the transition from internal combustion engine vehicles to electric vehicles needs to be augmented by a change in mobility attitudes and behaviours.

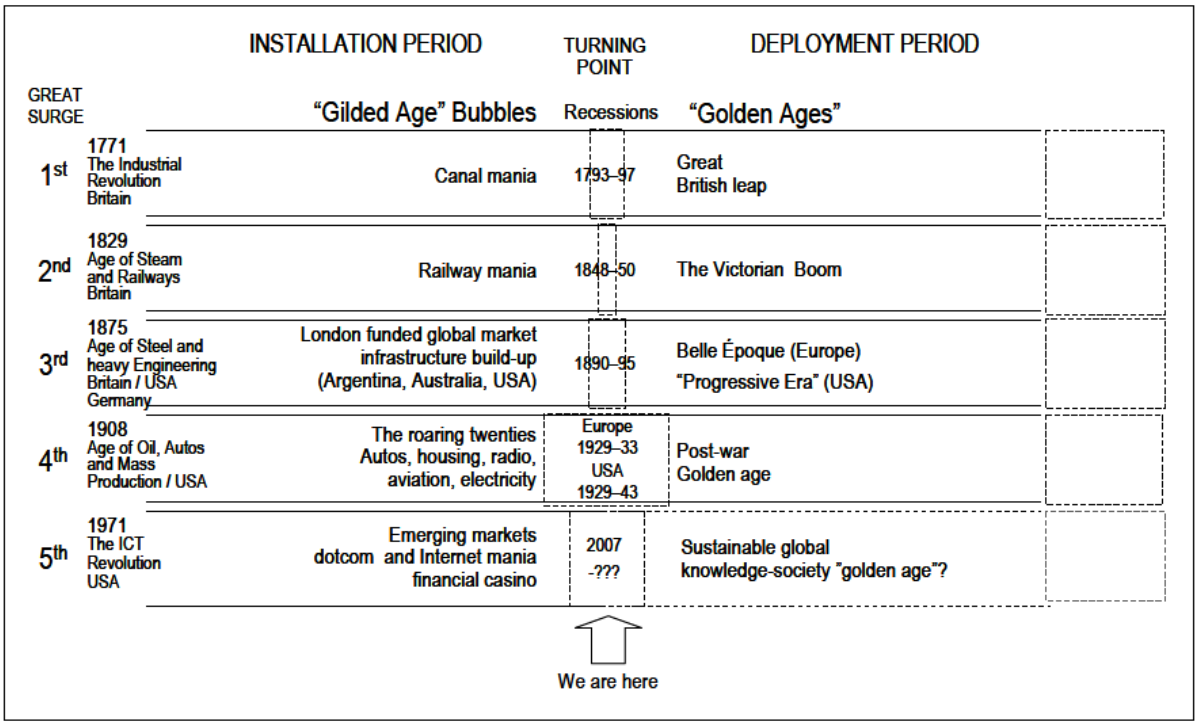
Despite these criticisms, the MLP has many useful attributes, including its macro-meso-micro analytical framework and its inclusion of many dimensions of the socioeconomic system. Therefore the MLP may shed additional light on the interpretation of the implications and mitigation of global oil depletion. Global oil depletion implies a massive change in the (global) socio-technical landscape, since it affects the availability and affordability of the dominant energy source, which is a critical input for transportation systems, agricultural production and a wide range of industries. Furthermore, the decline in world oil production will trigger changes in other features of the landscape, such as the geopolitical order, the financial system, patterns of world trade and globalisation, rates of urbanisation, etc. Regional and national scale landscape changes will depend on the specific context, such as the level of economic development, degree of dependence on oil, the availability of substitute energy sources, and so on. Changes could include the destabilisation of political coalitions and at some point, substantial changes in demographic trends (partly as a result of migration, but also changing birth and death rates).

These landscape changes wrought by oil depletion will destabilise many current regimes that are dependent on cheap oil. These include passenger and freight transportation systems based on ICE vehicles; fossil fuel powered electricity generation (since coal and gas will also become more costly as oil prices rise); industrialised agricultural production and food distribution; the debt-based money system; and settlement patterns characterised by private car-centred urban sprawl. Oil depletion will also challenge prevailing cultural attitudes and social norms, for example as mobility is constrained and consumerism is undermined by rising prices of goods and services. At the same

[207] Other areas of criticism include ontology, epistemology and methodology, but are beyond the scope of the present discussion.

time, oil depletion will open up new opportunities for sustainability-oriented niche technologies, such as solar PV and CSP, wind power, biogas digesters, biofuels, electric and hybrid-electric vehicles, public transit systems, high-speed rail, organic farming and permaculture, and local currencies. In time, many of these niches will grow and solidify into new socio-technical regimes. A challenge for policy-makers is to support what seem to be viable niche innovations, both technical and institutional. The issue of innovation is taken up later in this section.

Figure 6-2: Industrial technological revolutions, bubbles and golden ages



Source: Perez (2010: 3)

Techno-economic paradigms

Another approach to structural change or transition, building on the long wave theory pioneered by Kondratiev (1935), is that of so-called techno-economic paradigm (TEP) shifts (Freeman and Perez, 1988; Perez, 2002; Perez, 2010). "TEPs refer to configurations of pervasive technologies, methods of production, economic structures, institutions and beliefs that are stable for long periods" (Geels, 2011: 25). Perez (2010) identifies five historical TEP shifts or "technological revolutions" as having occurred since 1770 (see Figure 6-2). Each one involved widespread diffusion of new technologies that affected all economic sectors and industries. Further, each era is split into an 'installation period', which is led by financial capital, and a 'deployment period', which is led by productive capital. The two periods are separated by a major financial crisis and/or recession. In her view, the current informational era is only half-way through its diffusion path, the dot.com crisis of 2000/1 and the global financial crisis of 2008-9 marking a midpoint comprising these two linked but distinct bubbles (Perez, 2009). Perez (2010: 1) suggests that the sixth industrial revolution will be based on new knowledge such as biotech, nanotech, bioelectronics, new materials, etc. Arguably, however, this revolution has already begun, for example with the introduction of genetically modified organisms into agriculture. According to Geels (2011: 25), the main difference between the TEP and MLP approaches is that the former deals with aggregate economic processes, whilst the latter focuses on specific subsystems (e.g. energy, transport, agri-food) and the interactions of actors and resources within these systems. TEPs could perhaps be considered as broad clusters of MLP-type socio-technical regimes that co-evolve in a long wave process. Indeed, Geels (2011: 37) suggests that "economy-wide techno-economic paradigm shifts could perhaps be conceptualized as arising from multiple regime shifts."

In her recent work, Perez (2010: 4) has acknowledged that "the environmental threats of global warming, limits to resources and pollution health-risks do not allow the continuation and extension of the current wasteful and energy-intensive production and consumption patterns." She therefore implores policy-makers to work towards a "sustainable golden age", which she interprets as the deployment period of the fifth industrial era. Perez (2010: 9) expresses a high degree of technological optimism with regard to future prospects: "The technological potential is there for capitalism to unleash a golden age of unprecedented prosperity across the globe." This is at odds with much of the literature on global oil depletion, whose implications Perez does not seem to fully appreciate.

Summary: three levels of transition

By way of summary, it is possible to identify three levels of societal transition. The first, broadest level may be termed an "epochal" transition (see Swilling & Annecke, 2011, Chapter 4). Historical cases include the transition from hunter-gatherer to agrarian epochs (via the agricultural revolution, beginning about 13,000 years ago) and the transition from the agrarian to the industrial epoch (via the industrial or fossil fuel revolution, beginning in about 1770). The transition to a "sustainable" epoch will likely be of a similar order of scale and extent, including a reconfiguration of all sectors of the economy and society. The second, somewhat narrower level of transition concerns techno-economic paradigms (TEPs) or industrial eras, of which there have been five thus far. The industrial eras identified by Perez (2010) and other long-wave theorists all fall within the industrial epoch. Perez (2010) suggests that the "deployment period" of the fifth TEP might a "sustainable global knowledge-economy"; however, she seems to be conflating a TEP with a broader epochal sustainability transition. The third, narrowest level of transition involves "socio-technical regimes" as defined in the MLP literature. Such regime transitions can occur at varying scales, such as electricity production systems and motor vehicle technologies.[208] The transition from the industrial socio-metabolic regime (epoch) to a sustainable regime (epoch) could be interpreted within the MLP as a range of pervasive *landscape* level changes that in turn will stimulate regime-level transitions by opening windows for new niche innovations (cf. Swilling & Annecke, 2011, Chapter 4). The epochal transition to sustainability will be comprised of smaller-scale TEP and regime-level transitions. Looking forward, the sustainable epoch itself might involve a number of successive "sustainable eras" analogous to the industrial eras. At present, the world may be experiencing transitions at all three levels simultaneously.

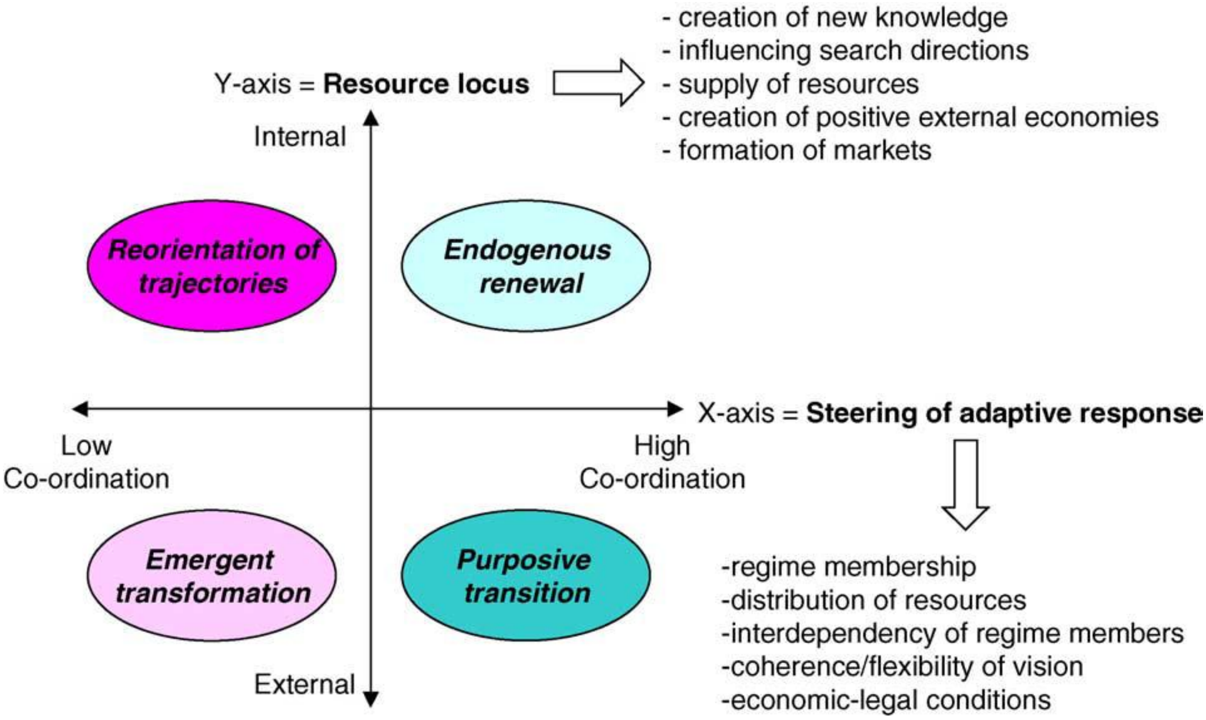
6.1.2 Transition governance

Governance is an important aspect of transition processes. Smith et al. (2005) provide a useful heuristic to understand alternative modes of transition governance: the *adaptive capacity* available for a regime transition depends on the *transition context*, which itself is a function of whether the necessary *resources* (e.g. factors of production, knowledge and capabilities) are internal or external to the regime, and the degree of *coordination* amongst members of the regime (i.e., whether the regime transformation is purposeful or unintentional). Figure 6-3 maps configurations of the locus of resources and degree of coordination into four quadrants representing different transition contexts. *Endogenous renewal* consists in "regime members (firms, supply chains, customers and regulators) making conscious efforts to find ways of responding to perceived competitive threats to a regime", but using only internal resources (Smith et al., 2005: 1500). *A re-orientation of trajectories* occurs as

[208] To avoid confusion, it could be useful to apply the term 'meta-regime' to describe a socio-metabolic regime, to distinguish it from smaller-scale, nested socio-technical regimes.

an uncoordinated (largely market-driven) response to an endogenous or exogenous shock. *Emergent transformation* is often stimulated by broad scientific and technological developments, for example those associated with successive Kondratiev cycles or 'energy successions'. *Purposive transitions* are coordinated responses to pressures that draw on external resources, and involve goal-oriented transition management. Transition management can involve practical exercises such as visioning and the formulation of transition pathways (Meadowcroft, 2011: 71). In light of this, Section 6.3 presents a vision, while Section 6.4 develops an oil-independence transition pathway.

Figure 6-3: Governance pathways for societal transition



Source: Smith et al. (2005)

The mitigation of global oil depletion calls for a set of coordinated, purposive transitions across the whole socioeconomic system, i.e. meta-regime transition management, rather than a series of piecemeal, regime- or niche-specific programmes or policies. Even more than that, a comprehensive response to oil depletion will involve conscious efforts to change elements of what the MLP regards as landscape features, such as the financial-monetary architecture and trade policy orientation.

6.1.3 Agents in the transition process

The discussion on transition governance calls for an elaboration of the role of various agents involved in transition processes. Using the transition context heuristic, we can identify the primary agents involved in uncoordinated and coordinated transitions. The main agents in uncoordinated transitions are businesses, which respond to market forces such as price incentives and technological developments, within the prevailing regime and landscape context, including the institutional and regulatory environment. To be sure, some corporations, especially larger ones, also play an active role in helping to shape market forces (such as competition) as well as the regulatory environment (through lobbying and by contributing to the policy discourse). As is customary in capitalist economies, the profit motive serves as the primary driver for firms, although to some extent they will respond to broad changes in consumer preferences determined by cultural trends.

Venture capital in particular can play a leading role in reallocating funds towards promising niche technologies. In the case of the post-oil transition, increasing oil (and other fossil energy) prices will be the key catalyst for business-driven, regime-level transitions. However, Chapters 4 and 5 showed that if the transition from an oil-powered socioeconomic system is left to market forces alone, it will be more chaotic and involve greater socioeconomic hardship than if it is effectively managed. A pro-active and coordinated (purposive) transition could be led by government entities in a top-down manner. In the developing country context, this aligns with the notion of a "developmental state". If state leadership is not forthcoming (or even if it is), another possibility is bottom-up, community-driven transition initiatives. The roles of the developmental state and communities as potential transition agents are considered in more detail in the following subsections.

The developmental state

A developmental state may be defined as "a state that intervenes to promote economic development by explicitly favouring certain economic sectors over others" (Chang, 2010: 83). In the South African milieu, the conception of the functions of the developmental state largely follows the East Asian model, in which "[d]evelopmental states have tended to be interventionist, productivist, ideologically opportunist, protectionist, obsessed with industrialisation (to 'modernise'), resource intensive and quite often authoritarian" (Swilling & Anneke, 2011). However, a key difference is that the ANC government's conception rests on democratic governance and social inclusion, in contrast with the authoritarian model of East Asia (Edigheji, 2010: 2). The South African government regards the primary mission of the developmental state as being industrialisation as a path to modernisation (Swilling & Anneke, 2011). More broadly, Evans (2010: 38) suggests that "enhancing [human] capabilities is the central goal of the 21st century developmental state", and that this can be achieved through public investments in health, education and other social infrastructure.

A successful developmental state must fulfil a number of conditions, including political, institutional, organisational and human resource requirements (Chang, 2010; Edigheji, 2010). The first condition is political will to create a developmental state. This commitment has been clearly expressed by the South African government and its ruling party, the ANC (Edigheji, 2010). Moreover, the government has a "mass party base", which allows it to implement policies more extensively than in many other countries (Chang, 2010: 88). However, this is countervailed to an extent by the power of huge conglomerates, such as the domestic energy and international mining firms dominating the minerals-energy complex (Fine, 2010). Second, the creation of a developmental state requires the construction of appropriate institutions (Edigheji, 2010: 2). At an ideological level, neoliberal economic dogma must give way to developmental statism. While this shift has gradually been occurring in South Africa over the past decade, perhaps a greater challenge is for the government and its constituents to recognise the reality and challenges of global oil depletion and other resource constraints on economic growth and development (Peter et al., 2010). Third, a developmental state has certain organisational requirements. For a start, Chang (2010: 91) suggests that the Department of Trade and Industry could play the role of a "pilot agency" akin to South Korea's Economic Planning Board. Also important is the building of state capacity for trans-sectoral interventions through inter-departmental collaboration, which aims to build bridges between policy 'silos' operating within the bureaucracy (see Westley et al., 2011: 24). The National Planning Commission, housed in the Presidency, is supposed to address this problem by coordinating policy across sectors and departments. However, Edigheji (2010: 30) argues that because it is comprised of *external* intellectuals and experts, as opposed to civil servants, the NPC is actually counterproductive to building the capacity required of a developmental state. Another organisational need is the forging of effective relations between government, labour, business and civil society organisations. The National Economic Development and Labour Council (NEDLAC) provide such a forum in South Africa, but it has yet to fully deliver on its potential. Fourth, an effective developmental state relies on sufficiently skilled human resources. In particular, it needs a capable bureaucracy that is strengthened by durable career opportunities for civil servants (Edigheji, 2010). A fifth requirement is a viable long-term development plan (Gumede, 2009).

The formation of an effective developmental state faces many challenges in South Africa (Edigheji, 2010). First, the State is characterised by weak institutions and inadequate technical, managerial and administrative capacities (compounded by an overly high turnover rate amongst bureaucrats), especially with regard to planning and implementation (Edigheji, 2010; van Holt, 2010). This is especially evident at the level of local government, where service delivery has been a growing problem (van Holt, 2010). However, Edigheji (2010: 3) contends that the "weak capacity of the state is not an excuse but rather a *motive* for constructing a developmental state." Second, the "resource curse" can perpetuate over-reliance on primary resources (mainly minerals in the South African case) and a consequent lack of economic diversification. This is reinforced by the dominance of the minerals-energy complex in South Africa (Fine, 2010). Third, corruption is proving to be a growing problem at all levels of government, and is undermining both policy implementation and public trust in government. Fourth, the forces of globalisation, especially with regard to footloose financial capital, to some extent circumscribe the capacity of a developmental state to implement its vision. Fifth, the high level of inequality and the need for nation-building and democratic deepening are additional challenges faced by a developmental state in South Africa (Gumede, 2009).

Despite these challenges, there are significant potentials for a developmental state in South Africa (Edigheji, 2010: 30-31). At a political level, South Africa is already a democracy founded on a strong constitution. Nevertheless, some democratic institutions still need to be strengthened, especially parliament and community-level institutions. The resource curse could potentially be circumvented by reinvesting resource rents in human capabilities though education, training and health care interventions (Peter et al., 2010). South Africa already has a set of large state-owned enterprises (SOEs) and Development Finance Institutions (DFIs) with a long track record, including the Development Bank of Southern Africa (DBSA) and the Industrial Development Corporation (IDC), whose capacities and roles could be further enhanced. These institutions could be complemented by the establishment of a state bank (as mentioned in Chapter 5) as well as interventions in the commercial banking aimed at facilitating credit extension for development projects. Finally, the state could focus more on recruiting highly skilled South Africans into the public sector.

Some specific policies appropriate to the attainment of social goals by a developmental state in South African include: agrarian reform; altering the structure of the economy to dilute the dominance of minerals-energy complex and halt the process of deindustrialisation; a novel and courageous plan to create employment; and encouragement of green industries (Edigheji, 2010). Swilling and Annecke (2011) go further, calling for a 'greening of the developmental state', in which the state pursues sustainability-oriented innovations as the lynchpin of its development programme.[209] This can be achieved through setting the 'rules of the game' for businesses, in terms of appropriate regulations incentives geared towards "new ways of building up an appropriate mix of knowledge, capabilities and investments to drive new value-chains that simultaneously create productive employment and reduce dependence on increasingly expensive primary materials and fossil fuels" (Swilling & Annecke, 2011).

A developmental state would need to specifically address the implications of global oil depletion, through selecting and implementing a broad array of mitigation policies as described in Chapter 5 (and summarised in Section 6.3 below). From a transition governance perspective, top-down, state-led initiatives could be led by a team of experts, who then formulate a vision, policies and measures that are presented to other major actors (Lawhon & Murphy, 2010: 9). This is essentially how several

[209] This concept will be explored further in the next subsection.

city-level and one national oil independence plan have been produced (e.g. Oil Independent Oakland (2007), Swedish Commission on Oil Independence (2006)).

Communities

Partly because the state never acts alone, and also due to its limitations, bottom-up community-driven responses are also essential for building resilience in an oil-scarce world. Various types of civil society organisations (CSOs) could potentially become involved in promoting a transition to sustainability. Of particular importance in South Africa, given their large and organised membership, are the trade unions. However, their role in facilitating regime-level transitions may be constrained to an extent by their own vested interests in existing industries – unless the members realise that their jobs in unsustainable industries are in jeopardy. Of particular relevance to global oil depletion is the advent of the "transition town" movement. Having originated in the towns of Kinsale, Ireland and Totnes, United Kingdom, there are now well over a hundred transition towns or cities in the UK and nearly 100 in the United States. Transition initiatives have sprung up when concerned citizens, recognising the threats posed by global oil depletion and climate change, have taken active steps to reduce their reliance on fossil fuels (Hopkins, 2008). In collaboration with local government authorities, communities in these towns typically develop "energy descent action plans" to cope with future increases in fuels costs and fuel scarcity. Elements of the plans include ways to boost local food security (e.g. through food gardens and local farmers' markets), localise the economies (e.g. by introducing a local currency), reduce reliance on automobile transport (e.g. through enhanced public transport or bicycle hire schemes), and an overhaul of spatial development policies.[210] Westley et al. (2011: 20) comment that "while undoubtedly innovative, these [transition town] initiatives are unlikely to stimulate the great transformation towards sustainability that we need in order to avoid pushing the earth system beyond planetary boundaries". For that to happen, the other major agents (businesses and government) must be involved.

Cooperation among role-players

Future energy constraints will likely engender even greater contestation over dwindling resources between various interest groups (e.g. business versus labour; political left versus right; and among ethic or tribal groups). Thus the formation of a social contract involving government, private sector businesses, labour unions and civil society organisations is probably essential for a successful transition to a post-oil future. Such a contract must involve an equitable sharing of developmental benefits as well as burdens (see Gumede, 2009). National government should provide leadership for an over-arching sustainability transition rooted in the National Framework for Sustainable Development, and this should filter down to provincial and local governments. A crucial part of this leadership will be an effective awareness campaign, since a properly informed citizenry is more likely to respond in a peaceful and appropriate manner to the impacts of oil depletion.

6.1.4 Innovation for transition

The discussion on the role of the developmental state led to the notion of innovation, which may be defined as the spread of new ideas in society (Westley et al., 2011:7). In particular, societal transition to sustainability requires sustainability-oriented innovations that foster relative decoupling through efficiency gains and dematerialisation of economic activity (Swilling & Anneke, 2011). At least four main categories of innovation can be identified (Swilling & Anneke, 2011; van den Bergh et al., 2011: 4). The most commonly discussed type is *technical* innovation, which involves the invention of new technologies or products and is driven by R&D and knowledge creation. Sustainability-oriented technical innovations include renewable energy systems, energy efficiency technologies and practices, closed loop production processes, agro-ecological farming and recycling industries. The

[210] A similar trend is the formation in the US of Common Security Clubs, which address the social impacts of a deteriorating economy through shared learning, mutual aid, and social action (Heinberg, 2011: 273-4).

second category of innovation is *organisational*, referring to new ways of organising production and distribution processes. Examples relevant to mitigation of oil depletion include farming cooperatives, localisation of economic activities, shortening of value chains, and so on. A third type of innovation is *institutional*, i.e. changes in customs, traditions, cultural habits, laws, rules and social norms that govern behaviour. On the side of producers, institutional innovations could include regulations mandating higher energy and materials efficiency, greater product durability, repair and maintenance, zero waste and closed loop production, and production of spare parts (Perez, 2010). On the consumption side, examples include shifting consumption patterns (e.g. from rich to poor), the adoption of a 'recycling mentality', and the replacement of consumerism by a culture of voluntary simplicity and sufficiency. Another example is the 'open source' model of knowledge sharing, which could potentially be a forerunner of a broader cooperative ethos in enterprise, whereby individuals collaborate and share rather than pursuing narrow self-interest and profits. Transition town innovations are a further example of an emerging cooperative, sharing value system as the basis for (local) transformation of socioeconomic systems. The fourth type of innovation is *relational*. This involves fostering networks between innovators, such as linkages between research institutions, government departments and businesses.

As mentioned earlier, the MLP highlights the fact that radical innovations – especially of the technical variety – generally take place within niches, where they are sheltered from prevailing regime pressures. Westley et al. (2011: 20; original italics) suggest a three-pronged strategy for promoting innovation: "ensuring an enabling context through *top down* incentives for innovation, ensuring a supply of innovation through identifying *bottom up* supply of inventive solutions, and ensuring the *two are connected* through nurturing institutional entrepreneurship that can anticipate and leverage crises as opportunities and designing governance processes for participation and inclusion." Top down support can come in the form of incentives such as tax rebates, subsidies and competitions for the private sector (Westley et al., 2011: 24). A bottom up approach would involve "nurturing cultural norms of learning and memory" (Westley et al., 2011: 26). Connecting top down and bottom up approaches could be achieved through cultivating "institutional entrepreneurs and shadow networks of change agents" and encouraging "distributed decision-making and participation in governance at all scales" (Westley et al., 2011: 34).

Westley et al. (2011) do not explicitly identify which agents should be responsible for implementing these measures, e.g. national government or local government. Furthermore, they appear to assume that the necessary knowledge, skills and entrepreneurial culture are already in place, but this appears to be a Euro-centric assumption that does not apply well to developing countries, especially in Africa. Innovation of all types faces a variety of obstacles, including positive externalities (e.g. knowledge spill-overs), an "ingenuity gap" (Homer-Dixon, 1995) between the supply of and demand for innovation that results from limitations on humans' cognitive ability to deal with complexity, a lack of resources for R&D, and the fact that innovation is characterised by path dependency and time lags between crisis and response (Westley et al., 2011). In addition, it must be borne in mind that some innovations might solve some problems but perpetuate others, such as environmental degradation (e.g. CTL and GTL). On the other hand, rising oil prices could drive sustainability innovations to tipping points and trigger desirable positive feedback loops, such as a rapid growth of renewable energy technologies and a shift from ICEVs to grid-connected electric vehicles. Finally, a crucial factor that could determine the viability and effectiveness of innovations concerns the degree to which they require energy. Technological innovation requires a considerable R&D effort, which in turn requires surplus energy above society's basic needs; as argued in previous chapters, this surplus energy is likely to wane as a result of fossil fuel depletion and declining EROI. However, institutional, organisation and relational innovations are generally less energy-intensive than technological innovation, and will thus play a critical role in the transition to sustainability.

6.1.5 *Examples of transition: energy and transport*

To conclude the general discussion on societal transition, this subsection provides a brief elaboration of regime-level transitions for the two subsystems most directly affected by global oil depletion, namely energy and transport. Fouquet (2010) studied historical examples of energy transitions for various services and sectors. He found that the "main economic drivers identified for energy transitions were the opportunities to produce cheaper or better energy services" (Fouquet, 2010: 6586). Fouquet focuses on transitions to low-carbon energy sources, mainly motivated by mitigation of climate change. Rising oil prices will in future make many renewable energy sources more competitive on price, fulfilling his first condition. However, this will be counteracted to an extent by adverse economic conditions resulting from oil price shocks, which will militate against R&D and rapid deployment of alternatives. The second condition (an improvement in services), may occur in some instances (e.g. less pollution from electric vehicles), but is likely to be of secondary importance. Although historical energy transitions were typically very slow, taking on average 100 years for the full innovation chain and 50 years for diffusion, the ICT revolution could facilitate more rapid energy transitions in the future (Fouquet, 2010: 6594). At a policy level, Fouquet suggests that governments need to provide protection for niche markets in order to overcome the free rider problem, and also avoid possible early lock-ins to undesirable technologies (Fouquet, 2010: 6594).

Gilbert and Perl (2008, 2010) argue that in order to keep ahead of oil depletion, transport will need to undergo revolutionary change, rather than the typical historical experience of incremental changes in mobility. Gilbert and Perl (2008: 265) define "a transport revolution as a substantial change in a society's transport activity – moving people or freight, or both – that occurs in less than about 25 years." They further state that "[m]ost but not all transport revolutions depend on major technological improvements", although revolutions do not automatically follow from such improvements (Gilbert & Perl, 2010: 1). They suggest that a transport revolution requires a tipping point in public attitudes (which could be triggered by a doubling or quadrupling of fuel prices), or strong political leadership that supports visionaries and innovators. They further argue that "innovation in implementing change," using readily available technologies, is more important than new technological inventions. Gilbert and Perl (2008, 279) suggest the creation of a transport redevelopment agency, whose board membership should include relevant Cabinet ministers (e.g. from Treasury, Transport, Energy and Defence). Efficiency improvements to existing ICEVs represent an *adaptation* to oil depletion. Conversion of transport systems to GCVs powered by renewable energy, by contrast, would be a *transformation* to a new (more sustainable) regime.

6.2 Vision of a post-oil, sustainable socioeconomic system in South Africa

If a society is to undertake a purposive transition toward (greater) sustainability, it could be useful to have a positive vision of the future to serve as a general goal.[211] It was noted at the beginning of this chapter that even some of the few scholars who do acknowledge an impending "great transformation" of society from an industrial to a sustainable socio-metabolic regime, are reluctant to propose what the latter kind of society might look like. For example, Haberl et al. (2011:11) state that "[f]rom today's perspective, it is extremely hard to say what this third transition should look

[211] Proops (1989: 66-67) describes "an image of the world as it might be" as a "utopia" (his use of the word in this instance also including "dystopias"). He cautions against turning a utopia into a concrete aim but suggests that a utopia "does offer a very useful yardstick for the policies that can be recommended, and for those that should be resisted." This however seems to be somewhat contradictory, for he says that a policy should be adopted if it is likely to take society closer to the (positive) utopia, and rejected if not, which implies that the utopia is a preferred outcome.

like." Nevertheless, some writers have proposed elements of a possible sustainable future. Early examples include Schumacher's (1974) *Small is Beautiful,* which called for the use of 'intermediate technology', and Ilich's (1973) *Tools for Conviviality.* More recent sketches of a sustainable society (or rudiments thereof) have been offered by Meadows et al. (2004), Jackson (2009), NEF (2008), Murphy (2008) and Heinberg (2011: 280-283). Hopkins' (2008) model of transition is most directly applicable to relatively small towns that have substantial pockets of land available for local agriculture; most large cities and sprawling urban areas will need other models. Perhaps the most comprehensive vision of a post-oil society has been painted by Greer (2009) in *The Ecotechnic Future*. Greer (2009: 30-31) describes an 'ecotechnic' society as "a human ecology that uses high technology produced, powered and maintained with renewable resources" and that "maximizes efficiency of energy and resource use... at the cost of more restricted access to goods and services."

Drawing on this literature, this section conducts a thought experiment: based on currently known technologies,[212] what might the South African socioeconomic system look like in 2050? This vision and its underlying norms are also informed by earlier discussions: (1) the principles of sustainable development summarised in Section 1.2.2; (2) the "planned descent" scenario outlined in Section 2.3.6; (3) the "powerdown/socioeconomic adaptation" response discussed in Section 4.3; (4) the vision statement for South Africa expressed in the National Framework for Sustainable Development as presented in the introduction to Chapter 5; and (5) the range of mitigation-adaptation policies discussed in Chapter 5. It is not intended necessarily to be the most likely or 'realistic' scenario, but rather is intentionally idealistic (in most respects) so as to present a positive goal for which society can strive. The SES perspective has clearly shown that a specific energy regime underpins each of the socio-metabolic regimes that have occurred thus far. Therefore, the appropriate point of departure for envisioning a sustainable society is its energy system, which will determine many other aspects of the broader socioeconomic system. Thereafter, consideration is given to transport, agriculture, and the economy and society more generally. For as Haberl et al. (2011: 8) state, "[a] radical reorganization of energy systems is simultaneously a radical reorganization of society."

By 2050, South African coal production is about 30 years past its peak and much lower than in 2011.[213] In addition, Sasol's CTL plant at Secunda reached the end of its functional economic lifespan more than a decade ago, and oil imports are negligible. Thus, to all intents and purposes, the oil age has drawn to a close. Instead, energy supply is derived from a diverse, localised and decentralised mix of renewable energy sources. The western interior of the country is home to massive solar parks, including both concentrated solar thermal and photovoltaic (PV) farms. In addition, solar PV and solar water heaters are installed on virtually every residential and commercial building across the country. Geothermal heat pumps are also used extensively for space and water heating. On-shore and off-shore wind farms generate electricity in the coastal areas of the Western Cape, Northern Cape and Eastern Cape Provinces. Ocean current energy has more recently become an economically viable source of base-load power. The large-scale hydro-electric power plants have been maintained as before, but are now complemented by thousands of micro-hydro turbines on small rivers and streams wherever these flow perennially close to human settlements, and particularly on farms. These decentralised RE generating units are connected by smart grids which manage the intermittency problem of solar and wind power as well as regulating demand to fit available supply. Waste biomass is used to generate process heat and cogeneration is used extensively in industrial processes. Nevertheless, society now has a much lower energy metabolism compared to the height of the fossil fuel era in the 2010s; energy use has fallen substantially both

[212] The possible role of nanotechnology in the quest for dematerialisation and resource substitution (e.g. carbon nanotubes to replace steel) is not discussed here, mainly because it is still in its infancy and because of related ethical, health and environmental concerns (e.g. see Mooney, 2006).
[213] The remainder of the section is written in the present tense, as is often done in scenario sketching.

per capita and per unit of economic activity, thanks to conservation and improved efficiency of energy generation and consumption.

The transport system has undergone a similarly radical transformation. Motorised transport is almost entirely electricity-driven. Most inter-city passenger and freight transport is by rail, although transport between port cities is partly by advanced sailing ships. Metropolitan and urban transport is a mix of non-motorised transport (walking and cycling), grid-connected public transport (commuter and light rail), and electric vehicles (buses and some cars). In rural areas, the predominant mode of passenger transport is non-motorised (walking, cycling and animal power), supplemented by some electric vehicles. Freight is moved by rail and trucks powered by biodiesel. Air travel, which is now very limited, is powered by third-generation biofuels made from cellulose and algae. Long-distance business travel has been replaced by telecommuting and teleconferencing. Car sharing clubs are common for rural travel and local tourism. Overall, the average level of mobility has decreased relative to that experienced in the 2010s, and has declined markedly for the wealthier portion of society. Nevertheless, this reduced mobility has been accompanied by health, safety and environmental benefits.

The post-industrial agricultural system in 2050 in many ways resembles pre-industrial agriculture, although it is more diverse and knowledge-intensive. Agricultural production is completely organic, with bio-fertilisers and bio-pesticides manufactured on a local basis. Use of agricultural machinery has been reduced substantially, and now runs on locally produced biodiesel; many farmers set aside a portion of their land for biofuel crop production. Average farm size has declined drastically since peaking around 2010. Farming cooperatives are now the norm. The percentage of the South African population involved in rural farming has risen substantially. In addition, small-scale urban agriculture is practiced all over the country. A majority of the population spends at least some of their time producing their own food. Diets have become more seasonal and local. Human and other organic wastes are completely recycled within the agro-ecological food production systems.

The economy is in a steady-state, dynamic equilibrium, conforming to the requirements for sustainability and on a scale that is within the region's carrying capacity. Rates of material and energy throughput are roughly constant over the longer term, although with minor short-term fluctuations depending on climatic conditions. Recycling of materials, especially minerals and metals, is pervasive, and virgin mining is very limited. Integrated industrial processes operate largely on closed-loop, zero-waste principles. Products are characterised by high quality and durability, and are designed to facilitate easy replacement of parts and recycling. Qualitative improvements continue to occur through technological and social innovations. Economies are localised, and many products are manufactured efficiently on a small scale with local raw materials. Employee-owned firms and cooperatives are more common than privately owned companies. The monetary system consists of local currencies that are connected into larger regional and global networks, facilitating trade at various scales, depending on the energy efficiency.

The population of South Africa has shrunk somewhat from its peak in the second decade of the century, partly as a result of increased death rates from diseases such as HIV/AIDS, but also because of falling fertility rates thanks to improved birth control. Absolute poverty no longer occurs as communities work together to ensure that everyone's basic needs are met. The distribution of income and wealth is much more egalitarian, with the Gini coefficient having halved from 2010. Both jobs and work hours are shared more evenly, and a four-day work week is standard. Political power is decentralised and based on a highly participatory system that is facilitated by Internet-based communication and voting tools. A variety of sustainable human settlements have emerged. Cities have become much more compact, with higher density core business and residential areas surrounded by 'urban villages'. Eco-village type settlements with sustainable building designs and small footprints have sprung up in rural areas with good arable land and favourable climate conditions. The industrial-era materialist and competitive value system has been replaced by a new ethic that embraces diversity, sharing, cooperation, self-sufficiency and local resilience.

These socioeconomic subsystems exhibit some common features. They are all characterised by decentralised power systems (energy, economic, political) and strong network relationships. Recycling of materials and respect for ecosystems as the basis of human welfare are integral elements of the new culture. Having described an idealistic vision of the future, the next question is, "how do we get there?"

6.3 A transition action plan for South Africa

A national strategy and action plan for transitioning South Africa to a sustainable society has already been developed, in the form of the National Strategy for Sustainable Development (NSSD). To date, however, it has yet to be implemented in practice as the over-arching policy strategy by national government. Moreover, the NSSD does not give sufficient attention to planning for oil depletion, which should be one of the strategic priorities. This section therefore addresses the aspects of a sustainability transition action plan specific to systematically reducing the oil dependence of the socioeconomic system, aiming for complete oil independence within about 40 years. The plan aims for a lower degree of societal complexity as there will most likely be less energy available in the future;[214] it therefore reflects the 'managed descent' scenario introduced in Section 2.3.6.

The National Planning Commission should take primary responsibility for co-ordinating the oil transition plan. It should appoint a National Oil Independence Task Team comprised of a relatively small group of experts. This Task Team would deliver recommendations for deliberation by a larger caucus comprised of representatives from all national government departments, organised business and labour, and civil society organisations. Through a consultative process, a National Transition Action Plan (NTAP) would be formulated. The oil independence plan must be consistent with the government's National Climate Change Response Policy, and be integrated with the NPC's National Vision and Strategic Plan and the Presidency's Medium Term Strategic Framework. In addition, due to geographic specificities, individual cities, towns and regional districts should formulate their own local transition action plans (in accordance with the NTAP), based on collaboration between municipal governments and local communities and businesses, and included in local Integrated Development Plans.

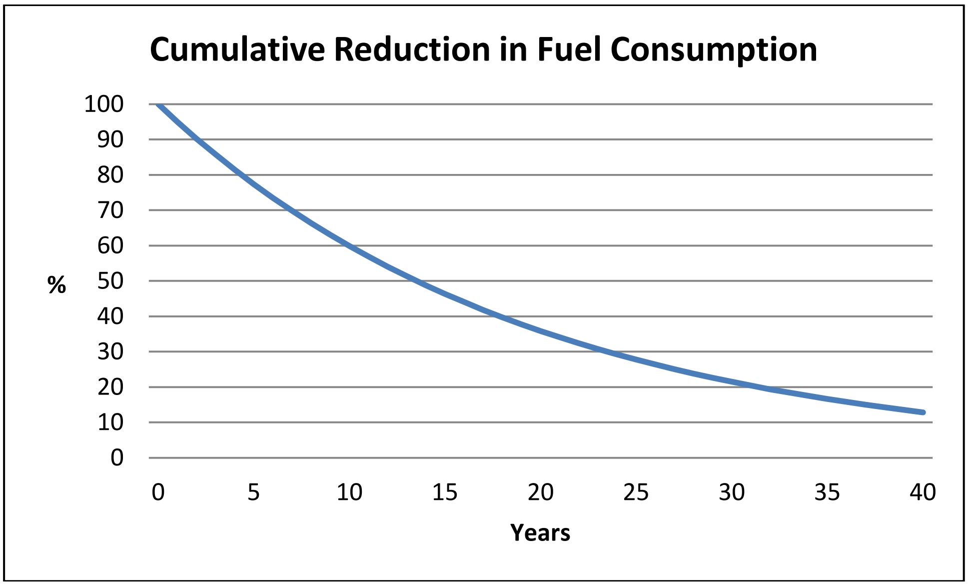
The NTAP should adopt a specific target for annual reductions in domestic petroleum consumption. A 5% per annum reduction seems reasonable, based on a mid-range estimate of the rate at which world oil exports will contract (see Section 2.1 and Section 4.2.4), and assuming that the lifespans of Sasol's Secunda CTL plant and PetroSA's Mossgas GTL plant will have terminated by 2050.[215] This would require a cumulative 50% reduction after 14 years and an 80% reduction after 30 years (see Figure 6-4). In reality, however, fuel savings are unlikely to decline smoothly, as some measures require lumpy investments (e.g. for modal shifts from road to rail). As mentioned in Chapter 3, South Africa achieved relative decoupling between petroleum consumption and real GDP at a rate of 2% per annum between 1998 and 2009. Petroleum consumption per capita rose to a peak in 2007, before declining in the recession of 2008-2009. The challenge for the era of declining global oil production is to reduce oil consumption per capita and per unit of GDP, while continuing to develop

[214] Tainter (2011) argues that greater complexity requires more energy.

[215] The Secunda plants (Sasol II and Sasol III) were commissioned in 1980 and 1982, respectively, while Mossgas was commissioned in 1992 (see Appendix B). Even assuming sufficient feedstock availability, capital stock of this nature would not be expected to have a lifespan longer than about 60 years.

the economy and reduce poverty, unemployment and inequality. A much more rapid degree of decoupling will be required once petroleum consumption begins to contract every year. If petroleum consumption falls by 5% per annum, then the rate of relative decoupling would need to rise to 5% per annum just to maintain real GDP at a constant level. In what follows, the major interventions that are required in the short-, medium- and long-term are summarised, based on the detailed policy recommendations presented in Chapter 5.

Figure 6-4: Targeted reduction in petroleum consumption (5% per year)



Source: Author's calculations

Note: The curve above represents an assumed 5% per annum decline in fuel consumption, in order to illustrate the cumulative reduction after five-yearly intervals.

Short term planning and implementation (i.e. one to two years) should focus on two major areas. The first step should be a national education and awareness programme to properly inform all sectors of society of the need to reduce petroleum consumption and become more sustainable in their lifestyles and business operations. This could take the form of information campaigns on national television and radio stations, as well as the press and online social media. This is because "it is important for government to galvanise popular support for a plan" (Patterson, 2009). Secondly, government should formulate emergency response plans to deal with sudden and drastic limitations on petroleum imports. Probably the largest short term risk is a broad military conflict in the Middle East involving Iran. This could lead to the closure of the Straits of Hormuz in the Persian Gulf, through which 15.5 million barrels of oil per day transited in 2009, representing 33% of world sea-borne oil and 17% of oil traded globally (EIA, 2011c). South Africa sources approximately 50% of its crude oil imports from Iran and Saudi Arabia (see Section 3.1), so a complete interruption of these supplies would reduce South Africa's total petroleum fuel supply by approximately 33%. Thus national government should formulate plans to cope with the logistical implications of a sudden loss of a third of the country's fuel supply, which could potentially last several months. Authorities must be ready to implement measures for rapid demand restraint in combination with a fuel rationing system (see particularly Section 5.2.1). The rationing system must include a fuel prioritisation plan to ensure the continued functioning of essential services (police, defence forces, fire, rescue, and ambulance services), transport of medical supplies, and food production and distribution (especially trucks that transport fresh produce, including fruits and vegetables, milk and meat products, to urban markets). In addition, a food security plan should incorporate a warehousing system to make provision for disruptions to the just-in-time food delivery system (City of Portland, 2007: 45). Given the limitations that refineries have on the proportions of various petroleum products that they can extract from a barrel of crude oil, consumption of diesel and petrol would have to shrink by similar percentages, implying that both passenger and freight transport will be affected. The greatest area for fuel saving with the least negative socioeconomic impacts would be: (1) discretionary driving (e.g. for leisure) and motor racing; (2) single-occupant commuting; and (3) freight movement along corridors where excess rail capacity exists. Air travel could be drastically reduced since it is mostly undertaken for leisure and for business commuting that could be replaced by telecommuting, although the air freight business would be negatively affected. Finally, the state must have plans in place to respond to social panic, hoarding behaviour or civil unrest that could accompany dislocations in fuel and food supplies and steeply rising prices.

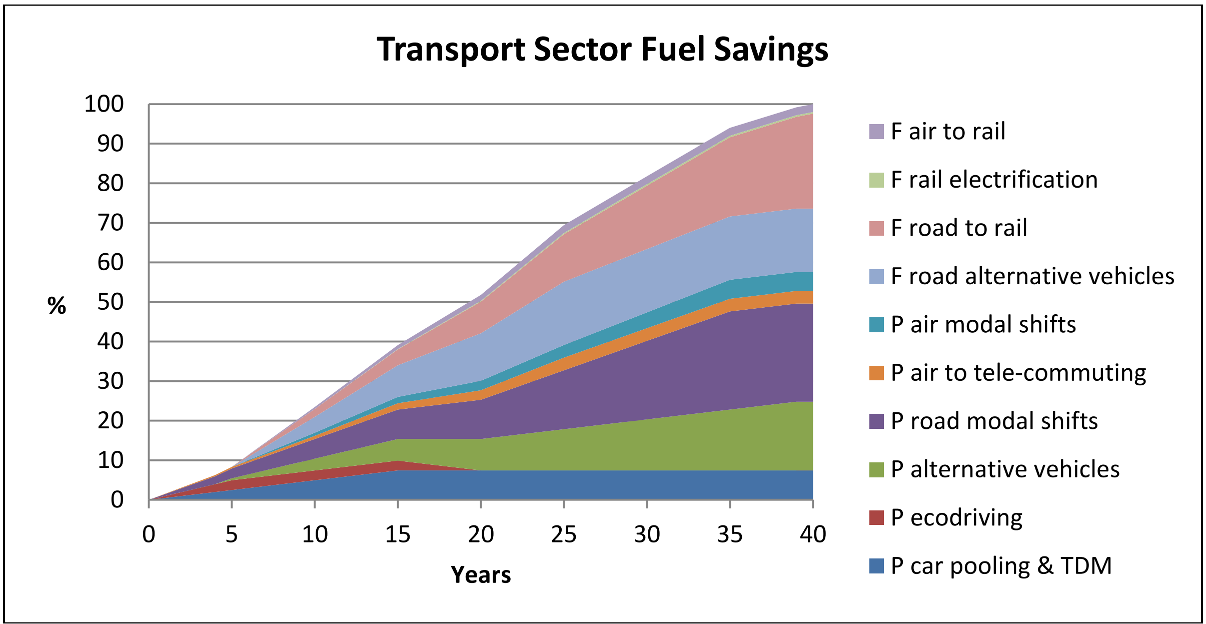
Medium term oil independence initiatives should aim to alter the behaviour of consumers and producers. This can be achieved firstly through the introduction of regulations for energy (liquid fuel) conservation and efficiency, car-pooling (e.g. via dedicated car pool lanes) and vehicle fuel efficiency standards. Secondly, fiscal incentives (taxes, subsidies and rebates) should be introduced to promote the manufacture and purchase of bicycles, electric bikes and scooters, BEVs, and PHVs as opposed to ICEVs, and to encourage modal shifts from private to public transport and from road to rail freight.

Long term strategies for reducing oil dependence centre on new infrastructure investments for sustainable energy and transport. Specific infrastructure investment projects will need to be informed by detailed studies based on appropriate evaluative methodologies, such as life-cycle analysis, cost-benefit analysis and/or cost effectiveness analysis. Key criteria for energy investments should be the energy return on investment and net energy, while for transport investments the oil saved for energy invested is a crucial variable. Any new transport infrastructure with an intended lifespan of over 25 years should only be built if it is compatible with a zero-oil future. Thus, for example, government and state-owned enterprises should opt for light rail trains or trams rather than BRT systems, unless the buses could ultimately be powered by electricity. Another critical question, which will need to be answered on a geographic-specific basis, is whether to focus on providing non-oil based transport to ensure that people can access services and work opportunities, or rather to achieve this by channelling resources into relocating people and redesigning human settlements. In other words, is it more resource- and cost-efficient to move people on a continual basis or to move physical capital? Another crucial aspect of long-term planning is the development of appropriate skills. This will require the formulation of new curricula for primary, secondary and tertiary education institutions that are compatible with an era of declining oil availability, such as agro-ecological farming, engineering skills for renewable energy and sustainable transport technologies.

Finally, the national and local TAPs should be subject to annual monitoring and evaluation processes, which will evaluate progress made towards reaching the petroleum conservation targets. The appropriateness of the targets themselves should also be reviewed on an annual basis and revised if necessary depending on global and national circumstances.

To conclude this section, consideration is given to the sectoral components of petroleum product demand and how these can be reduced through conservation and substitution over a 40-year period. As noted in Chapter 3 (Section 3.1.1), the sectoral composition of petroleum demand in 2007 was as follows: transport (77%), agriculture (6%), industry (5%), residential (4%), commercial and public services (2%), and other sectors (6%). Each sector will need its own oil independence action plan. For agriculture, the goal should be to reduce liquid fuel consumption (e.g. by employing more labour intensive production methods), perhaps by about half, and to substitute the remaining fuel consumption with locally produced biodiesel. Industry uses petroleum products mostly for lubrication, and diesel to run machines and electricity generators. The latter will need to be substituted with renewable electricity, and innovation will be required to develop lubricants from biomass. The residential sector and commercial and public services use petroleum mainly in the form of LPG, paraffin and diesel for small electricity generators, all of which need to be replaced by renewable electricity over time. For the transport sector, a scenario for achieving 100% fuel savings after 40 years through a range of mitigation measures is illustrated in Figure 6-5 (see Appendix G for details). Fuel savings are expressed as a percentage of the petroleum fuels consumed by passenger (road and air) and freight (road, rail and air) transport in 2009. While deviating slightly from the 5% per annum target, this scenario is deemed plausible assuming that the economy remains intact and the will to formulate and implement policies is forthcoming.

Figure 6-5: Fuel savings in the transport sector



Source: Author's calculations

Notes: P = passenger; F = freight; TDM = travel demand management. Each of the 'wedges' represents the percentage of 2010 transport fuels that could be saved through the implementation of groups of fuel saving measures. The various wedges are added vertically to indicate the potential total fuel savings. Some interventions will take longer to implement than others. Savings from eco-driving are assumed to phase out as the current internal combustion engine vehicle fleet is replaced by electric-powered vehicles and mass transit. See Appendix G for detailed assumptions and data.

6.4 Barriers and risks to implementation

Numerous obstacles and risks might potentially thwart the implementation of the transition strategy. Recognising that there are overlaps between them, seven categories of barriers to transition can be identified, namely: cultural-ideological, behavioural–psychological, social, political, institutional, economic and environmental (see van den Bergh et al., 2011).

At an ideological level, adherence to an outdated intellectual paradigm (such as neoclassical economics) or cornucopian faith in the ability of technology to overcome resource constraints could lead to a failure to recognise the challenge of global oil depletion and a continuation along the path of denial and false hopes.[216] Ideological lock-in would likely result in a misinterpretation of economic signals, e.g. financial volatility and economic distress not being understood as symptoms of underlying energy constraints. Echoing Mitchell (2008, cited in Fouquet, 2010), it appears that the prevailing ideological and policy paradigm in South Africa will have to undergo a fundamental shift if a proactive transition action plan is to be adopted and implemented.

Similarly, the persistence of cultural values such as consumerism, greed, individualism, and independence would result in citizens attempting to cling to current or aspired-to consumer lifestyles and preferences (Geels, 2011: 25) (e.g. ICEVs, which historically have offered a high degree of mobility), and thwart the introduction of more sustainable alternatives (e.g. sharing initiatives such as car-pooling). Cultural conservatism could hinder the kinds of social innovations that are required for a sustainability transition. Behavioural–psychological traits such as bounded rationality and short time horizons (myopia) amongst producers and consumers could also obstruct appropriate adaptive responses (van den Bergh et al., 2011: 7). Citizens could react to socioeconomic challenges by blaming particular sectors of society or the government for crises, instead of cooperating to find solutions. Socially, a serious lack of education, flexible skills and an entrepreneurial culture that are required to support innovation and the adoption of new technologies is a constraint of particular relevance to a developing country like South Africa.

Political barriers to the implementation of a transition strategy involve power relations among various groups in the country. Lobbying by incumbent vested interests serves to preserve the status quo and militates against the adoption of new policies (Barbier, 2011). In South Africa there are several vested interests that wield considerable political power. The most important is the minerals-energy complex (MEC), a component of which is the "energy intensive users group", which comprises the largest industrial consumers of electricity, and which apparently had a significant influence on the IRP2010 (Baker, 2011). Another member of the MEC is the electricity utility, Eskom, which by virtue of its position as monopoly purchaser and distributor of electricity has stymied the attempts of independent power producers to supply power to the national grid[217] (Baker, 2011; Trollip & Tyler, 2011). Sasol, also a key component of the MEC, apparently used its economic power to influence the National Treasury's decision in 2006 not to impose a windfall tax on synthetic fuels, by intimating that it would cancel its plans to build a second coal-to-liquids plant (National Treasury, 2007). If this "Project Mafutha" did materialise, it would further entrench lock-in to the fossil fuel-ICEV regime nexus and seriously retard South Africa's transition to sustainability. Similarly, the state-owned oil company PetroSA is intent on building a new large oil refinery at Coega based on the assumption that domestic and regional petroleum demand will continue to grow for decades. Should this "Project Mthombo" be approved by Cabinet, it will almost certainly represent a monumental misallocation of resources that the country can ill afford. A second group that stands in opposition to oil mitigation policies are those companies with an interest in maintaining the dominance of road-based transport. This group includes automobile manufacturers, who would oppose the withdrawal of state subsidies for ICEV production, likely using potential job losses as a lever. Other key members of this interest group are SANRAL and the road construction companies, which profit from upgrades and extensions to national (and urban) roads. Third, trade unions might resist support for new sectors such as manufacture of renewable energy technologies, to the extent that this would require a shift of resources away from established industries. Fourth, financial institutions (dominated by an oligopoly of five banks) are likely to vigorously oppose proposals for monetary reform, as they would stand to lose some of their considerable profits. Overcoming these vested interests is a tall order,

[216] Atkinson (2010: 314) writes that "There is still almost no admission that effective action to halt global warming will mean putting the global economy into sharp reverse and that peak oil will in any case have the same effect."
[217] Not a single renewable energy power purchase agreement had been concluded as of mid-2011 (Baker, 2011: 11).

although to some extent it might be made easier by unfolding economic circumstances, which will erode the financial power of resource and energy-intensive sectors and commercial banks. For example, the MEC is "under threat from rising coal costs, electricity supply issue, rising tariffs and a utility struggling to hold onto its monopoly" (Baker, 2011: 28). Similarly, the power of commercial banks is being weakened in other countries by the debt crisis, and this could spill over to South Africa. Nevertheless, the fact that "[t]here is no one national champion of renewable energy to forge a path but rather a number of different entities acting at times in competition with each other" (Baker, 2011: 28) makes it harder for the RE niches to challenge the dominance of incumbent fossil fuel regimes.

Many policy and institutional failures result from institutional inertia, or the persistence of institutions (in the sense of formal and informal social rules governing human behaviour) over time, which have often evolved to minimize transaction costs (Barbier, 2011). The social order that evolved with a given resource base (e.g. fossil fuels) locks in that development trajectory, since it may be incompatible with reducing transaction costs associated with an alternative resource base (Barbier, 2011: 61). More specific institutional constraints include government failure resulting from rent-seeking behaviour, corruption in state apparatuses (which could deteriorate as people in positions of power attempt to cling to their wealth as the economy declines), and a lack of institutional and managerial capacity in the state (as discussed earlier in Section 6.1.3). Furthermore, the capacity of the state to implement the transition strategy might be eroded by the impacts of declining world oil production, such as tightening financial constraints and social protests that undermine the state's capacity to govern. Heinberg (2004) points out that his "powerdown" scenario presents a paradox to national governments, in that they need to implement policies that in the long term will undermine their power. However, if they fail to implement the transition strategy, their capacity to govern will be steadily eroded in any case – and probably much more rapidly. Yet another example of institutional failure is a lack of coordination among state-owned enterprises and agencies, such as disputes between railway operator Transnet and the Passenger Rail Authority of South Africa (PRASA) (Fin24, 2011). Lastly, some aspects of a transition strategy will be circumscribed to a degree by global institutional factors such as the World Trade Organisation (WTO), the global financial architecture and international climate negotiations.

Economic barriers to a sustainability transition include various kinds of market failure as well as financial conditions. The first market failure is that of imperfect information: most economic agents are grossly ill-informed about the likely future trajectory of global oil production and the risks of continued oil dependence. This is compounded by explicit and implicit subsidies for fossil fuel consumption and production, which hinder improvements in energy efficiency and the growth of renewable energy sources (Barbier, 2011: 64). Second, sustainability is a public good which is subject to free-rider and prisoner's dilemma problems (Geels, 2011: 25). Third, there are several externalities, both positive and negative, associated with sustainability-oriented innovations (van den Bergh et al., 2011: 4-5). One is negative environmental externalities, which result in socially damaging investments being made. Another is positive knowledge/information externalities, which lead to suboptimal levels of private investment in R&D and innovations. A third is lock-in to existing (unsustainable) socio-technical regimes, which can occur as a result of economies of scale, sunk investments in infrastructure and skills, land tenure systems, actions by professional and fraternal organisations to maintain the status quo, and various incentives and regulations (Geels, 2011: 25; Westley et al., 2011: 34). For example, the minerals-energy complex favours the construction of new coal power plants, possibly another coal-to-liquid plant, and the extraction of shale gas, exhibiting lock-in to a fossil fuel regime rather than development of sustainable energy sources. In addition, financial constraints will almost certainly pose a major obstacle to transition, for instance in the form of a domestic credit crunch and cost escalation, especially for mega-projects such as new railways.

Finally, environmental factors may hinder the implementation of certain preferred elements of a transition strategy. These may take the form of resource depletion or scarcity (e.g. related to water, or rare earth metals that are required for many renewable energy technologies, or lithium for batteries), or environmental impacts of new technologies, or climate change impacts (e.g. upon small-holder farming yields).

In addition to these myriad obstacles, various risks face the implementation of a transition strategy. The first risk is that the transition strategy is a political non-starter. Proactive leadership might not be forthcoming, with no champion emerging to tackle this issue as a national emergency. Instead, the state could respond with reactive crisis management in which short-term solutions are favoured for expediency rather than long-term efficiency, locking the country into decisions that will compound the problems in the longer term. The evidence and argument presented in this dissertation attempts to reduce this risk.

The second set of risks involves unintended consequences of transition policies and measures. For example, government acknowledgement of the oil depletion issue might result in a collapse in business and consumer confidence and a resulting crash in the stock market and contraction of economic activity.[218] However, in 2006 the Swedish government publicly adopted a plan to reduce oil dependency by 50% by 2020, and this did not result in substantial adverse impacts on the economy or stock market. Another common worry is that the introduction of unconventional policies, such as monetary reform, could trigger rapid capital flight. On the other hand, capital flight could be substantially worse later on if proactive mitigation strategies are not implemented and the economy deteriorates more rapidly. Concerns over the rebound effect of energy efficiency measures are much less significant in a context of rising energy prices. There may be substantial labour unrest as state support undergoes sectoral shifts; but significant sectoral economic shifts will take place in any case. While it is not possible to foresee all potential unintended consequences, this should not hamstring the transition strategy as a whole.

A third category of risks may be termed "black swan" events (following Taleb, 2007). These include: severe oil price shocks (e.g. $300 per barrel) and shortages (e.g. a 10% loss in one year) occurring soon and bringing severe economic consequences, such as a collapse of the global financial system; a world war involving a majority of the major powers, for example centred on the Middle East and Central Asia; invasion of South Africa by a foreign power in order to gain control over its strategic mineral resources (e.g. coal, uranium, platinum group metals, magnesium and chromium)[219]; regional immigration on a scale that overwhelms the capacity of the state; and massive regional climate change impacts resulting in widespread crop failures, food shortages and social chaos. Any of these events would dramatically worsen the prospects for a successful transition, at least in the short to medium term. However, prior efforts towards transition would likely mitigate their impacts in any event, so if anything the possibility of black swans increases the motivation for early transition initiatives.

A fourth type of risk could be termed a "pink swan". An example would be a major discovery of oil or natural gas within South Africa's territorial boundaries (including offshore), which could be a game-changer if it was sufficiently large to replace imported oil. However, pricing would still be an issue, as the oil or gas would be extracted by (possibly foreign-owned) private companies that would seek to sell the hydrocarbons for the highest price attainable in the international market. The only way such a discovery would make a material difference to South Africans would be if the state (possibly

[218] Atkinson (2010: 317) contends that "there is political silence about [peak oil] because of its catastrophic economic implications."
[219] A paper by Burgess (2010), Associate Professor at the US Air War College, advised the US government to consider military intervention in Southern Africa to secure access to its strategic mineral resources.

through its oil company PetroSA) negotiated sufficiently large royalties that it would be in a financial position to subsidise domestic petroleum products. Should such a 'pink swam' materialise, however, the rents accruing from the resource should be diverted to sustainability-enhancing investments of the types discussed in Chapter 5.

On the other hand, there is also the possibility of what might be termed "green swans", namely disruptive technological developments that render older investments obsolete. Examples might include revolutionary developments in solar cell efficiency, electricity storage technology, commercial production of biodiesel from algae on a large scale, success in the quest for nuclear fusion, and radically new propulsion mechanisms for transport. The risk then is that early adoption of current, less efficient and effective technologies would result in lock-in and reduce the potential for widespread deployment of the newer technologies. Nonetheless, any of these new technologies would likely take a decade or more to be commercialised and scaled up to a significant extent, whereas transition planning should ideally begin immediately to mitigate the risks of early-onset impacts from peaking world oil production. The possibility of 'green swans' does however suggest that a transition strategy should be designed as flexibly as possible so that new, disruptive technologies can be taken advantage of if or when they arise.

In a similar vein, there is a risk that elements of the transition strategy follow dead end paths. This could occur if the uncertainties surrounding the timing of oil shock impacts and behavioural responses lead to a misallocation of resources, for example if the state were to build new public transport infrastructure in cities, only to have a large exodus of people to rural areas in later years. Other dead ends could be reached for energy, transport and housing infrastructure projects that cannot be completed, for instance if cost escalation (driven by increasing global demand for mitigation-related capital equipment, higher energy and material input costs and rising interest rates) intersects with shrinking tax revenues to render the projects unaffordable. Again, however, steering investments in a more sustainable manner from now on will attenuate this risk.

In conclusion, while there are many potential risks that could disrupt the implementation of a transition strategy, failing to attempt such a strategy would in most cases make the situation worse. Any sustainability-oriented initiatives that are undertaken sooner rather than later will help to mitigate the risk of severe socioeconomic consequences.

6.5 Conclusions

The review of the societal transition literature concluded that there are various levels at which transitions occur. The broadest level of transition was termed an "epochal" shift in the socio-ecological regime (or socio-technical landscape), which itself would be comprised of many smaller transitions at the level of socio-technical regimes. An epochal transition would also overlap with techno-economic paradigm shifts within the socio-ecological regime. Each successive socio-metabolic regime is founded upon a specific mix of energy sources, which gives rise to new social systems and cultures. Thus while epochal transitions begin with energy transitions, they cascade to all aspects of society and human interactions with the biosphere. The current industrial regime is based on the family of fossil fuels, of which oil is the dominant sibling today. Therefore, the peak and decline in world oil production will trigger an epochal shift to a new socio-metabolic regime that is based on renewable sources of energy.

Depletion of global oil resources therefore has implications for contemporary research into societal transitions. Firstly, while much of this literature is oriented toward reducing environmental degradation and mitigating climate change, the literature on oil depletion suggests that the major driver for the 'sustainability revolution' could in fact be resource depletion in general, and oil depletion in particular. This has implications for the emphasis of policies designed to accelerate transition. For example, rising prices and growing shortages of oil (and other commodities) will be a major driver of transition; hence governments will not need to rely as much on regulations and artificial incentives (taxes and subsidies) to drive efficiency. However, there will still be a need to protect the environment from more polluting alternatives such as unconventional oil and gas. Second, the economic climate following the oil peak will most likely be deteriorating, possibly rapidly. This will make broad contestations over resources between sections of society more vociferous, and will reduce the pool of funds available for R&D. Third, the 'sustainability revolution' triggered by oil depletion will involve socio-technical transitions across the full range of subsystems and sectors, in contrast to the rather piecemeal modernisation described in much of the transition literature. Fourth and more broadly, global oil depletion challenges the notion of perpetual progress through technological change, mainly because we are likely transitioning to less concentrated sources of energy with lower EROI. Finally, the rather Eurocentric transition literature needs to be balanced by a developing country perspective that takes into account constraints on democratic governance and state capacity.

The perspective on societal transition informed by global oil depletion carries broader implications for transition in other countries. First, it is clear that industrialised countries cannot sustain the current metabolic rate for much longer (in fact it is already changing as consumption of fossil fuels has decreased in OECD countries since 2007), and certainly not in the longer term. Given their high degree of oil dependence, most major systems (energy, transport, agriculture) will have to undergo a fairly rapid transition over the coming decades. Second, developing countries cannot continue to follow the fossil fuel intensive path of industrial development because there are insufficient quantities of affordable fossil fuel resources remaining. The challenge for these countries is to leap-frog to the sustainable socio-ecological regime.

In particular, global oil depletion represents an opportunity and an imperative for South Africa to accelerate its inevitable transition to a sustainable socioeconomic meta-regime, involving sustainable energy, transport, agricultural, industrial and social systems. This chapter presented an idealised vision of elements of a sustainable society. It then offered an action plan for a transition strategy. To be sure, there are a number of potential barriers and risks that the transition plan would fail partially or wholly, which highlight several necessary conditions for a successful transition to sustainability: ideological transformation to real sustainability thinking based on sound ecological-economic principles; political will and bold leadership; an effective, well capacitated developmental state that relinquishes conventional conceptions of its role (e.g. stimulating large-scale, capital-intensive projects) in favour of promoting small-scale, local, sustainability-oriented innovations; business and community cooperation and leadership within their spheres of influence; enabling economic conditions (i.e. economic contraction or collapse is not too rapid); long-term relative decoupling, i.e. increasing eco-efficiency; and overcoming socio-technical lock-in through technological, institutional, organisational and relational innovations. These conditions have to be met simultaneously; there are no individual sufficient conditions that can guarantee a successful transition. However, for the most part these obstacles are either surmountable (mostly addressed within the transition plan itself) or are external eventualities whose impacts would in any event be mitigated by the transition strategy.

CHAPTER SEVEN

7. Conclusions

Oil has been the dominant energy source in the modern world economy for at least half a century. Petroleum powers 95% of global transport systems, sustains a highly mechanised agribusiness and food distribution industry, and provides the feedstock for a staggering array of products. Historically, global economic growth has been closely coupled with consumption of energy in general and oil in particular. Thus the depletion of global oil resources has profound implications for the long-term sustainability of industrial civilisation.

While the nature and implications of global oil depletion have garnered a rapidly growing amount of attention in the past decade in the international academic literature on energy as well as in the mainstream media, there has to date been a serious dearth of attention given to this vital subject within South African energy, economic and policy discourses. This dissertation sought to address this important deficiency in knowledge and policy formulation in South Africa. Specifically, the aims were to understand the implications of global oil depletion for socioeconomic welfare and to propose viable strategies and policies for mitigating and adapting to potential negative impacts, and for assisting a transition to a sustainable socioeconomic system.

Sustainable development, or the pursuit of sustainability, is widely recognised in the international literature as a complex problematique that requires a transdisciplinary approach to be properly understood and managed. Therefore, this dissertation employed a transdisciplinary and holistic methodological approach to understanding the implications of global oil depletion. The research technique of critical literature surveys was used extensively, especially in Chapters 1 and 2 and Sections 4.1 and 6.1. Specific analytical methods were not pre-selected, but were rather chosen and developed during the course of the literature surveys in response to the nature of the subject matter. From the review of the theoretical literature, ecological economics and the socioecological systems perspective provided the conceptual language and analytical framework. Three analytical methods were deemed most appropriate, namely: (1) empirical economic history incorporating an element of energy flow analysis (in Chapters 3 and 4); (2) scenario building (in Chapter 4 and Sections 6.2 and 6.3); and (3) policy analysis (in Chapter 5 and Section 6.4). Other empirical techniques, commonly used in conventional economic research, were not employed for the following reasons. First, econometric methods based on time series data, whether structural macro-econometric models or multivariate (a-theoretic) time series models such as vector auto-regressions, assume that the relationships among the variables are linear and that the coefficients remain constant over time. However, these assumptions are unlikely to hold after the massive structural break implied by the peak and decline in world oil production. Second, while input-output and computable general equilibrium type models provide a useful snapshot of the macroeconomic and distributive impacts of oil price shocks by incorporating economy-wide interactions and adjustments, several of their foundational assumptions are very tenuous, such as competitive markets, factor substitutability, and a constant price level. Moreover, the CGE models do not include the lagged, indirect effect of an oil price shock on the demand for South Africa's exports and on the capital account of the balance of payments, which the historical analysis indicated could be more important than the direct impacts of domestic fuel price increases. CGE models are also unsuited to analysing longer term impacts of cumulative price shocks. More generally, both conventional time series and cross section models do not account for the key features of 'peak oil', namely: (1) the special role of energy in economic systems; (2) the fundamental shift from growing to shrinking oil supplies; (3) the prospect of sustained and cumulative oil price shocks; (4) the socioeconomic impacts of physical oil shortages; and (5) the global nature of oil depletion and the transmission of its impacts to South Africa. It was therefore deemed that repeating these types of empirical studies would not shed additional light on the research topic.

The originality of the dissertation consists in several elements. First, it applies a transdisciplinary, holistic perspective to a complex societal problem rather than a narrow, discipline-specific approach. Second, it fills a large gap in the South African energy and economic literature, which has almost entirely failed to address the issue of global oil depletion. Third, it provides practical policy recommendations for dealing with a serious societal challenge facing South Africa. Fourth, the research provides a useful microcosm case study of an issue that is of great relevance both to the world as a whole, and to other countries. Fifth, this study contributes a novel developing country perspective to the international literature on global oil depletion, which thus far has been predominately focused on the implications for industrialised nations. Sixth, the dissertation makes a contribution to the international and national literature on energy, economic and societal transitions. Finally, it begins to bridge a gulf that has existed between the distinct bodies of research on 'peak oil' and 'societal transitions'.

This concluding chapter has four objectives, which are addressed in the subsections that follow. The first is to distil the essence of the argument by summarising and weaving together the conclusions of the six chapters. The second is briefly to spell out the relevance of this South African case study for the world as a whole and to draw out some implications of global oil depletion for transition research and economic theory. The final objective is to suggest avenues for further research, which can elaborate upon the issues dealt with in this dissertation and extend its coverage to areas that were beyond its scope.

7.1 Summary of the argument

The following subsections present and link together the essential conclusions of the six chapters. The subsection titles represent the major propositions arising from each chapter.

7.1.1 Energy is the master resource

Chapter 1 reviewed and evaluated three theoretical paradigms that analyse the role of energy in the socioeconomic system. In terms of methodological approach, it was found that neoclassical economics is hamstrung by its modernist and monist approach, while ecological economics and the socioecological systems school both favour methodological pluralism and a transdisciplinary approach to knowledge acquisition, which are more appropriate for an analysis of the implications of global oil depletion.

With regard to the energy-economy relationship, it was found that neoclassical economics (a short-hand for the prevailing mainstream economics paradigm) has several key deficiencies: it erroneously views nature (resources) as a subset of the economy; it does not sufficiently incorporate energy into its key macroeconomic models; it largely ignores the physical laws of thermodynamics; and it assumes, without adequate foundation, that factor substitutability and technical progress will necessarily and easily overcome the exhaustibility of finite resources, including energy sources such as oil. Nevertheless, the mainstream literature on the macroeconomic impacts of oil price shocks has some relevance for the current research.

In contrast, ecological economics provides a highly relevant set of conceptual tools for a valid analysis of the role of energy. This paradigm (and specifically the biophysical economics literature) properly locates the human economy and society within the broader ecosystem, and is rooted in the laws of thermodynamics. The principal findings emerging from the ecological economics literature on the energy-economy nexus may be summarised as follows: all economic activity is dependent on energy, although different types of activities have different energy intensities; energy is mostly complementary to physical and human capital; historically, increasing economic activity (measured by growth in GDP) has been tightly correlated with increasing energy consumption; and the quality characteristics of energy sources are of vital importance, especially the energy return on investment and the net energy delivered by an energy generating process. Ecological economics also provides a balanced set of normative goals for society, including economic efficiency, intra- and inter-generational social equity, and ecological sustainability (the three pillars of sustainable development), as well as precautionary risk management. Ecological sustainability requires that non-renewable resources must be replaced by renewable resources as the former deplete, that stocks of renewable resources must not be consumed faster than they can regenerate, and that the waste-absorption capacity of the environment must not be exceeded. These conditions imply that there are limits to the physical scale of the economy, in terms of rates of throughput of energy and materials.

Socioecological systems analysis provides a very useful long-term historical perspective which augments the ecological economics toolkit, and it also highlights the utility of the materials and energy flow analysis technique for helping to understand the potentials for and constraints on decoupling economic activity from energy use. The SES literature emphasizes that the metabolism of industrial economies involves high rates of fossil fuel consumption. This sets the 'industrial era' apart from the previous 'agricultural' and 'hunter-gatherer' eras, which had much lower rates of energy and materials throughput. By implication, the depletion of fossil fuels will inevitably usher in a new era (tentatively labelled 'sustainable'), in which societal metabolism is once more sustained by renewable energy sources. MEFA studies have shown that a degree of relative decoupling of economic growth from energy and materials consumption is possible, by way of rising resource productivity and dematerialisation. The related literature on resilience shows the importance of developing strategies to enhance the resilience of complex adaptive socioeconomic systems to external shocks.

In summary, the ecological economics and socioecological systems approaches, complemented by the neoclassical economics literature on oil price shocks, together provide an adequate theoretical, methodological and normative basis for analysing the implications of global oil depletion. The difference in perspective between neoclassical and ecological economists on the role of technology and factor substitutability has been characterised as a debate between 'technological optimists' and 'technological pessimists', and is very evident in the long-running debate over global oil depletion, as evidenced in Chapter 2. The South African case study developed in Chapters 3 and 4 utilises empirical and historical analytical tools drawn from the oil shocks, ecological economics and socioecological systems literatures. Chapters 5 and 6 follow the ecological economics and SES call for active government interventions, such as regulations, market-based incentives and moral suasion, to address pervasive market failures and barriers to societal transition that are inadequately recognised by neoclassical economics.

7.1.2 The end of cheap and abundant oil has profound socioeconomic implications

Chapter 2 critically reviewed the literature on global oil depletion, which has for many years been polarised into two camps. The 'pessimist' group, which is comprised mostly of geologists and other natural scientists, holds that oil *resources* are finite and subject to depletion. The 'optimist' camp, consisting mainly of neoclassical economists, emphasizes that oil *reserves* respond to price incentives and technological progress, and are therefore not fixed quantities. Ecological economics recognises the importance of geological, technological, economic and political factors in determining oil supply and demand dynamics, and can help to bridge the intellectual gap between the economic and physical science paradigms and provide a synthesis view of global oil depletion.

On the human time scale, oil is a finite, non-renewable resource subject to depletion. Estimates of ultimately recoverable oil resources (both conventional and unconventional) vary greatly and are influenced by a combination of geological, economic and technological factors. However, the critical issue for oil-dependent societies is not the size of remaining oil reserves, but the annual rate of oil production. World oil production will inevitably reach a maximum peak or plateau and thereafter decline irreversibly, marking the transition from an era of cheap and abundant oil to one of increasingly expensive and scarce oil. A review of forecasts suggests that there is a significant risk of the global oil peak being reached before 2020, and that it is possible that conventional oil production peaked around 2006-2008. Various scenarios are possible for the shape of the global oil peak and decline, ranging from a fluctuating plateau followed by a gradual decline (of about 2-5% per year) to a sharp peak and steep decline (of greater than 5% per annum). However, the net energy derived from oil is of greater importance than the gross supply of oil, and will decline more rapidly as the EROI for oil continues its historical decline. In addition, world oil exports appear to have peaked in 2005 and will decline more steeply than total world oil production if the trend of rising consumption in oil producing countries continues.

Neoclassical economists believe that there will be adequate substitutes for oil that will become economically competitive when oil prices are sufficiently high. An ecological economics perspective, in contrast, draws attention to the vital quality characteristics of oil and alternative energy sources, especially the energy return on investment (EROI). Oil has several special characteristics that explain its position as the world's foremost energy source, including historically high EROI, massive energy surplus, ease of storage and transport, and versatility of use. Although there are many potential substitutes for oil, all of them have important quality limitations, such as intermittency, limited scale and/or concentration, low EROI, and in some cases harmful environmental impacts. Thus alternatives may not be more economically *viable* even with higher oil prices. Furthermore, it will take considerable amounts of time and investment capital to develop and scale up the alternatives, while current infrastructures and spatial development ensure 'lock-in' to oil dependency for many years. There is a strong possibility that the total accessible net energy will decline once (or possibly even shortly before) oil production begins its descent, and this will most likely be compounded by declines in coal and nuclear energy supplies within a few years or at most a decade or two. Enhanced energy efficiency will be necessary, but is subject to diminishing returns and the rebound effect. Thus curtailment of energy use will likely be essential, especially in the medium term while alternatives are being developed. Certainly curtailment is the cheapest response to growing oil scarcity.

Global economic, transportation and agricultural systems are highly dependent on oil and historical experience has shown that even relatively small disruptions to the supply of petroleum can have severe economic impacts such as rising inflation and unemployment, and economic recession. Given the long lead times required to develop alternative energy sources and infrastructure, mitigation efforts should ideally be initiated at least 20 years prior to the oil peak. Even if the more optimistic estimates of the peak date turn out to be valid, there may be insufficient time to mobilise mitigating responses that can avoid all harmful economic, social and political impacts. If not adequately mitigated, a sustained decline of world oil production is likely to result in a sustained decline in gross world product. Given the dependence of debt-based money systems on continuous economic growth, this situation could precipitate a systemic global financial crisis. Oil depletion will also raise transport costs and curb mobility, and could result in a contraction of agricultural production over the longer term. Thus one post-oil peak scenario foresees a 'long descent' in which global economic activity oscillates around a gradually declining trend as energy supplies progressively diminish. A worst case scenario envisages resource wars, famines, a financial system implosion and a cascading collapse of industrial societies to a much lower level of societal complexity. Chapters 3 and 4 explore the vulnerabilities of South African society to these outcomes under business-as-usual behavioural and policy responses. This builds a strong case for a managed transition towards a sustainable socioeconomic regime; the policies and strategies required for such a transition are described in Chapters 5 and 6.

7.1.3 South Africa's petroleum dependencies render it vulnerable to oil scarcity

The South African energy, transport, agriculture, macroeconomic and social systems are all very dependent on energy flows in general and to varying degrees on oil in particular. South Africa's economy is highly energy-intensive by world standards. More than 70% of primary energy supply is derived from coal, while renewables (including hydro, biomass, wind and solar) contribute just 13%. Imported oil contributes just 12% of primary energy although petroleum fuels account for over 30% of final energy consumption. The country depends on imported oil for approximately two-thirds of petroleum fuels, the other third being supplied by indigenous coal-to-liquid and gas-to-liquid synthetic fuel producers at import parity prices. Strategic stocks of oil products are rather low and there are significant fuel distribution bottlenecks. South Africa is fortunate to possess large coal and uranium reserves, but these are often over-stated and are depleting. There are abundant, untapped solar resources and substantial wind resources. The potential for these as substitutes for imported oil is discussed in Chapter 5 in the context of mitigation.

The national transport system is 98% dependent on petroleum fuels. Motorised transport is overwhelmingly road-based, for both passengers and freight. Public transport services are very inadequate, and nearly three quarters of the population rely on the minibus taxi industry and/or non-motorised transport (chiefly walking). Although there is an extensive rail network, it has been neglected for decades and most of the rolling stock is near the end of its operational lifespan. Geographic vulnerabilities to oil scarcity arise from the great distance of South Africa from its trading partners, the substantial distances between major cities, the concentration of industry in the interior of the country, and the legacy of apartheid spatial planning mixed with urban sprawl.

Agriculture depends on petroleum for more than two thirds of its energy inputs. The vast majority of agricultural produce comes from highly oil-intensive commercial farming, which is exposed to rising input costs for fuel, fertilisers and packaging, all of which are affected by oil prices. Fuel shortages are potentially catastrophic at critical times such as during planting and harvesting. Agro-ecological and subsistence farming contribute tiny shares of output. The nation is self-sufficient in most commodities, including the main staple maize in most years, but has recently become a net food importer in value terms. A small percentage (13%) of land area is arable and an ever smaller percentage is rain-fed. Agriculture is also vulnerable to recurring droughts, climate change, soil erosion and pollution.

South Africa's macro-economy is fairly diversified by developing country standards, but nonetheless is dominated by energy-intensive minerals extraction and processing. Petroleum consumption relative to GDP has declined slightly over the past two decades, indicating modest relative decoupling. Government debt is not excessive but has been rising since 2009, while household debt has recently declined slightly from record levels, and presents a significant economic vulnerability in the face of oil-related inflationary pressures. Other vulnerabilities include a large and persistent current account deficit, and vulnerability to rapid short-term capital flight and currency depreciation. Major structural problems, such as chronic high unemployment and skills shortages, beset the economy.

South African society has progressed in many respects since the successful transition to democracy in 1994. There have been 17 years of stable democracy underpinned by a strong constitution. There has been marked improvement in access to social services such as electricity, housing, water and sewage, although deficits still remain. An extensive system of social grants provide a safety net for the poor, but nearly half of the population still eke out an existence below the poverty line and income inequality is amongst the highest in the world. More than half of all households are afflicted by food insecurity, mainly as a result of income poverty, while at least a quarter of the population experiences outright hunger. The most vulnerable groups are the urban poor, the landless rural poor and households who have members suffering from HIV/AIDS. Urban settlements are characterised by car-dependent urban sprawl, and many high-density informal settlements are located far from job opportunities and community services. Immigration and inter-provincial migration compound the pressures in densely populated informal settlements. These various social ills contribute to high levels of crime, sporadic protests over inadequate service delivery, and occasional outbreaks of xenophobic violence. All in all, the prevailing social conditions render the majority of South Africa's population very vulnerable to the economic impacts of global oil depletion.

The five subsystems discussed above are intricately connected by many linkages and feedbacks, which in many ways intensify the dependencies on oil and magnify the vulnerabilities to oil shocks.

7.1.4 Socioeconomic impacts under business-as-usual will be severe

Chapter 4 investigated the likely socioeconomic impacts on South Africa of the looming peak and decline in world oil production, under business-as-usual policies. Specifically, it was assumed that no effective mitigation had been undertaken by foreign governments or by the South African government. World oil exports were assumed to decline by 5% per annum, and oil prices were anticipated to follow a rising trend but with heightened volatility. The conventional economics perspective highlights the short- to medium-term macroeconomic consequences of oil price shocks, most of which are expected to be negative. The ecological economics perspective emphasizes in addition the impacts of declining oil availability and physical fuel shortages, which implies that there will be less and less energy to perform useful work in the economy.

The review of historical experience and various empirical estimates of the impact of oil shocks on South Africa are broadly consistent. They demonstrate that crude oil price shocks generally result in: a rise in the oil import bill; a boost for some export commodities such as coal and gold, at least initially, but a decline in other exports as world demand contracts; flight of short-term capital; a depreciation of the rand exchange rate; higher rates of producer and consumer price inflation; lower (or negative) growth in real GDP; falling employment and real wages; and greater poverty and inequality. The sectors most adversely affected include agriculture, light manufacturing and private services, while the sectors benefitting most in relative terms are domestic synthetic fuels, electricity, and coal and gold mining. It appears that the indirect impacts of oil shocks via the global economy are possibly more significant than the direct impact of higher fuel prices. It was also established that demand for petroleum fuels has historically been more responsive to income than to price, especially in the case of diesel.

Based on this empirical background, two scenarios were developed for the impacts of world oil depletion on South Africa. The first scenario envisages a gradual economic contraction that results from progressively rising oil prices and consequently falling demand for oil imports. In the absence of proactive mitigation, this translates into rising costs of transport and impaired mobility, which has knock-on economic and social consequences. Farmers experience rising input costs and over time those that are less able to adapt face bankruptcy, which gradually undermines national food security. Gross domestic product could contract by about 2% per annum on average, although there are likely to be cycles of recession followed by partial recoveries. A growing number of households and businesses face liquidation as they cannot repay their debts. The rising cost of living, together with job losses, results in a mounting incidence and depth of poverty, rising income inequality and deteriorating household food security. These worsening economic conditions are likely to breed social protests and possibly increased crime and violence.

The second scenario recognises the complex interdependencies and interactions among several critical infrastructural and logistical systems such as electricity, transport, financial, supply chain, information and communication technology, and food production and distribution systems. These inter-linkages imply that a serious disruption in one system could catalyse a cascading, systemic collapse in several critical systems. Examples of possible triggers include a sudden, severe shortage of liquid fuels (for instance if there is a war involving Iran) or a contagious international financial crisis. Collapse could also occur as a result of threshold effects, for example a cumulative lack of maintenance of energy and transport infrastructure and a shortage of road-delivered coal stocks at power stations (as occurred in 2008). Collapse in the financial or electricity system would very quickly lead to widespread hunger and social chaos.

The chapter then discussed several possible national responses to the global oil depletion problem. First, it was concluded that predatory nationalism, i.e. the seizure by force of neighbouring countries' fossil fuel resources, is unlikely to be a feasible option for South Africa given the limitations of its military's force projection capabilities and the strategic interest of large foreign powers in the region. Conversely, South Africa's mineral resources might become a target for intervention or acquisition by foreign powers such as the US or China. Second, despite the current democratic dispensation, it is possible that political and economic elites might impose a totalitarian retrenchment on the general population, condemning large sections of the population to sink deeper into poverty and ultimately starvation. A third possibility is nationalistic populism, but as shown by the recent Zimbabwean experience this would in all likelihood have disastrous economic repercussions. Fourth, in a systemic economic collapse scenario centralised government might progressively lose its ability to govern effectively, resulting in a fragmentation of society into conflicting ethnic groupings, possibly punctuated by lifeboat communities that attempt to preserve aspects of contemporary culture. Lastly, civil society might lead a socioeconomic adaptation response through cooperation, sharing, and localised initiatives to boost resilience in the face of declining energy availability. The following chapter considered a proactive response by government to mitigate oil scarcity and adapt to economic shocks.

7.1.5 Mitigation policies can gradually decouple economic activity from oil use

The economic and social threats posed by global oil depletion call for proactive policy responses by government. This pragmatic rationale is underpinned theoretically by the ecological economics paradigm, which recognises pervasive market failures and the importance of applying the precautionary principle, i.e. taking steps to reduce the risk of serious calamities. The need for mitigation, adaptation and enhancing societal resilience is further motivated by the South African government's commitment to building a developmental state and its vision for sustainable development. However, current government policy in all sectors and at all levels largely ignores the issue of global oil depletion and its implications. Mitigation aims to proactively lessen the future impact of oil scarcity and price shocks by reducing reliance on imported oil, both by developing viable energy substitutes and by curtailing demand for oil through conservation and efficiency initiatives. Adaptation implies coping with rising oil prices and later with declining oil supplies. If mitigation is delayed too long, it will by default give way to more costly adaptation. Building societal resilience requires measures to boost energy security, food security, macroeconomic stability and social cohesion in the face of oil-related economic shocks. As discussed in Chapter 1, there are broadly speaking three means to achieve these goals, namely market-based incentives, government regulations, and public education and awareness campaigns. These three approaches need to be used in the areas of energy, transport, agriculture, macro-economy and society more generally.

In terms of alternative energy supplies, the most sustainable option is to massively scale up renewable energy investments, especially in solar and wind power (bearing in mind that this must happen in conjunction with a progressive electrification of the transport system, as discussed below). Biodiesel produced on a small, local scale may play a small but critical role in providing fuel mainly for agricultural machinery. Although South African companies are world leaders in coal-to-liquid and gas-to-liquid technologies, these fuel options are inherently energy inefficient and have serious negative environmental impacts, notably in terms of greenhouse gas emissions and water usage and pollution. Conventional nuclear power has very high up-front capital and decommissioning costs, takes many years to plan and build, relies on a finite and depleting feedstock, and has unresolved problems of radioactive waste disposal and contamination risks. Given that the EROI of coal appears to be much higher than for virtually any other energy source at present (with the possible exception of hydro-electricity, whose large-scale potential in South Africa is already utilised), South African society must weigh very carefully how it uses its remaining endowment of coal. This is especially so considering recent research which indicates that national coal production could peak by 2020. Since the future may not deliver energy sources with comparably large net energy surpluses and EROI as coal, inter-generational equity concerns suggest that the current generation should not seek to increase the rate at which it burns these limited coal resources. Society needs to use its remaining coal reserves (and/or ‘carbon budget’) to support the development of sustainable technologies and infrastructures. In addition to developing sustainable energy supplies, energy conservation and improved efficiency are vital for enhancing energy security and boosting sustainability.

In the transport sector, curtailment and efficiency are the quickest and cheapest options for reducing oil dependency. A combination of eco-driving campaigns, improved traffic management, car-pooling, telecommuting, flexible work schedules, fiscal incentives, and fuel rationing schemes can substantially reduce demand for petroleum fuels. However, these measures need to be supplemented by supply side alternatives to ensure sustainable mobility for the long term. Most importantly, this will entail the progressive electrification of the transport system through increased use of grid-connected vehicles and stand-alone electric vehicles. Vehicle energy efficiency can be improved through advanced design and alternative propulsion systems. However, more important are modal shifts away from cars, airplanes and trucks towards mass public transit, safe non-motorised transport, and freight rail.

Given its extensive dependence on diesel and other petroleum-based inputs, and its vital role in national food security, the agriculture sector should in the short- to medium term receive government support to cope with oil price shocks and growing fuel scarcity. This support could be in the form of subsidies and priority fuel allocations in times of shortage. However, financial support must be linked to a programme aimed to gradually phase out the use of petroleum products and undertake a transition to agro-ecological farming practices. Such agro-ecological methods will likely involve smaller scale farms and higher labour intensity of production. Emerging farmers will need training assistance and the land reform process will need to be accelerated and managed very carefully so as not to undermine food production. Finally, since the current food distribution system is heavily reliant on road transport, the mitigation strategy should aim towards a gradual localisation of agricultural production and consumption.

Macroeconomic policy must recognise that oil depletion implies and necessitates a fundamental economic restructuring towards greater localisation and greening of the economy across all sectors. Fiscal policy is a vital tool for shifting economic incentives to promote sustainability and resilience. A windfall tax on domestically produced synthetic fuels would allow resource rents to be spent on sustainable energy and transport infrastructure. The Reserve Bank should allow a moderate increase in the inflation rate as a way of enabling relative prices to adjust less painfully, for debts to be reduced, and to prevent high interest rates from causing a collapse in property values and a rise in business liquidations. Ultimately, the monetary system needs to be reformed as the debt-based, interest-bearing system is incompatible with long-term sustainable development. Trade and industrial policy should assume a gradual unwinding of globalisation (as applied to trade in physical goods), prepare for disruptions to global value chains, and support sustainable local industries. Labour market policy should facilitate a change in the workforce away from energy-intensive industries towards green industries such as renewable energy, bicycle and electric scooter manufacture, repair and maintenance, organic farming, etc.

A range of policies and measures will be required to protect the most vulnerable members of society and to maintain social cohesion in the face of economic shocks. Community resilience can be enhanced through the adoption of fuel rationing systems, economic localisation initiatives, formation of community banks and local currencies, and expansion of labour absorbing initiatives such as the Community Work Programme. Spatial planning should urgently recognise future oil scarcity and restrictions on mobility, and therefore prioritise densification around public transport networks in urban areas, and sustainable development based on land reform and skill acquisition in rural areas.

This dissertation assumes, conservatively but arguably realistically given the lack of international action to date, that the rest of the world will not adequately mitigate declining world oil production; therefore South Africa will have to mitigate the impacts for itself. However, for both moral and pragmatic reasons, South Africa should lead by example on the international stage (much as it did with the democratic political transition in 1994), for example by proposing the adoption of the Oil Depletion Protocol (as discussed in Section 5.1.3). Domestic mitigation efforts will generally be easier if other countries are following suit, as oil price spikes would be moderated and there would be greater R&D investment in alternatives to oil.

7.1.6 Peaking world oil production necessitates a managed transition to sustainability

Chapter 5 made it clear that technological solutions in the areas of energy and transport are necessary but not sufficient; adequate mitigation of global oil depletion requires a comprehensive set of responses covering the economy and society as a whole. Chapter 6 situated these policy responses within the literature on societal transition. This transition perspective permits the framing of the peak and decline in world oil production as a catalyst for an epochal shift from the industrial socio-metabolic regime to a 'sustainable' regime that is based on renewable sources of energy. Because of its wide-ranging macroeconomic and cross-sectoral impacts, global oil depletion will serve as a catalyst for a sustainability transition that filters down to virtually all nested socio-technical regimes within the industrial meta-regime. This transition will affect all aspects of society, including technological, infrastructural, political and economic systems, as well as culture, institutions and behaviours.

The prospects for a successful transition will be enhanced by purposive governance by a developmental state which actively manages incentives, regulations and public education in pursuit of sustainability. A South African developmental state must fulfil certain political, institutional, organisational and human resource conditions, and must overcome obstacles such as institutional weakness, the resource curse, corruption, and the need for nation-building in the face of stark inequalities. A key aspect of purposive transition management is support for sustainability-oriented innovations, which can take the form of technological, institutional, organisational and relational innovations. These innovations mostly occur at a niche level but require support to break the dominance of incumbent socio-technical regimes. The need for conscious and concerted effort by social actors and governments is further motivated by historical evidence which shows that past energy and transport transitions or revolutions have taken several decades at least.

A positive vision for a future sustainable society can help to guide an intentional transition process. Aspects of such a vision for South Africa are contained in the National Framework for Sustainable Development, but this needs to be augmented by an extrapolation of the policies and strategies discussed in Chapter 5 to cater for oil depletion. By about 2050, the fossil fuel era would have largely drawn to a close. Instead, energy supply would be derived from a diverse, localised and decentralised mix of renewable energy sources. The decentralisation of energy production would in turn erode hierarchical structures of political power, since groups would no longer be able to gain monopoly control over concentrated stocks of energy. The transport system would largely be electrified, aside from limited use of biofuels in key areas such as farming and aviation. Agro-ecological farming production would be based on locally available bio-resources and be more labour-intensive. Economic activity would have undergone a process of re-localisation, and would be facilitated through the use of locally-based by interconnected monetary systems whose design makes them more equitable and ecologically sustainable. Global oil depletion can be viewed in a positive light as presenting an opportunity to change society for the better in various ways, including: mitigating climate change; achieving greater social equity; stabilising the human population; reducing environmental degradation resulting from resource exploitation; and stimulating values such as cooperation and sharing. Such opportunities will not bear fruit automatically, but will depend on conscious choices.

The formulation and implementation of an oil independence transition action plan would help to steer South African society in the direction of a desirable sustainable future. The government should appoint a National Oil Independence Task Team to develop through a consultative process a National Transition Action Plan. This plan must be commensurate with the government's National Climate Change Response Policy and integrated with other policies in all spheres and across all sectors of government. The plan should aim to systematically reduce the country's oil dependence in order to achieve complete oil import independence within about 40 years, based on a target for an annual reduction in petroleum consumption of about 5% per annum. Short term planning and implementation (i.e. one to two years) should focus on a national education and awareness programme to properly inform all sectors of society of the need to reduce petroleum consumption, and the formulation of contingency plans to deal with sudden and severe constraints on petroleum imports. Medium term initiatives should aim to encourage consumers and producers to reduce oil consumption through the use of appropriate regulations and fiscal incentives. Long term strategies would involve new infrastructure investments for sustainable energy and transport. The oil independence plan should be treated as urgent because delay will be financially costly and will raise the risk of harmful socioeconomic impacts and possibly even systemic collapse.

Nevertheless, it is important to recognise that there are many potential obstacles and risks facing the implementation of a transition plan. These barriers imply several jointly necessary but individually insufficient conditions for a successful transition to sustainability, namely: ideological transformation to real sustainability thinking based on sound ecological-economic principles; political will and bold leadership; an effective, well capacitated developmental state that prioritises sustainability-oriented innovations; business and community cooperation and leadership within their spheres of influence; long-term relative decoupling of energy use from economic activity through increased resource productivity; and overcoming vested interests and socio-technical lock-in. The recent adoption of the National Climate Change Response Policy shows that sufficient political will can be mustered, and pressure from vested interests overcome, to introduce a major policy shift with significant implications for broad structural economic change. The real test, however, lies in successful implementation.

It is worth noting that mitigation of peak oil in a developing country context such as South Africa is arguably less politically and morally contentious than mitigation of climate change. For developing countries the goal of mitigating climate change, specifically by reducing greenhouse gas emissions from the combustion of fossil fuels, is often regarded as inimical to the objectives of socio-economic development and poverty alleviation (at least for the current generation). The main reason given for this viewpoint is that fossil fuels are cheaper than alternative energy sources and thereby allow more rapid and extensive industrialisation. In contrast, mitigation of global oil depletion does not involve forgoing a cheaper industrialisation path, or deliberately retarding economic growth (aside perhaps from the very short term as resources are reallocated to reduce oil dependency). Furthermore, many of the peak oil mitigation strategies and policies advocated in Chapter 5 are expressly designed to ameliorate the negative impacts of oil depletion on poverty, employment and human wellbeing. Thus the State has a clear moral and constitutional obligation to mitigate global oil depletion, to limit its detrimental societal impacts and avoid economic and social collapse.

Nonetheless, one possible strategic response to peak oil that the South African government might consider, namely to pursue a coal-to-liquids intensive mitigation path, could be ethically and politically contentious. A CTL intensive strategy, whereby the government would give policy and financial support to expanded CTL production aimed at making South Africa self-sufficient in liquid fuels, would on the face of it bring several advantages. It would build on existing technological expertise (in Sasol and PetroSA), rely largely on domestic resources (coal), and serve to preserve the status quo, both economically and politically, for as long as possible. It could be argued that this would be an efficient use of domestic resources that would give the country time and funds to develop renewable energy and electrified transport infrastructure. The ethical question that such a path raises is related to climate change mitigation, since CTL is a highly carbon-intensive process. The voluminous extra greenhouse gas emissions that would be associated with expanded CTL production could make South Africa an international pariah as the world begins to mitigate and adapt to a warming climate. Economically, such increased emissions could seriously harm this country's export sectors if there were international GHG regulatory regimes such as a cap and trade system or carbon taxes. Therefore this path would likely be one of increasing international isolation, echoing the apartheid era (when CTL technology was first developed). Domestically, the negative environmental and health impacts associated with coal mining and combustion are also important ethical considerations, which involve differential intra- and inter-generational welfare impacts (most benefits accrue diffusely to the current generation of South Africans, while costs are borne disproportionately by local communities and future generations).

Aside from these debates, there are serious pragmatic questions about the feasibility and desirability of a CTL-intensive path. Firstly, the recent studies cited in Section 5.1 that evaluate South Africa's remaining coal reserves and plausible production profiles indicate that there is likely to be increasing competition for coal among expanded CTL, export markets and demand from power utility Eskom. At the very least, this would significantly boost coal feedstock prices, and after a number of years may result in serious physical coal shortages for one of more of these uses. Secondly, as mentioned earlier, water shortages in the Waterberg area could seriously inhibit the exploitation of these coal fields. Finally, pursuing a CTL-intensive path would entrench the nation's lock-in to a mineral and energy intensive development path, with its associated political economy ramifications in terms of increased power for the minerals-energy complex. It would also delay the adoption of renewable energy technologies and squander an opportunity for South Africa to develop domestic RE manufacturing capacity while the rest of the world forges ahead in this growth industry.

7.2 Wider relevance of the research

The significance of this national case study research goes beyond the geographic borders of South Africa and the intellectual boundaries of policy analysis. First, the practical findings and policy recommendations are relevant to much of the world in general, and to oil importing developing countries in particular. Second, the research is relevant to the academic literature on societal transitions and its relationship to the oil depletion literature. Third, the repercussions of global oil depletion also carry implications for economic theory.

In many ways, South Africa represents a microcosm of the world at large. It has an industrial economy with sophisticated agribusiness, mining, petrochemical, manufacturing, and financial service industries, while nearly half the population lives in poverty and at least a quarter suffer from food insecurity. The country is comprised of many different ethnic groups and has a high degree of income and wealth inequality. Furthermore, South Africa is confronted by most of the same challenges that face the world as a whole, such as fossil fuel dependence, water scarcity, and climate change. There are powerful vested interests, especially in the fossil fuel sector and its affiliates. Thus the challenges posed by global oil depletion, as well as the mitigation responses that are called for, are broadly similar for South Africa and the world. Both need to implement policies and measures to decouple economic wellbeing from oil consumption and to insulate themselves from the impacts of oil shocks. Most of the mitigation policies and measures discussed in Chapter 5 are applicable to other net oil importing countries, both industrialised and developing, to a greater or lesser degree depending on their economic structures and energy endowments. Some responses, such as the Cap and Share scheme for limiting carbon emissions and sharing resource rents, can in principle be generalised to the world as a whole.

Global oil depletion has several ramifications for the theory and practicalities of societal transition. Firstly, while much of this literature deals with the need to reduce environmental impacts (including climate change), rising prices and growing shortages of oil will be a major driver for the 'sustainability revolution'. Moreover, the economic fallout from oil depletion could hamper sustainability-oriented investments. Secondly, the peak and decline in world oil production will trigger an epochal transition at the landscape level that will filter down to virtually all nested socio-technical regimes and thereby help to open up opportunities for niche-level innovations. Thirdly, the discussion in Chapter 6 exposed a gulf between the literatures on oil depletion and transition. While the former is generally thin on the role of various types of innovation and the possibilities for decoupling and dematerialisation, the latter does not sufficiently address the depletion of high-quality fossil fuels that have historically delivered massive energy surpluses at rates of energy return well above those of most current alternatives. Thus more engagement is needed between these research groupings on the question of whether technological progress can continue to support current levels of societal complexity as fossil fuels deplete. Fourthly, the somewhat Eurocentric transition literature needs to be augmented with a developing country perspective that takes into account constraints on democratic governance, state capacity, technological sophistication, and access to resources. Finally, oil depletion implies that the socio-metabolic characteristics of industrialised countries are unsustainable and will undergo a radical change in the coming years and decades. Furthermore, developing countries will have to abandon their quest to emulate the fossil fuel based path of industrial development, and instead will need to attempt to leap-frog to a sustainable socio-ecological regime.

The review of the literature on global oil depletion, and the South African case study, carry significant implications for economic theory. It is evident that mainstream (neoclassical) economics is ill equipped methodologically and theoretically to deal realistically with the implications of fossil fuel depletion. In particular, much of contemporary mainstream macroeconomics is essentially obsolete, being implicitly contingent upon cheap and abundant energy and other resources. The study of oil depletion requires a transdisciplinary approach that integrates insights from economics with those of natural sciences such as geology and ecology. Second, the end of the oil age calls for a new paradigm for economics that is based on biophysical principles and recognises the central role of energy in socioeconomic systems (see Hall and Klitgaard, 2006). Ecological economics, augmented with insights from the socioecological systems perspective, addresses both of these requirements. The peak and decline in net energy derived from oil likely heralds the end of conventional economic growth and calls for a new focus on 'sustainability economics' (see Heinberg, 2011). As a corollary, the way that economic activity is measured needs to adapt to reflect the way that economic systems will change. Gross domestic product needs to be revised to reflect ecological realities like resource depletion and waste emissions, and should be supplemented with alternative measures of human wellbeing.

7.3 Issues for further investigation

There is a great need for further research to extend both the depth and the breadth of this dissertation's analysis. Greater depth of investigation is warranted for aspects of both the impacts of and the responses to global oil depletion. While the dissertation largely focused on the macro level, the analysis can be deepened to the meso level (i.e. economic sectors and industries such as construction, manufacturing, retail and tourism) and the micro level (firms, households and individuals). In addition, certain critical issues require further attention, such as national and household food security, and financial stability and monetary system reform. In addition, and engineering systems perspective is needed to drill down further into the technical details of a transition plan. For human settlements and the space economy, a key question to be answered at the local level is whether it would be more economically and socially feasible to build new transport infrastructure for moving people, or rather to relocate the buildings (factories and/or houses) in order to reduce the need for transport and/or locate people closer to arable land. More detailed research is needed on the pros and cons of energy alternatives in the South African context, especially the vital but neglected issue of EROI. Mitigation policies need to be informed by much better data on liquid fuel consumption, in aggregate for the country as a whole, as well as disaggregated by economic sectors and geographical regions. The Department of Energy, in collaboration with Statistics South Africa, must take responsibility for collecting, verifying and publishing such data. There is also a need for more detailed analysis of the lifecycle financial and energy costs and benefits of various mitigation policies; many projects need to be assessed on a geographic-specific basis, which was beyond the scope of this dissertation.

Further research is also required to broaden the analysis to other important aspects of society. First, oil depletion carries significant implications for education and healthcare. Second, environmental implications of declining oil production should be evaluated, such as the implications for pollution, carbon emissions and climate change. While many of the oil mitigation policies are complementary to climate mitigation (e.g. energy conservation and efficiency, and expanding renewable energy), there are notable exceptions such as new coal-to-liquid production and exploitation of shale gas resources. Another crucial topic related to energy is water: could water scarcity be a binding constraint on certain forms of energy production? What is the energy return on water invested? (see Mulder, Hagens & Fisher, 2009). Third, the political economy of transition away from oil needs more attention. For instance, what are the possible political impacts of economic turmoil and intensifying contestation over diminishing or degrading natural resources, and what is the role of civil society movements in bringing about transition? Fourth, various demographic issues should be explored, such as what is a sustainable population size for South Africa and how might oil depletion impact on birth and death rates via its impact on health and the economy? Fifth, the psychological and cultural impacts and responses to the changes wrought by oil depletion are likely to be massive. Will people react with denial, despair or action? Will individuals and communities compete with each other in an attempt to maintain their lifestyles, or will there be a shift in values towards cooperation, sharing and sufficiency? Lastly, what are the implications for the Southern African region, both in terms of inter-connected impacts and the need for co-ordinated mitigation and adaptation strategies?

Notwithstanding these many areas for further research, the gravity of the oil depletion challenge suggests that mitigation should not be delayed. The inevitable decline in world oil production is imminent and has profound global and national implications for human society. Mitigation is desirable and possible with many known technological and institutional innovations, but the longer interventions are delayed the more difficult and costly they are likely to become. The risks of inaction far outweigh the risks of informed action. It is hoped that this dissertation has provided a compelling argument and sound launching pad for concerted action to accelerate the transition to a sustainable South African society.

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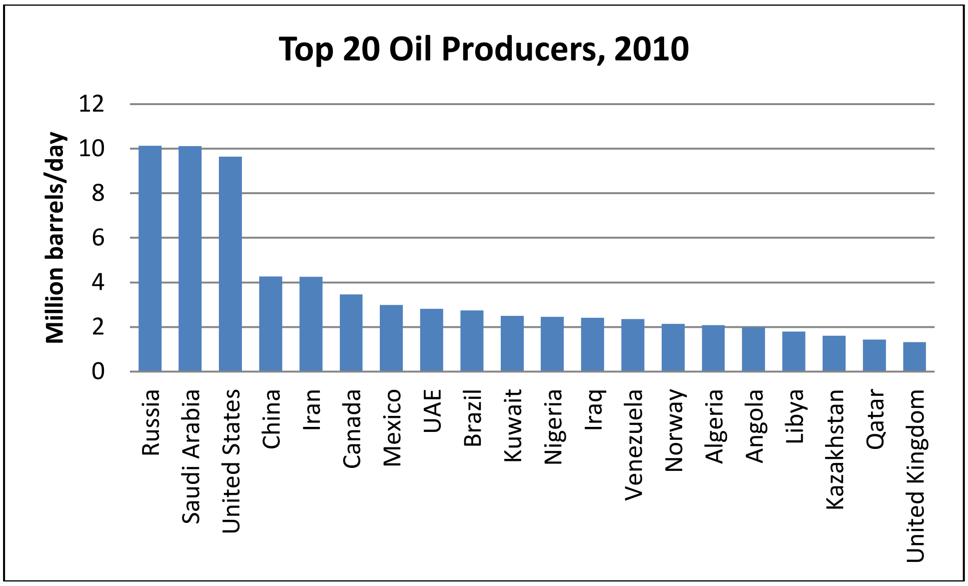
Appendices

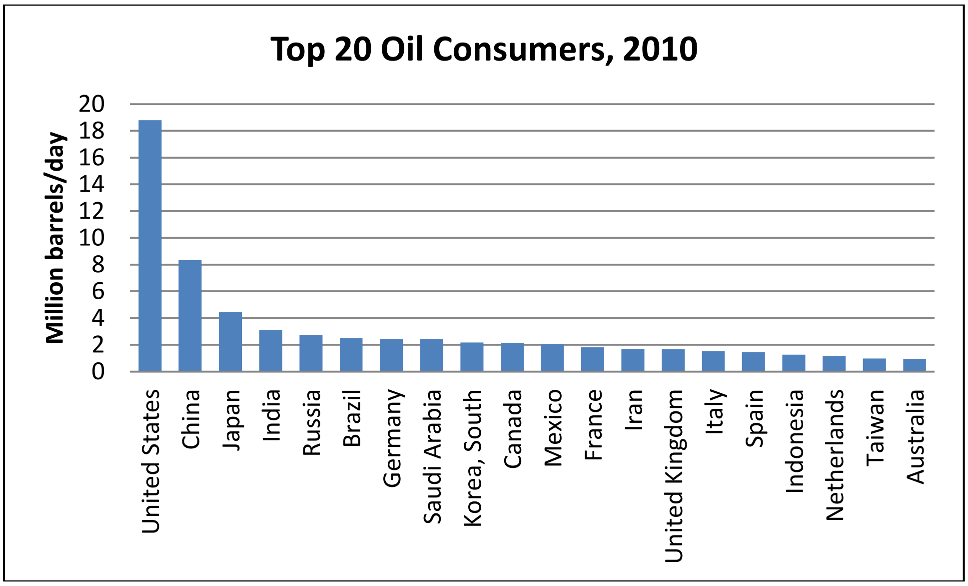
Appendix A: World oil statistics

Figure A 1: World's top 20 oil producers, 2010



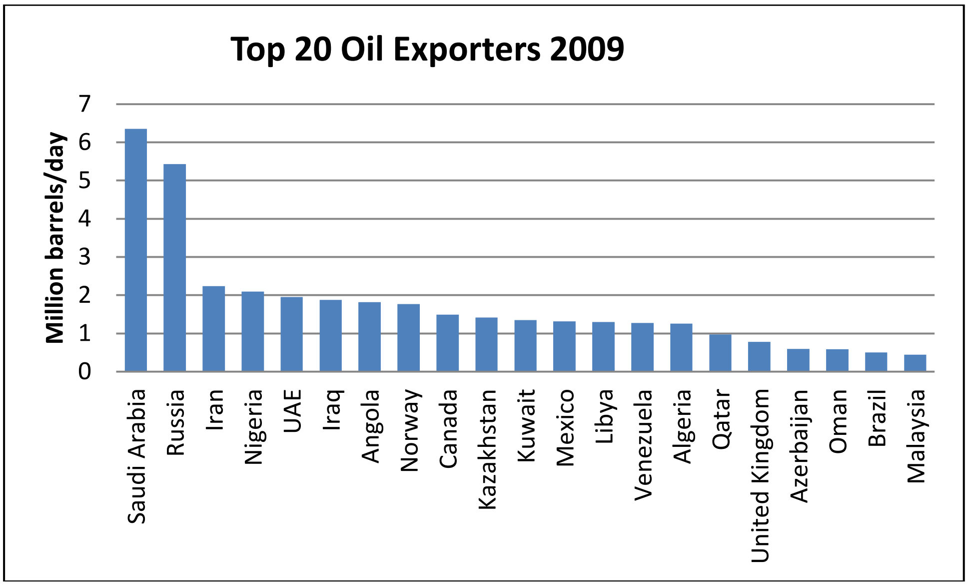
Source: EIA (2011a)

Figure A 2: World's top 20 oil consumers, 2010



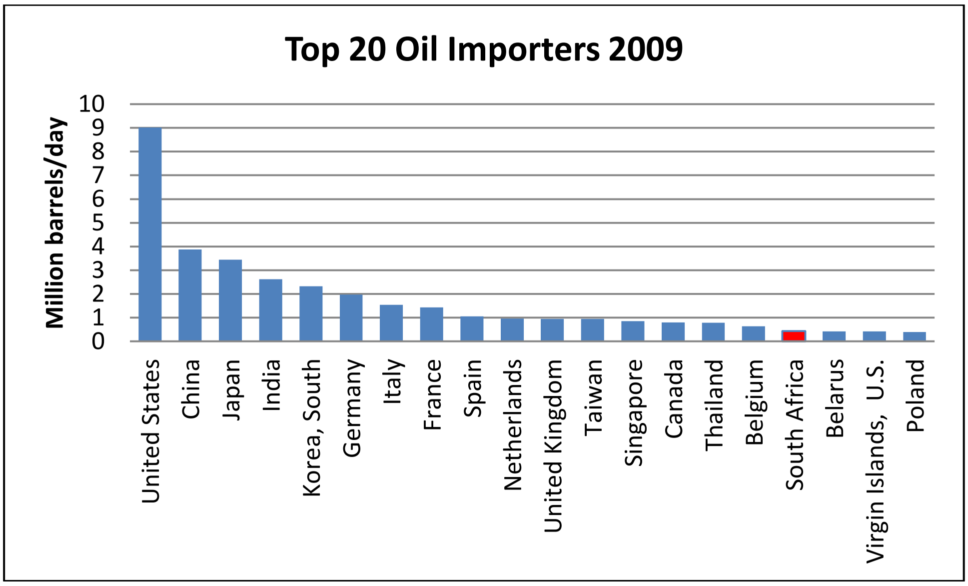
Source: EIA (2011a)

Figure A 3: World's top 20 oil exporters, 2009



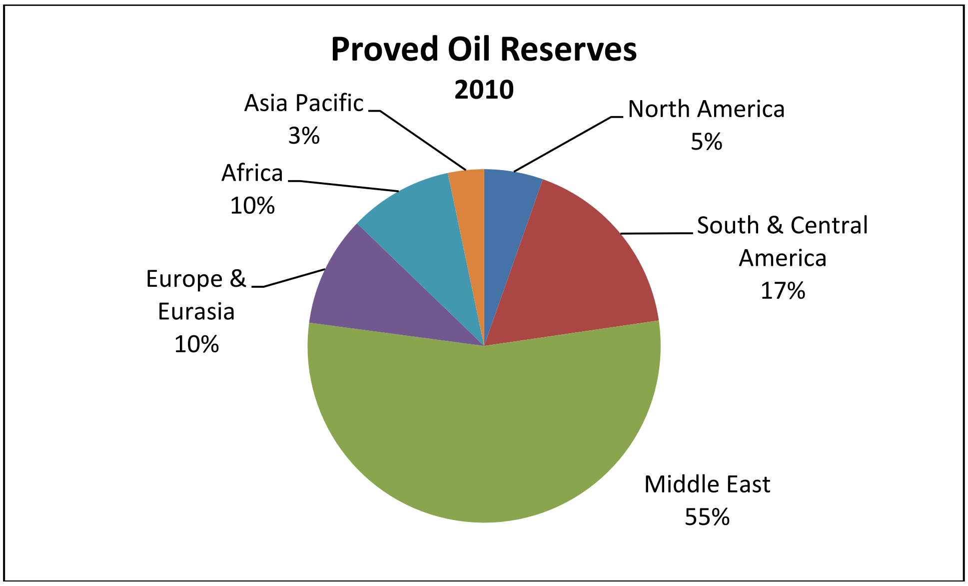
Source: EIA (2011a)

Figure A 4: World's top 20 oil importers, 2009



Source: EIA (2011a)

Figure A 5: Proved oil reserves by region, 2010



Source: BP (2011)

Table A 1: Oil producing countries past peak production (2010)

Country	Peak year	Peak rate (mbpd)
Russia	1987	11.5
United States	1970	11.3
Iran	1974	6.06
Mexico	2004	3.82
Venezuela	1970	3.75
Iraq	1979	3.49
Norway	2001	3.42
Libya	1970	3.36
Kuwait	1972	3.34
United Kingdom	1999	2.91
Indonesia	1979	1.69
Oman	2001	0.96
Egypt	1993	0.95
Argentina	1998	0.89
Columbia	1999	0.84
Australia	2000	0.81
Syria	1995	0.60
Yemen	2002	0.46
Vietnam	2004	0.43
Denmark	2004	0.39
Gabon	1997	0.37
Romania	1976	0.30
Trinidad & Tobago	1978	0.28
Brunei	1979	0.26
Peru	1982	0.20
Uzbekistan	1999	0.19
Cameroon	1985	0.18
Tunisia	1984	0.12

Source: BP (2011) and ASPO-USA (2011)

Appendix B: Historical timeline of South African oil industry developments

Table A 2: Historical timeline of South African oil industry developments

Year	Development
1950	Sasol (Pty) Limited established by Industrial Development Corporation
1954	Mobil refinery commissioned at Durban
1955	Sasol 1 commissioned at Sasolburg
1963	SAPREF refinery commissioned in Durban – joint venture between Shell and BP
1964	Creation of the Strategic Fuel Fund (SFF) to manage strategic stocks
1965	Refined fuels pipeline commissioned by South African Railways & Harbours (SAR&H) from Durban to Johannesburg via Sasolburg
1965	Soekor established by IDC and government to explore for oil and gas
1966	CALREF refinery commissioned in Cape Town – Caltex
1967	Crude oil pipeline commissioned by SAR&H from Durban to Johannesburg via Sasolburg
1967	Government began a project to build strategic crude oil stocks at disused coal mines at Ogies
1969	NATREF company formed between Sasol, Total and National Iranian Oil Company (NIOC)
1971	NATREF refinery commissioned in Sasolburg
1973	SAR&H commissioned a new dedicated pipeline to transport Natref's jetfuel to the Johannesburg International Airport
1977	UN imposed mandatory crude oil sanctions on South Africa
1977	Central Energy Fund (CEF) established, incorporating SFF
1978	Refined fuel pipeline commissioned by SAR&H from Durban to Alrode via Secunda
1979	Sasol purchased NIOC shares of NATREF and becomes majority shareholder
1979	Sasol privatised and listed on the JSE
1980	Sasol 2 commissioned at Secunda
1982	Sasol 3 commissioned at Secunda
1986	Government commenced planning for a new alternative synthetic fuel plant
1989	Mobil sold its SA assets to Gencor, which formed Engen (incorporating Trek)
1992	Mossgas GTL refinery commissioned in Mossel Bay
1993	UN crude oil sanctions lifted
1995	Petronet converts Alrode pipeline for methane rich gas, from Secunda to Durban
2001	Soekor and Mossgas consolidated to form PetroSA, as a wholly-owned subsidiary of CEF
2000s	Sasol 1 at Sasolburg converted to produce only petrochemical feedstocks
2000s	Strategic oil stockpiles at Ogies sold to Natref
2003	Sasol terminates 'Upliftment Agreement' and enters retail market
2006	Sasol begins pre-feasibility studies on Mafutha CTL project at Waterberg
2008	PetroSA begins feasibility studies into Mthombo refinery at Coega
2010	Multi-product pipeline from Durban to Johannesburg under construction by Transnet Pipelines

Source: Adapted from Rustomjee et al. (2007)

Appendix C: South African oil data

Oil and petroleum data for South Africa reveal inconsistencies between various sources. During the Apartheid era up until 1993, oil data were kept as a State secret and had to be estimated by international data agencies, which could explain some of the discrepancies (see Table A 3). However, despite the oil industry being declassified from 1994, some data discrepancies have persisted.

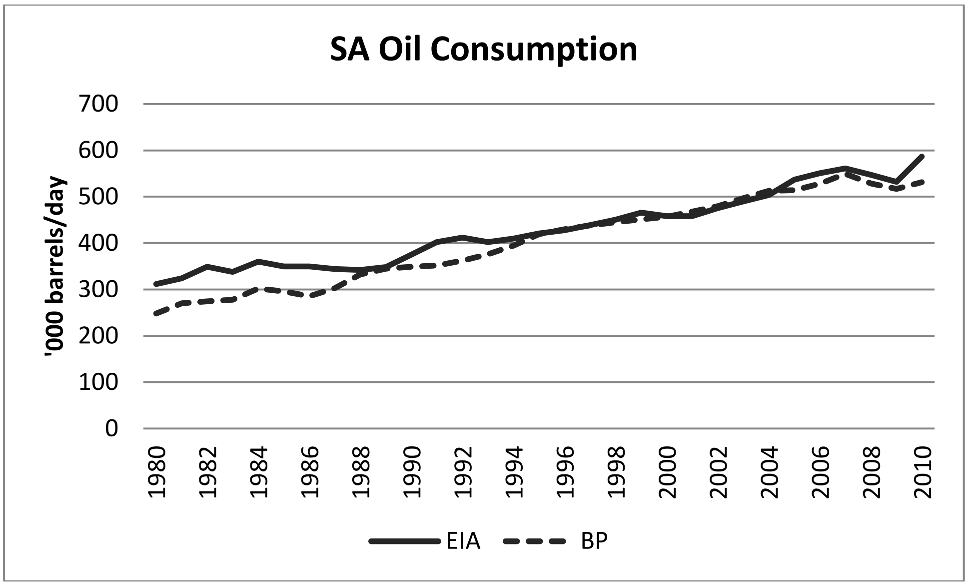
Table A 3: South African crude oil and refined petroleum data

Source	EIA	EIA	BP	EIA	EIA	EIA	EIA
Unit	kbpd	kbpd	kbpd	kbpd	kbpd	kbpd	kbpd
Year	Production	Consump-tion	Consump-tion	Imports (crude)	Exports (crude)	Imports (refined petroleum)	Exports (refined petroleum)
1980	100	312	248	-	-	-	-
1981	100	324	270	-	-	-	-
1982	150	349	275	-	-	-	-
1983	150	338	278	-	-	-	-
1984	150	360	302	-	-	-	-
1985	150	350	296	-	-	-	-
1986	150	350	285	250	0	8	20
1987	150	345	303	280	0	10	10
1988	150	342	332	280	0	10	10
1989	150	348	345	280	2	15	17
1990	150	375	349	330	0	15	40
1991	150	403	352	330	0	15	17
1992	150	412	362	331	0	16	20
1993	195	402	376	229	0	12	24
1994	195	410	394	240	0	3	17
1995	207	421	420	314	2	7	68
1996	208	428	430	266	0	21	67
1997	210	439	438	252	0	20	50
1998	214	451	445	321	14	20	68
1999	195	466	451	386	29	22	101
2000	202	458	457	365	4	10	117
2001	209	458	468	366	4	10	108
2002	211	475	480	403	4	22	143
2003	202	490	497	465	0	30	201
2004	234	504	513	471	0	31	218
2005	216	537	514	538	4	48	264
2006	202	551	528	443	5	48	124
2007	196	561	549	451	4	85	48
2008	194	547	528	470	6		
2009	192	532	517	436	7		
2010	192	587	531				

Sources: EIA (2011a), BP (2011)

Notes: kbpd = thousand barrels per day; production figures for 1980 to 1992 are estimated as per commissioning of Sasol synfuel plants.

Figure A 6: South African oil consumption, 1980-2010



Source: EIA (2011a) and BP (2011)

Appendix D: Econometric estimates of petrol and diesel demand elasticities

In order to estimate the price and income elasticities of demand for petroleum fuels in South Africa, separate demand functions were specified for petrol and for diesel (see below). The auto-regressive distributed lag (ARDL) estimation technique developed by Pesaran and Shin (1995) was applied to quarterly time series data drawn from SAPIA (2010), SARB (2011) and NAAMSA (2011), using the Microfit 4.0 software package. The econometric procedure begins by testing for cointegration (the existence of long run relationships) based on an ARDL specification with a certain number of lags for each variable. The modified critical F statistics from Pesaran and Pesaran (1997) are used to determine whether or not there is a long-term relationship among the variables, and if so, which variable(s) is (are) the long-run forcing variable(s). If evidence of a long-run relationship is found, then the short-run and long-run ARDL coefficients are estimated for a specification of lag lengths selected by the Schwarz Bayesian criterion and other diagnostic tests.

Demand for petrol

The demand for petrol (LDEMSA) was specified as a function of the real price of petrol (LPRICE), real disposable income of households (LINCOME), and seasonally adjusted new car sales (LCARSSA) as a proxy for the total number of vehicles. All variables were expressed in natural logarithms. The ARDL test for cointegration for four variables, each with four lags, has lower and upper bound critical values of F_l = 3.219 and F_u = 4.378, respectively. With DLDEMSA (demand for petrol) as the dependent variable, the test statistic was F(4, 33) = 4.4614, which enables us to reject the null hypothesis of no long-run relationship (i.e. the variables are cointegrated). However, the tests using each of the other three variables as the dependent variable yielded test statistics less than F_l, implying no long run relationship. Thus, according to Pesaran and Pesaran (1997), LINCOME, LPRICE and LCARSSA can be treated as long-run forcing variables for LDEMSA, i.e. the demand function holds.

Table A 4: ARDL test for cointegration for petrol demand

Dependent variable	Test Statistic F(4, 33)	F_l lower bound	F_u upper bound
DLDEMSA	4.4614	3.219	4.378
DLINCOME	0.7248	3.219	4.378
DLPRICE	1.9113	3.219	4.378
DLCARSSA	2.2675	3.219	4.378

In the next step, an ARDL(3,0,0,0) model was selected based on the Schwarz Bayesian Criterion; all other diagnostics tests were adequately passed. The estimated long run coefficients were all statistically significant. The signs are as expected (positive for income and cars, and negative for price), and the long run coefficients are larger than the short run coefficients, indicating that full adjustment in demand takes more than one quarter.

Table A 5: Estimated elasticities for petrol demand

Variable	Long run coefficient	Short run coefficient
LINCOME	0.508 (0.123)	0.163 (0.048)
LPRICE	-0.522 (0.123)	-0.167 (0.026)
LCARSSA	0.157 (0.056)	0.050 (0.013)

Note: standard errors in parentheses

Demand for diesel

The demand for diesel (LDEMSA) was specified as a function of the real price of diesel (LPRICE), real seasonally adjusted gross domestic product (LINCOME), and new commercial vehicle sales (LVEH) as a proxy for the total number of vehicles. The ARDL test for cointegration for four variables, each with two lags (more lags were found not to be significant), has lower and upper bound critical values of F_l = 3.219 and F_u = 4.378, respectively. With DLDEMSA (demand for petrol) as the dependent variable, the test statistic fell between the lower and upper bounds, indicating that the test is indeterminate. The same applies when DLPRICE is the dependent variable. However, the tests using each of the other two variables as the dependent variable yielded test statistics less than F_l, implying no long run relationship. Although these tests are inconclusive, it is assumed that the demand function holds for the second stage of the estimation.

Table A 6: ARDL test for cointegration for diesel demand

Dependent variable	Test Statistic F(4, 43)	F_l lower bound	F_u upper bound
DLDEMSA	3.4610	3.219	4.378
DLINCOME	0.9852	3.219	4.378
DLPRICE	3.1015	3.219	4.378
DLVEH	1.0850	3.219	4.378

In the next step, an ARDL(0,1,0,0) model was selected based on the Schwarz Bayesian Criterion; all other diagnostics tests were adequately passed except the RESET test, and the adjusted R-squared was 0.98. The estimated long run coefficients were all statistically significant. The signs are as expected (positive for income and cars, and negative for price). The short run coefficients for LPRICE and LVEHICLES are same as long run coefficients, i.e. full adjustment in diesel demand occurs within one quarter.

Table A 7: Estimated elasticities for diesel demand

Variable	Long run coefficient	Short run coefficient
LINCOME	1.411 (0.056)	0.938 (0.219)
LPRICE	-0.136 (-0.033)	-0.136 (0.033)
LCARSSA	0.079 (0.021)	0.079 (0.021)

Note: standard errors in parentheses

Appendix E: Oil Depletion Protocol

As drafted by Dr. Colin J. Campbell*

WHEREAS the passage of history has recorded an increasing pace of change, such that the demand for energy has grown rapidly in parallel with the world population over the past two hundred years since the Industrial Revolution;

WHEREAS the energy supply required by the population has come mainly from coal and petroleum, such resources having been formed but rarely in the geological past and being inevitably subject to depletion;

WHEREAS oil provides ninety percent of transport fuel, is essential to trade, and plays a critical role in the agriculture needed to feed the expanding population;

WHEREAS oil is unevenly distributed on the Planet for well-understood geological reasons, with much being concentrated in five countries bordering the Persian Gulf;

WHEREAS all the major productive provinces of the World have been identified with the help of advanced technology and growing geological knowledge, it being now evident that discovery reached a peak in the 1960s, despite technological progress and a diligent search;

WHEREAS the past peak of discovery inevitably leads to a corresponding peak in production during the first decade of the 21st Century, assuming no radical decline in demand;

WHEREAS the onset of the decline of this critical resource affects all aspects of modern life, such having grave political and geopolitical implications;

WHEREAS it is expedient to plan an orderly transition to the new World environment of reduced energy supply, making early provisions to avoid the waste of energy, stimulate the entry of substitute energies, and extend the life of the remaining oil;

WHEREAS it is desirable to meet the challenges so arising in a co-operative and equitable manner, such to address related climate change concerns, economic and financial stability, and the threats of conflicts for access to critical resources.

NOW IT IS PROPOSED THAT

A convention of nations shall be called to consider the issue with a view to agreeing an Accord with the following objectives:

- to avoid profiteering from shortage, such that oil prices may remain in reasonable relationship with production cost;
- to allow poor countries to afford their imports;
- to avoid destabilizing financial flows arising from excessive oil prices;
- to encourage consumers to avoid waste;
- to stimulate the development of alternative energies.

Such an Accord shall have the following outline provisions:

- The world and every nation shall aim to reduce oil consumption by at least the world depletion rate.

- No country shall produce oil at above its present depletion rate.
- No country shall import at above the world depletion rate.
- The depletion rate is defined as annual production as a percent of what is left (reserves plus yet-to-find).
- The preceding provisions refer to regular conventional oil—which category excludes heavy oils with cut-off of 17.5 API, deepwater oil with a cut-off of 500 meters, polar oil, gas liquids from gas fields, tar sands, oil shale, oil from coal, biofuels such as ethanol, etc.

Detailed provisions shall cover the definition of the several categories of oil, exemptions and qualifications, and the scientific procedures for the estimation of Depletion Rate.

The signatory countries shall cooperate in providing information on their reserves, allowing full technical audit, such that the Depletion Rate may be accurately determined.

The signatory countries shall have the right to appeal their assessed Depletion Rate in the event of changed circumstances.

*This text, with slight changes in wording, has elsewhere been published as “The Rimini Protocol” and “The Uppsala Protocol.”

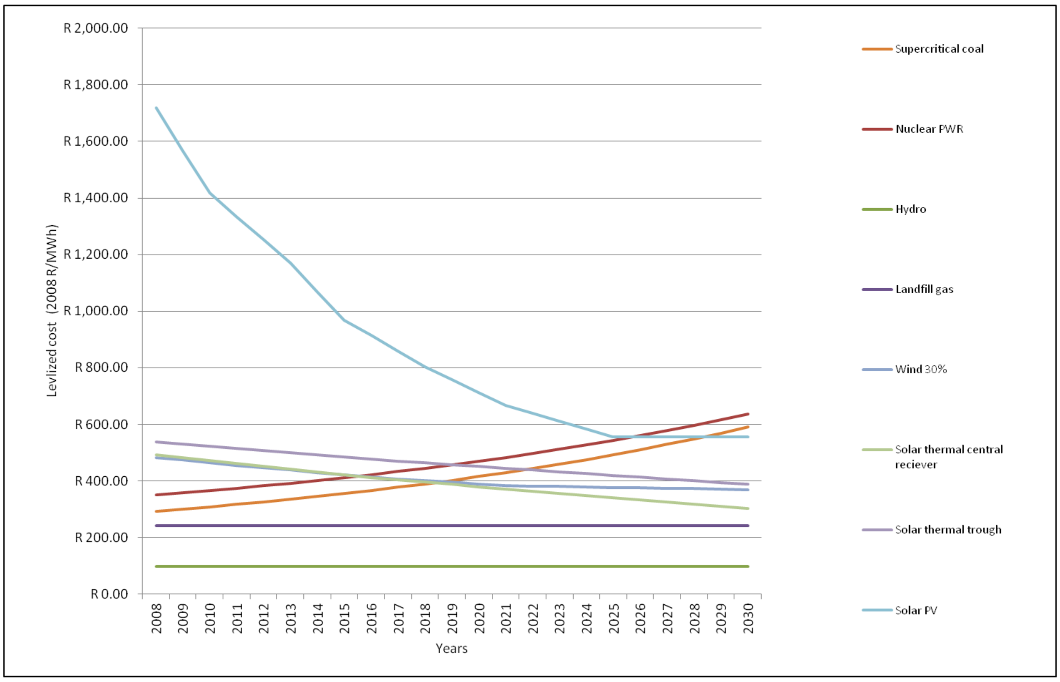
Source: Campbell (2006)

Appendix F: Sensitivity analysis for electricity levelised cost estimates

In Section 5.1.3, levelised cost estimates were presented for a range of energy sources, given a set of assumptions, including a discount rate of 2%. The following two graphs depict cost estimates gained by varying the (real) discount rate to 0.1% and 8%, respectively. The other key assumptions remain the same, namely that fossil fuel and uranium costs rise by 5% per annum and cost-reducing technological learning occurs in solar and wind technologies.

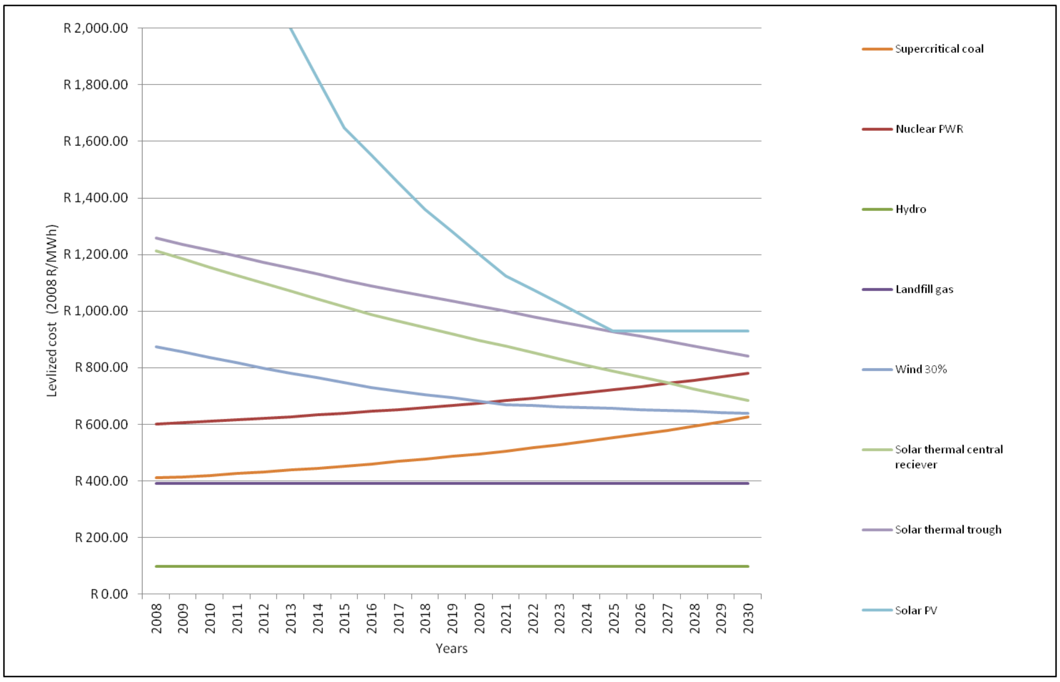
With a lower discount rate of 0.1%, the main difference compared to the baseline scenario (discount rate equals 2%) is that solar PV is less costly to begin with and becomes more competitive than nuclear and supercritical in 2025 and 2028, respectively (see Figure A 7).

Figure A 7: Levelised costs of alternative electricity generation options, discount rate = 0.1%



Source: Author's calculations based on ERC (2010)

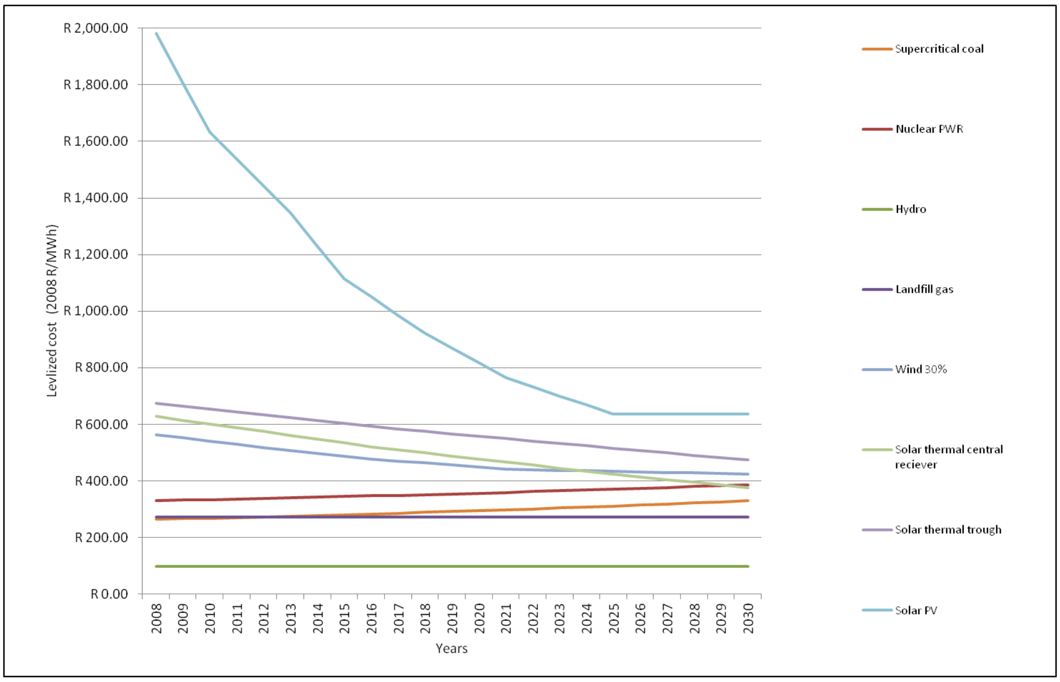
Figure A 8: Levelised costs of alternative electricity generation options, discount rate = 8%



Source: Author's calculations based on ERC (2010)

In the final scenario, the discount rate is again 2%, but fossil fuel and uranium prices increase at just 2.5% per annum, instead of 5% p.a. This means that fuel prices do not quite double by 2030. In this instance, the levelised costs of coal and nuclear power start much lower and remain below those of wind and solar power throughout most of the period.

Figure A 9: Levelised costs of alternative electricity generation options, fuel prices rise 2.5% p.a.



Source: Author's calculations based on ERC (2010)

Appendix G: Transport sector fuel saving scenario assumptions and data

In Section 6.3, a scenario for technically feasible fuel savings in the transport sector is presented. Table A 8 shows the percentages of fuel saved within a particular mode. For example, the second column shows the percentage of passenger road fuel that is saved by car-pooling and travel demand management (TDM) by year. It is assumed to increase by one percentage point per year until it reaches a maximum of 15% of the original fuel consumption by passenger road transport. The mode share percentages of fuel consumption are taken from Table 3-9 in Section 3.2, and sum to 100% horizontally. Table A 9 shows the percentage of *total* transport fuel saved by each measure by year. Additional assumptions are as follows:

- Ecodriving ramps up to 5% but phases out later as BEVs and mass transit replace ICEVs.
- Alternative vehicles (BEVs, HEVs, GCVs) gradually replace ICEVs.
- The existing fleet of airplanes is phase out over 35 years.
- Diesel trains are replaced by electric trains.
- As can be seen, some measures are assumed to be implementable immediately, while others begin after a certain number of years.
- Financial affordability has not been taken into consideration.

Notes:

- P = passenger
- F = freight
- TDM = travel demand management

Table A 8: Transport fuel savings (% of a particular mode)

Type	Passenger						Freight			
Mode	Road				Air		Road		Rail	Air
Share (%)	49.6%				8%		40%		0.4%	2%
Year	car-pooling & TDM	ecodriving	alternative vehicles	modal shifts	tele-commuting	modal shifts	alternative vehicles	modal shift to rail	electrify	modal shift to rail
1	1	1		1	1					
2	2	2		2	2					
3	3	3		3	3					
4	4	4		4	4					
5	5	5	1	5	5					
6	6	5	2	6	6	2	2	1		5
7	7	5	3	7	7	4	4	2		10
8	8	5	4	8	8	6	6	3		15
9	9	5	5	9	9	8	8	4		20
10	10	5	6	10	10	10	10	5		25
11	11	5	7	11	12	12	12	6	5	30
12	12	5	8	12	14	14	14	7	10	35
13	13	5	9	13	16	16	16	8	15	40
14	14	5	10	14	18	18	18	9	20	45
15	15	5	11	15	20	20	20	10	25	50
16	15	4	12	16	22	22	22	12	30	55
17	15	3	13	17	24	24	24	14	35	60
18	15	2	14	18	26	26	26	16	40	65
19	15	1	15	19	28	28	28	18	45	70
20	15	0	16	20	30	30	30	20	50	75

Table A 8 continued

Type	Passenger						Freight			
Mode	Road				Air		Road		Rail	Air
Share (%)	49.6%				8%		40%		0.4%	2%
Year	car-pooling & TDM	ecodriving	alternative vehicles	modal shifts	tele-commuting	modal shifts	alternative vehicles	modal shift to rail	electrify	modal shift to rail
21	15	0	17	22	32	32	32	22	55	80
22	15	0	18	24	34	34	34	24	60	85
23	15	0	19	26	36	36	36	26	65	90
24	15	0	20	28	38	38	38	28	70	95
25	15	0	21	30	40	40	40	30	75	100
26	15	0	22	32	40	42	40	32	80	100
27	15	0	23	34	40	44	40	34	85	100
28	15	0	24	36	40	46	40	36	90	100
29	15	0	25	38	40	48	40	38	95	100
30	15	0	26	40	40	50	40	40	100	100
31	15	0	27	42	40	52	40	42	100	100
32	15	0	28	44	40	54	40	44	100	100
33	15	0	29	46	40	56	40	46	100	100
34	15	0	30	48	40	58	40	48	100	100
35	15	0	31	50	40	60	40	50	100	100
36	15	0	32	50	40	60	40	52	100	100
37	15	0	33	50	40	60	40	54	100	100
38	15	0	34	50	40	60	40	56	100	100
39	15	0	35	50	40	60	40	58	100	100
40	15	0	35	50	40	60	40	60	100	100

Table A 9: Transport fuel savings (% of total by measure and mode)

Type	Passenger						Freight				Total
Mode	Road				Air		Road		Rail	Air	
Share (%)	49.6%				8%		40%		0.40%	2%	100%
Year	P car-pooling & TDM	P ecodriving	P alternative vehicles	P road modal shifts	P air to tele-commuting	P air modal shifts	F road alternative vehicles	F road to rail	F rail electrification	F air to rail	
1	0.5	0.5	0.0	0.5	0.1	0.0	0.0	0.0	0.0	0.0	1.6
2	1.0	1.0	0.0	1.0	0.2	0.0	0.0	0.0	0.0	0.0	3.1
3	1.5	1.5	0.0	1.5	0.2	0.0	0.0	0.0	0.0	0.0	4.7
4	2.0	2.0	0.0	2.0	0.3	0.0	0.0	0.0	0.0	0.0	6.3
5	2.5	2.5	0.5	2.5	0.4	0.0	0.0	0.0	0.0	0.0	8.3
6	3.0	2.5	1.0	3.0	0.5	0.2	0.8	0.4	0.0	0.1	11.4
7	3.5	2.5	1.5	3.5	0.6	0.3	1.6	0.8	0.0	0.2	14.4
8	4.0	2.5	2.0	4.0	0.6	0.5	2.4	1.2	0.0	0.3	17.4
9	4.5	2.5	2.5	4.5	0.7	0.6	3.2	1.6	0.0	0.4	20.4
10	5.0	2.5	3.0	5.0	0.8	0.8	4.0	2.0	0.0	0.5	23.5
11	5.5	2.5	3.5	5.5	1.0	1.0	4.8	2.4	0.0	0.6	26.6
12	6.0	2.5	4.0	6.0	1.1	1.1	5.6	2.8	0.0	0.7	29.7
13	6.4	2.5	4.5	6.4	1.3	1.3	6.4	3.2	0.1	0.8	32.9
14	6.9	2.5	5.0	6.9	1.4	1.4	7.2	3.6	0.1	0.9	36.0
15	7.4	2.5	5.5	7.4	1.6	1.6	8.0	4.0	0.1	1.0	39.1
16	7.4	2.0	6.0	7.9	1.8	1.8	8.8	4.8	0.1	1.1	41.7
17	7.4	1.5	6.4	8.4	1.9	1.9	9.6	5.6	0.1	1.2	44.2
18	7.4	1.0	6.9	8.9	2.1	2.1	10.4	6.4	0.2	1.3	46.7
19	7.4	0.5	7.4	9.4	2.2	2.2	11.2	7.2	0.2	1.4	49.3
20	7.4	0.0	7.9	9.9	2.4	2.4	12.0	8.0	0.2	1.5	51.8

Table A 9 continued

Type	Passenger						Freight				Total
Mode	Road				Air		Road		Rail	Air	
Share (%)	49.6%				8%		40%		0.40%	2%	100%
Year	P car-pooling & TDM	P ecodriving	P alternative vehicles	P road modal shifts	P air to tele-commuting	P air modal shifts	F road alternative vehicles	F road to rail	F rail electrification	F air to rail	
21	7.4	0.0	8.4	10.9	2.6	2.6	12.8	8.8	0.2	1.6	55.3
22	7.4	0.0	8.9	11.9	2.7	2.7	13.6	9.6	0.2	1.7	58.9
23	7.4	0.0	9.4	12.9	2.9	2.9	14.4	10.4	0.3	1.8	62.4
24	7.4	0.0	9.9	13.9	3.0	3.0	15.2	11.2	0.3	1.9	65.9
25	7.4	0.0	10.4	14.9	3.2	3.2	16.0	12.0	0.3	2.0	69.4
26	7.4	0.0	10.9	15.9	3.2	3.4	16.0	12.8	0.3	2.0	71.9
27	7.4	0.0	11.4	16.9	3.2	3.5	16.0	13.6	0.3	2.0	74.4
28	7.4	0.0	11.9	17.9	3.2	3.7	16.0	14.4	0.4	2.0	76.8
29	7.4	0.0	12.4	18.8	3.2	3.8	16.0	15.2	0.4	2.0	79.3
30	7.4	0.0	12.9	19.8	3.2	4.0	16.0	16.0	0.4	2.0	81.8
31	7.4	0.0	13.4	20.8	3.2	4.2	16.0	16.8	0.4	2.0	84.2
32	7.4	0.0	13.9	21.8	3.2	4.3	16.0	17.6	0.4	2.0	86.7
33	7.4	0.0	14.4	22.8	3.2	4.5	16.0	18.4	0.4	2.0	89.1
34	7.4	0.0	14.9	23.8	3.2	4.6	16.0	19.2	0.4	2.0	91.6
35	7.4	0.0	15.4	24.8	3.2	4.8	16.0	20.0	0.4	2.0	94.0
36	7.4	0.0	15.9	24.8	3.2	4.8	16.0	20.8	0.4	2.0	95.3
37	7.4	0.0	16.4	24.8	3.2	4.8	16.0	21.6	0.4	2.0	96.6
38	7.4	0.0	16.9	24.8	3.2	4.8	16.0	22.4	0.4	2.0	97.9
39	7.4	0.0	17.4	24.8	3.2	4.8	16.0	23.2	0.4	2.0	99.2
40	7.4	0.0	17.4	24.8	3.2	4.8	16.0	24.0	0.4	2.0	100.0