# Solar roof tiles: Towards a macro-economic model

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# Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the owner of the copyright thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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# Abstract

The thesis examines whether a residential solar power system (comprising a solar photovoltaic [PV] system and a solar water heater [SWH]), a demand-side option, has a lower life-cycle cost than a coal-fired power plant, a supply-side option, or vice versa. It also investigates whether a million residential solar power systems could potentially replace a 4 800 MW coal-fired power plant in South Africa. The study also explores, should a million solar power systems be installed on residential units, what the total energy output, the equivalent in coal-fired generation capacity, and the comparative costs of the two power systems would be.

The common belief is that solar PV technology is unviable for electricity production because it is too expensive compared to coal-based electricity. Statements such as these are made because the initial capital costs (procurement costs) are often used as the primary (and sometimes only) criterion for project, equipment or system selection based on a simple payback period. Due to life-cycle stages, often the real costs of the project or equipment are not reflected by the upfront capital costs. In this thesis, a methodology is developed to investigate the life-cycle cost effectiveness of a residential solar power system (comprising a 5 kW PV roof tile system and a 300 litre SWH) and a 4 800 MW coal-fired plant in order to choose the most cost effective alternative in terms of the project's functional unit (kWh).

A 5 kW solar PV roof tile system and a 300 litre SWH system have been installed at Lynedoch Eco-village. The operational results from this experiment was used as a basis for developing a model for a million residential rooftops that will have a 5 kW PV roof tile system plus a 300 litre SWH system. The focus of the million rooftops model is operating costs over the lifetime of the solar power system, on the assumption that the capital costs will be financed from coal-fired generation capacity that will no longer be needed.

The results of the study indicate that a residential solar power system is most cost effective over a 40-year life-cycle period in terms of the project's functional unit (kWh). The thesis also finds that a million residential solar power systems (comprising a 5 kW PV system and a 300 litre SWH) could potentially replace 40% of

a 4 800 MW coal-fired generation capacity. In total, 2.3 million residential solar power systems are needed to replace a 4 800 MW coal-fired generation capacity.

Emissions of 37 million tonnes of $CO_2$ equivalent per year could be avoided if 2.3 million residential solar power systems were to be installed. However, the investment needed to install Lynedoch solar power systems (comprising a 5 kW PV roof tile system and a 300 litre SWH) on 2.3 million residential rooftops is fifteen times more than the investment needed to build a 4 800 MW coal-fired power plant. The investment needed to install 2.3 million Lomold residential solar power systems (comprising a 5 kW Lomold PV roof tile system and a 300 litre SWH) is six and half times more than the investment needed for a 4 800 MW coal-fired power plant.

It was established during the study that if Lynedoch residential solar power systems were to be installed on the roofs of a million South African households, 152 308 jobs would be created in the manufacturing and installation supply chain. For the 2.3 million Lynedoch residential solar power systems needed to replace an entire 4 800 MW of coal-fired generation capacity, 340 690 jobs would be created in the manufacturing and installation supply chain. Installation of a million Lomold residential solar power systems would create 63 929 jobs in the supply chain. Installation of 2.3 million Lomold residential solar power systems would essentially create 147 298 jobs.

# Opsomming

Die tesis stel ondersoek in na die vraag of ŉ residensiële sonkragstelsel (bestaande uit ŉ fotovoltaïese (FV) stelsel en ŉ sonwaterverhitter [SWV]), ŉ vraagkant-opsie, ŉ laer lewensikluskoste as ŉ steenkoolkragsentrale, ŉ aanbodkant-opsie, het of omgekeerd. Daar word ook ondersoek of ŉ miljoen residensiële sonkragstelsels potensieel ŉ 4 800 MW-steenkoolkragsentrale in Suid-Afrika kan vervang. Verder word daar ondersoek, indien ŉ miljoen sonkragstelsels op residensiële eenhede aangebring word, wat die totale energie-uitset, die gelykstaande uitset van steenkool-opwekkingskapasiteit en die vergelykende koste van die twee kragstelsels sal wees.

Die algemene oortuiging is dat sonkrag- FV tegnologie ongeskik is vir elektrisiteitsopwekking omdat dit te duur is in vergelyking met steenkoolgebaseerde elektrisiteit. Sodanige stellings word gemaak omdat die aanvanklike kapitaalkoste (aankoopkoste), gegrond op ŉ eenvoudige terugbetalingstydperk, dikwels as die primêre (en soms selfs die enigste) maatstaf tydens die keuse van ŉ projek, toerusting of stelsel dien. Die werklike kostes van ŉ projek of toerusting word egter dikwels nie in kapitaalkostes weerspieël nie, omdat hierdie maatstaf nie totale lewensikluskoste in ag neem nie. In hierdie tesis word ŉ metodologie ontwikkel om die lewensiklus-kostedoeltreffendheid van ŉ residensiële stelsel (bestaande uit ŉ 5 kW FV-dakteëlstelsel en ŉ 300 liter-SWV) en ŉ 4 800 MW-steenkoolkragsentrale te bereken sodat die kostedoeltreffendste opsie in terme van die projek se funksionele eenheid (kWh) gekies kan word.

ŉ Residensiële sonkragstelsel bestaande uit ŉ 5 kW FV-dakteëlstelsel en ŉ 300 liter-SWV is in Lynedoch Eco-village geïnstalleer. Die operasionele resultate van die eksperiment is gebruik as grondslag vir die ontwikkeling van ŉ model vir die installering van ŉ 5 kW sonkrag-FV-dakteëlstelsel en ŉ 300 liter-SWV op ŉ miljoen residensiële dakke. Die fokus van die hierdie model is die operasionele koste oor die leeftyd van die sonkragstelsel, gegrond op die aanname dat die kapitaalkoste gefinansier sal word deur fondse wat nie meer vir die oprig van steenkoolkragsentrales benodig word nie.

Die tesis se bevindinge dui daarop dat ŉ residensiële sonkragstelsel die kostedoeltreffendste is oor ŉ lewensiklustydperk van 40 jaar in terme van die projek se funksionele eenheid (kWh). Daar is ook gevind dat ŉ miljoen residensiële sonkragstelsels (bestaande uit ŉ 5 kW FV-dakteëlstelsel en ŉ 300 liter-SWV) potensieel 40% van ŉ 4 800 MW-steenkoolkragsentrale se kapasiteit kan vervang. Altesaam 2.3 miljoen residensiële sonkragstelsels is nodig om die kapasitiet van ŉ 4 800 MW-steenkoolkragsentrale ten volle te vervang.

Gasvrystelling van 37 miljoen ton $CO_2$-ekwivalent per jaar kan vermy word as 2.3 miljoen residensiële sonkragstelsels geïnstalleer word. Die belegging wat benodig word om Lynedoch-sonkragstelsels (bestaande uit ŉ 5 kW FV-dakteëlstelsel en ŉ 300 liter-SWV) op 2.3 miljoen residensiële dakke te installeer, is egter vyftien keer groter as die belegging wat benodig word om ŉ 4 800 MW-steenkoolkragsentrale te bou. Die belegging wat benodig word om Lomold-residensiële sonkragstelsels (bestaande uit ŉ 5 kW Lomold-FV-dakteëlstelsel en ŉ 300 liter-SWV) te installeer, is ses en ŉ half keer groter as die belegging wat nodig is om ŉ 4 800 MW-steenkoolkragsentrale op te rig.

Die studie het bepaal dat as Lynedoch- residensiële sonkragstelsels op die dakke van ŉ miljoen Suid-Afrikaanse huishoudings geïnstalleer word, 152 308 werksgeleenthede in die vervaardigings- en installeringsaanbodketting geskep sal word. Met die 2.3 miljoen Lynedoch- residensiële sonkragstelsels wat benodig word om ŉ 4 800 MW-steenkoolkragsentrale te vervang, sal 340 690 werksgeleenthede in die vervaardigings- en installeringsaanbodketting geskep word. Die installering van ŉ miljoen Lomold- residensiële sonkragstelsels sal 63 929 werksgeleenthede in die voorsieningsketting skep, terwyl die installering van 2.3 miljoen Lomold- residensiële sonkragstelsels 147 298 werksgeleenthede sal skep.

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## Abbreviations, acronyms and units

| | |
|---|---|
| AC | Alternating current |
| AR4 | IPCC's Fourth Assessment Report |
| ASGISA | Accelerated and Shared Growth Initiative of South Africa |
| BEE | Black economic empowerment |
| BETTA | British Electricity Trading and Transmission Arrangements |
| BFBC | Bubbling fluidised bed combustion |
| CCGT | Combined-cycle gas turbine |
| CCS | Carbon capture storage |
| CDM | Clean Development Mechanism |
| CER | Certified emission reduction |
| CFBC | Circulating fluidised bed combustion |
| CFL | Compact fluorescent light (bulb) |
| CMM | Coal mine methane |
| $CO_2$ | Carbon dioxide |
| $CO_2e$ | Carbon dioxide equivalent |
| CPI | Consumer Price Index |
| CSP | Concentrating solar power |
| CTL | Coal-to-liquid |
| DC | Direct current |
| DEAT | Department of Environmental Affairs and Tourism |
| DG | Distributed generation |
| DME | Department of Minerals and Energy |
| DNI | Direct normal irradiation/insolation |
| DPE | Department of Public Enterprise |
| DSM | Demand side management |
| DST | Department of Science and Technology |
| EE | Energy efficiency |
| EIA | Energy Information Administration |
| EIUG | Energy Intensive User Group |
| EJ | Exajoule ($10^{18}$ Joules) |
| EPC | Engineering, procurement and construction |
| ERC | Energy Research Centre |
| ETS | Emission Trading Scheme |
| EU | European Union |
| EUR | Euro |
| GBP | British pound |
| GDP | Gross domestic product |
| GHG | Greenhouse gas |
| GNP | Gross National Product |
| GTL | Gas-to-liquid |
| GW | Gigawatt |
| GWC | Growth without constraints |

| | |
|---|---|
| GWh | Gigawatt-hour |
| GWth | $GW_{thermal}$ |
| HD | Human development |
| IEA | International Energy Agency |
| IEP | Integrated Energy Plan |
| IGCC | Integrated gasification combined cycle |
| IPCC | International Panel on Climate Change |
| IPP | Independent Power Producer |
| IRR | Internal rate of return |
| ISEP | Integrated strategic electricity planning |
| kW | kilowatt |
| kWh | kilowatt-hour |
| LCCA | Life-cycle cost analysis |
| LTMS | Long-term mitigation scenarios |
| MFA | Material flow analysis |
| MIT | Massachusetts Institute of Technology |
| MTEF | Medium-term expenditure framework |
| Mtoe | Million tonnes of oil equivalent = $4.1868 \times 10^4$ TJ or 11630 GWh |
| MW | Megawatt |
| MWh | Megawatt-hour |
| MWp | Peak megawatt |
| NERSA | National Energy Regulator of South Africa |
| NIRP | National Integrated Resource Plan |
| $NO_x$ | Nitrogen dioxide gases |
| NPV | Net present value |
| O&M | Operation and maintenance |
| OCGT | Open-cycle gas turbine |
| OECD | Organisation of Economic Cooperation and Development |
| OM&R | Operation, maintenance and repair |
| PBMR | Pebble bed modular reactor |
| PF | Pulverised fuel |
| PJ | Petajoule ($10^{15}$ Joules) |
| PPA | Power purchase agreement |
| ppm | parts per million |
| PV | Photovoltaic(s) |
| PV | Present value |
| PVPS | Photovoltaic power systems |
| R&D | Reserach and development |
| RBS | Required by Science |
| RE | Renewable energy / Renewables |
| RECs | Renewable energy certificates |
| REEEP | Renewable Energy and Energy Efficiency Partnership |
| REEF | Renewable Energy and Efficiency Forum |
| REPA | Renewable Energy Purchasing Agency |
| RSA | Republic of South Africa |

| | |
|---|---|
| SBT | Scenario building team |
| SD | Sustainable development |
| SI | Sustainability Institute |
| $SO_x$ | Sulphur dioxide gases |
| STC | Standard test condition |
| SWH | Solar water heater |
| TMR | Total material requirements |
| TWh | Terawatt-hour |
| UCG | Underground coal gasification |
| UK | United Kingdom |
| UNCED | United Nations Conference on Environment and Development |
| UNDP | United Nation Development Programme |
| UNFCCC | United Nations Framework Convention for Climate Change |
| US | United States |
| USD | United States dollar |
| W | Watt |
| WCED | World Conference on Environment and Development |
| WCI | World Coal Institute |
| WEC | World Energy Council |

# Key concepts with definitions

Defining and clarifying key concepts of this study is important and necessary to avoid confusion that could arise from using specific concepts as synonyms, such energy and power, global warming and climate change.

i. Energy

> In our human existence on earth we intuitively realise that something allows us to move around, move objects, heat our bodies and merely stay alive. We need shelter to prevent us from perishing from exposure to hot or cold environments and need to consume food to stay alive. The invisible mysterious entity that allows all these things to happen is called Energy.
>
> (Swanepoel, 2008a)

For the purpose of this study energy shall be defined according to its scientific meaning: Energy is the ability to do work (Swanepoel, 2008a). For the sake of simplicity we will refer to work as moving things around (Swanepoel, 2008). According to Aubrecht (2006), “work done by any force is the product of the force and the distance moved in the direction of the force”. Energy is required to do work, therefore energy is converted into the work that is being done, hence the International System of Units unit for energy and work is the same: Joule (J) (Aubrecht, 2006).

Work = force x distance

= Newton (N) x meter (m)

= Nm

Therefore, Newton-meter (Nm) is also known as Joule (J).

Energy can exist in different forms, but can neither be created nor destroyed. This is one of the fundamental laws of physics, namely the law of conservation of energy, which forms the basis of all reasoning and conclusions in the study of energy (Swanepoel, 2008a). It is, therefore, scientifically incorrect to say that energy is used or consumed (Smit, 2009: 18). For the sake of convenience and understanding the term ‘energy use’ or ‘energy consumption’ will be used in this study.

ii. Power

> An object can possess energy, transfer energy and perform work. In practice the rate at which these processes occur is also important. For example, it requires 98 Joules of energy to lift an object of 1 kilogram through a height of 10 meters. This process can be performed slowly that it takes an hour or it can be performed fast that it takes place in 1 second.
>
> (Swanepoel, 2008a)

The energy transferred by an object to perform work is the same as the work done by that object. The concept of power is therefore defined scientifically as follows: Power is the rate of performing work or energy transfer (Swanepoel, 2008a).

If an amount *W* work is performed in *t* seconds the power is:

Power = $\frac{Work}{time}$ = $\frac{Joule}{second}$ = J/s = Watt (W)

Watt is the SI unit for power. The concept of power is often confused with that of work or energy. A useful relation to remember is:

*Work or Energy = Power (W)* x *Time (s)* (Swanepoel, 2008a; Aubrecht, 2006)

*J = Ws*

In the power generation industry, it is common practice to refer to the unit of electrical energy (the ability of moving charges to perform work) as kilowatt-hour (kWh) (Smit, 2009: 18). In this study kWh will be the main unit of energy used.

*kWh = 3 600 000 J = 3.6 MJ* (Mokheseng, 2008a)

iii. Conventional energy

In the 19th century, scientists developed the concept of thermodynamics and realised that heat can be converted to mechanical work in a device called an engine (Swanepoel, 2008). Sadly though, this invention of engines and machines changed the harmonious existence between humans and their environment that existed for thousands of years. Wood, coal and later oil and natural gas were sources of energy that were used to drive engines. The situation gradually developed to a point where humans suddenly realised that their way of life is totally dependent on the availability of these energy sources (Swanepoel, 2008a), especially fossil fuels (coal, oil and natural gas). Fossil fuels, nuclear energy and large hydro are collectively called conventional energies. In the last 20 years, evidence emerged that the use of conventional energy sources disturbed the natural energy balance of the earth because of the extra heat that has been released and the fact that a byproduct of burning fossil fuels, carbon dioxide ($CO_2$), changes the mechanisms of balancing energy received and radiated from the earth (Swanepoel, 2008a).

iv. Renewable energy

Renewable energy (RE) is derived from sources that are constantly replenished by natural processes such as solar, wind, water, biomass and others. According to Swanepoel (2008a), renewable energy is the energy that does not disturb the natural energy balance of the earth. For example, solar energy can be captured with photovoltaic (PV) cells to be converted into electricity that can be used in households and industry without disturbing the natural flow of energy (Swanepoel, 2008a). Renewable energy technologies do not emit greenhouse gases during their operation in power generation and the use of liquid fuels, and can thus contribute to the sustainability of societies, economies and the environment.

v. Climate change

According to the IPCC's Third and Fourth Assessment Reports, climate change is occurring and will continue to occur even if there is an immediate drastic cut in emissions of global greenhouse gases (IPCC, 2001; IPCC, 2007). The global consensus is that human activities on earth have greater than realised influence on global climate (IPCC, 2007). The knock-on effects of increasing atmospheric temperatures caused by increased concentrations of greenhouse gases in the atmosphere impact upon all aspects of the physical environment, influencing wind and rainfall patterns, ecosystem services, sea level and the frequency of severe weather events (DEADP, 2008: 3; IPCC, 2007). Climate change is a natural phenomenon that has occurred throughout history due to natural processes (geological, biological and cosmological) and it is an expected natural occurrence; however, in recent years climate change has been associated with the induced effect of anthropogenic activities that have increased levels of greenhouse gases in the atmosphere, stimulating an enhanced greenhouse effect, known as global warming (Smit, 2009: 21).

vi. Carbon dioxide ($CO_2$)

Carbon dioxide is a naturally occurring atmospheric gas, and a byproduct of burning fossil fuels. It is the main culprit among greenhouse gases, blamed for stimulating global warming and hence inducing climate change.

vii. Net present value (NPV)

The present value of a future amount of income can be expressed through the following formula: Present Value = (Future Value)/(1 + Discount Rate)$^n$, where the exponent $^n$ is the number of years in the future that the future value will be received. The discount rate is the same as the interest rate. The present value equation follows:

$$PV = \frac{FV}{(1+r)^\wedge n}$$

An income stream is a series of future values. The net present value of an income stream is calculated by adding up the present values of all the items in the income stream.

Note: The abbreviation PV is used in this thesis to refer to both photovoltaic(s) and present value. However, a clear distinction regarding the intended meaning is made whenever it is used.

# Chapter 1 : Introduction

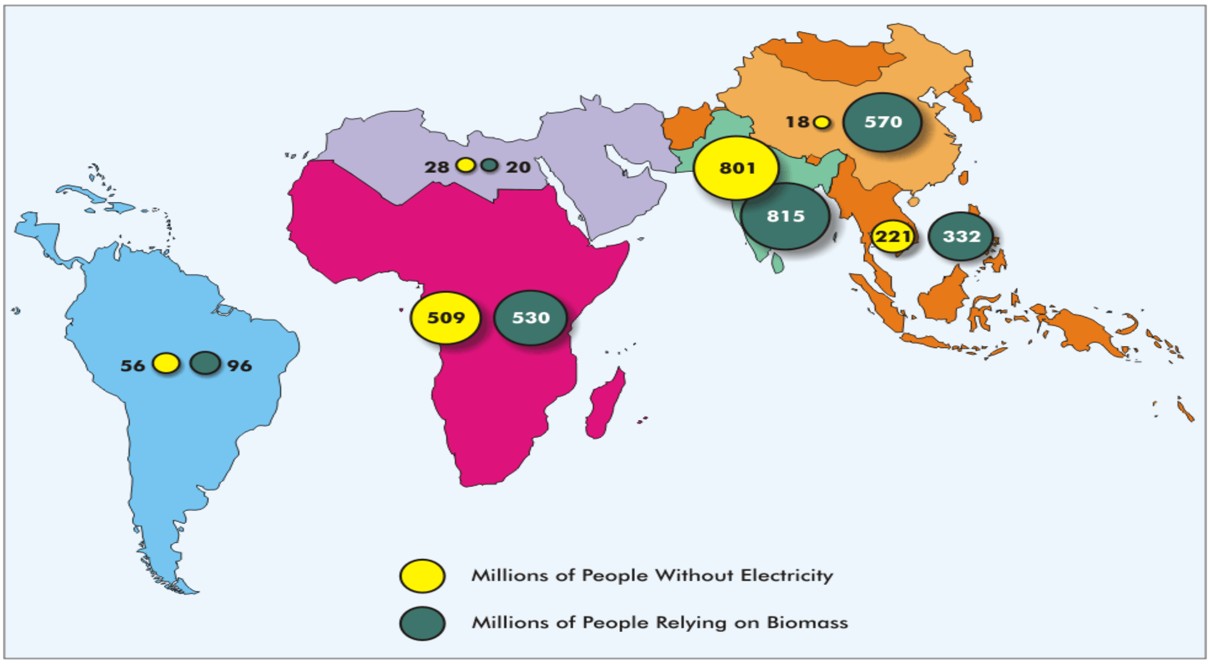
## 1.1 Framing the research problem and study

### 1.1.1 The global energy context

The global human population has increased almost threefold between 1950 and 2008 (UN DESA, 2008, cited in Kelly, 2009: 1). As a result of the continued increase of people over the years, new scarcities had been created, especially in land, water and energy (Mebratu, 1998: 495). Projections indicate that there will be an increase of 50% to around nine billion people living on earth by 2050 (UN DESA, 2008: 1; Kelly, 2009: 1; UNDP, 2007). The significant increase from 5.4 billion to 7.9 billion will occur in the developing countries whilst the population in developed countries will remain constant at 1.2 billion (Smit, 2009: 4). This growth in population numbers simply translates into a need for more energy production and supply. Energy is a vital ingredient for growth and development for the vast majority of economies, particularly emerging economies. Long-term development is contingent on availability of affordable energy (Haw & Hughes, 2007). According to UNDP (2007), "countries with low levels of access to modern energy systems figure predominantly in the low human development group". Every society requires availability of energy to meet its fundamental needs, namely food, drinking water, clothing, housing and sanitation. According to the World Energy Council (2007: 2) and the World Energy Report (2005: 7), global primary energy demand increased by more than 50% since 1980 and this demand is set to continue at an annual average rate of 2% between 2008 and 2050.

It is of concern that this high global energy output has not benefited the majority of the world's population (see Figure 1.1).

**Figure 1.1: Map showing global energy poverty**




Source: IEA (2002)

For example, UNDP (2007) indicates that annual energy consumption per capita in 2004 in highly developed countries, primarily high-income OECD countries, was 10 360 kWh compared to 119 kWh in the least developed countries (Smit, 2009: 4) (see Table 1.1).

**Table 1.1: Regional energy consumption per capita (2004)**

| **Region** | **Energy consumption (kWh/capita)** |
|---|---|
| Least developed countries | 119 |
| Sub-Saharan Africa | 478 |
| South Asia | 628 |
| Developing countries | 1 221 |
| East Asia and the Pacific | 1 599 |
| Arab states | 1 841 |
| Latin America and the Caribbean | 2 043 |
| Central, Eastern Europe and the Commonwealth of Independent States (CIS) | 4 539 |
| Organisation for Economic Cooperation and Development (OECD) | 8 795 |
| High-income OECD | 10 360 |

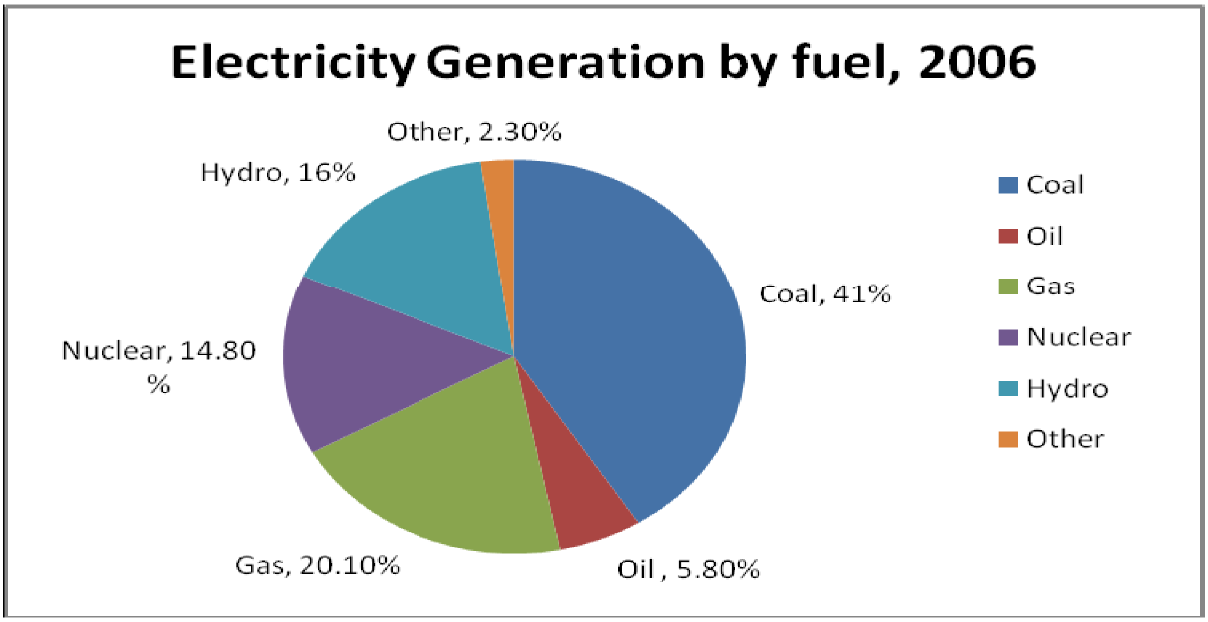
Source: Smit (2009); IEA (2008b)

If it is assumed that the developing world will aspire to achieve the same living standard as the developed world, the developing world will increase its energy consumption (Smit, 2009: 5). As access to affordable energy resources and services improves, the desired energy consumption per capita will jump from 1 221 kWh to 8 795 kWh (IEA, 2008b).

According to the WEC (2007: 2), about 70% of this energy demand will come from emerging economies given the significant increase in population numbers and the desire to improve the standard of living. China alone will account for some 30% of increased global energy demand (WEC, 2007: 2). This increased demand for energy resources will undoubtedly put pressure on an already stressed ecological threshold, which will lead to the collapse of ecosystem services that both human and non-human species depend on for living.

Haw and Hughes (2007: 1) suggest that historically the most used primary energy sources were those nearest and easiest to consume. This led to over-reliance on fossil fuels world-wide; primarily coal, followed by increasing quantities of oil (Haw & Hughes, 2007: 1). Over the past two centuries, the most used primary and secondary sources of energy were solid fuels, mainly coal and petroleum coke. However, these fuels no longer contribute to the final energy consumption in highly developed countries, with the exception of large-scale industrial processes such as aluminium smelting and production of iron, steel and cement (WER, 2005: 19). Coal contributed between 2 300 and 2 500 million tonnes of oil equivalent (Mtoe) to final primary energy consumption by source in 2002 out of a total 10 000 Mtoe (EIA, 2002). Coal, however, has retained its role as a major primary energy source in the electricity generation industry. In 2006, global electricity generation was fuelled predominantly by coal (41%) (see Figure 1.2), followed by natural gas (20.1%), hydro (16%), nuclear (14.8%) and oil (5.8%), while the remaining 2.3% was supplied by both commercially-traded renewable energies and traditionally used technologies (e.g. burning wood, cow dung) (IEA, 2008b: 24, cited in Smit, 2009: 3).

**Figure 1.2: Electricity generation by fuel in 2006**




Source: IEA (2008b, cited in Smit 2009)

Energy is critical for human development – to such an extent that modern living would cease to exist should we 'unplug' ourselves (Smit, 2009: 1). Theoretically, there are two basic sources of energy that could be used to meet humans' rising energy needs in the 21st century: exhaustible natural resources embedded within the earth's crust (fossil fuels, uranium and thorium) and the renewable energy sources (solar, wind, 'small' hydro, geothermal, oceanic, amongst others) that regenerate themselves infinitely (WER, 2005: 20). But the consequences of unsustainable use of exhaustible natural resources – such as climate change, breakdown of ecosystem services, loss of biodiversity, depletion of key renewable and non-renewable resources – for human and economic development will eventually threaten the existence of large numbers of humans and other species on earth (Burger & Swilling, 2009: 1). The use of coal for power generation emits large quantities of greenhouse gases (GHGs), especially carbon dioxide ($CO_2$). In 2004, forty per cent of $CO_2$ emissions which has been proven to cause climate change (IEA, 2006; IPCC, 2001; IPCC, 2007) came from burning of coal.

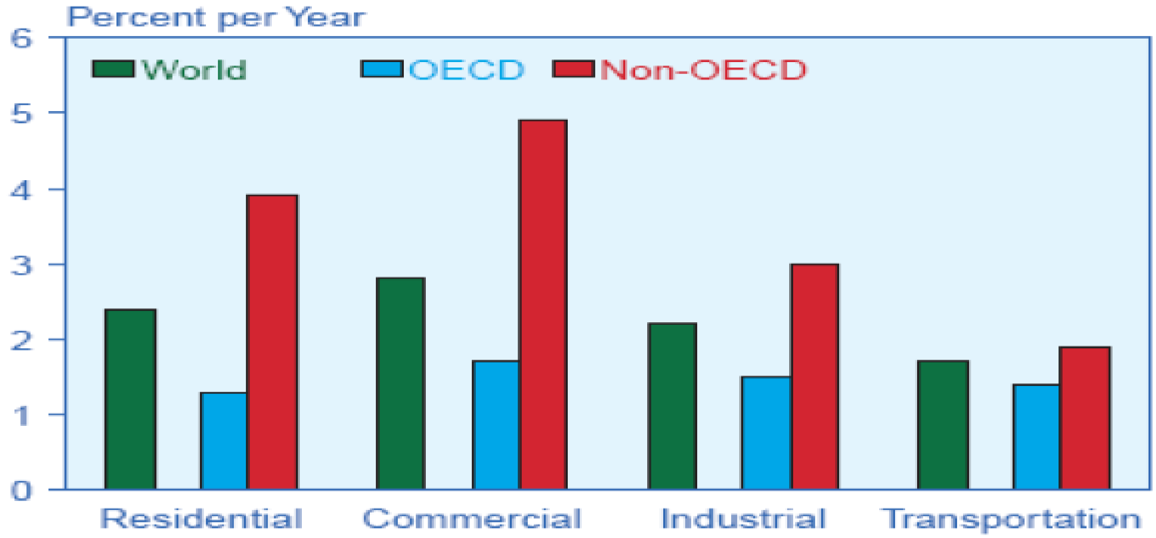
There is now an emerging global consensus that unsustainable use of conventional energy sources is detrimental to the natural environment (Burger & Swilling, 2009: 2; IPCC, 2007; IEA, 2008a) and poses major health risks for both humans and non-humans (UNDP, 2007). The search for alternative sources of sustainable energy has led to the conclusion that renewable energy (RE) sources with energy efficiency (EE) as a technological aid will achieve a sustainable energy future (Smit, 2009: 2).

The review of the global energy context will now be followed by a review of the global electricity market.

### 1.1.2 The global electricity market

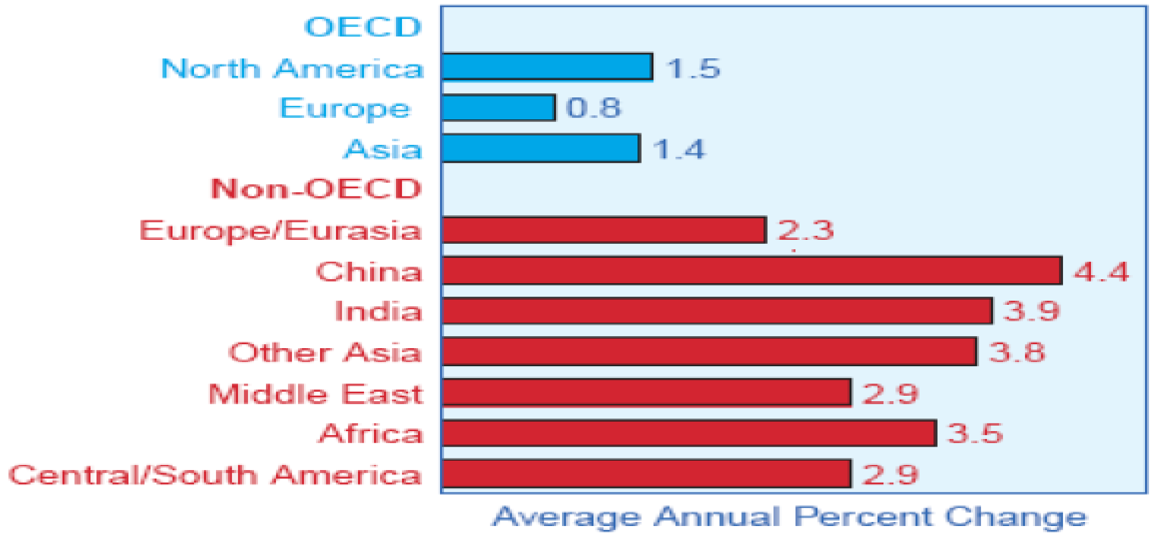
As mentioned earlier it is generally assumed that people in the developing world aspire to the living standards of the developed world (i.e. OECD countries). The increased electricity demand from non-OECD countries is expected to grow threefold compared to that of OECD countries by 2030 (EIA, 2007: 61). The increased end-use electricity demand is predicted to come from commercial, residential, industrial and transport sectors of non-OECD countries (see Figure 1.3).

**Figure 1.3: Average annual change in end-use sector electricity demand (2004-2030)**




Source: EIA (2007)

**Figure 1.4: Annual growth in electricity generation by region (2004-2030)**




Source: EIA (2007)

Fossil fuels are expected to meet the majority of the increased electricity demand going forward to 2050. Coal is one energy source that still remains abundant, more than any other fossil fuel, and is available in 70 countries worldwide. According to the WEC (2007: 2), about 850 billion tonnes of coal are currently recoverable and global coal reserves are estimated to last for another 150 years. Fossil fuels, especially coal, will continue to provide more than 80% of the total electricity demand, which will inevitably lead to an increased concentration of greenhouse gases (WEC, 2007: 2).

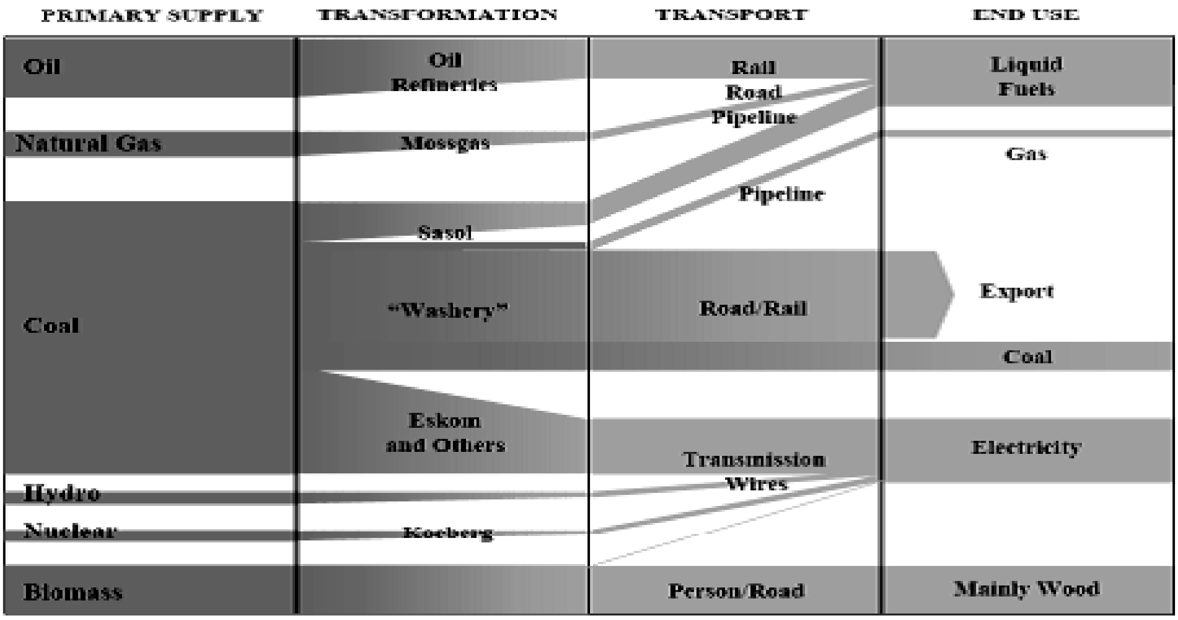
So, there is an urgent need to diminish greenhouse gases as we "decouple" (Swilling, 2008) economic growth from carbon-based energy sources. However, a multiplicity of 'clean' coal technologies has been and continues to be developed to address carbon emission concerns regarding coal utilisation (see Appendix A1).

### 1.1.3 The South African energy context

South Africa is endowed with large reserves of coal, but very small reserves of oil and gas (Haw & Hughes, 2007: 1). The consequence is that coal is largely being used for electricity generation and coal-to-liquid (CTL) fuel production (Haw & Hughes, 2007: 1). Coal is used as a primary energy source to supply approximately 90% of the electricity generated in South Africa (DME, 2008; Smit, 2009: 8). Apart from coal featuring significantly in South Africa's energy mix, South Africa has an energy-intensive economy which relies heavily on the extraction and processing of raw materials (Haw & Hughes, 2007: 1). Energy-intensive industries, such as aluminium smelting and iron and steel extraction and production, form the backbone of the country's economy (Haw & Hughes, 2007: 1). Without access to modern energy South Africa's human and economic development would be highly compromised. South Africa, therefore, needs a stable and secure supply of affordable energy to address its developmental needs.

The burning of fossil fuels have been proven for a long time to have local side-effects, such as heavy smoke, dust and other pollution, with associate respiratory problems. Additionally, at the end of the previous century attention was drawn to the fact that the emission of greenhouse gases (GHGs) by burning fossil fuels contributes to a change in the earth's atmospheric structure which ultimately will result in a change in climatic conditions (Haw & Hughes, 2007; IPCC, 2007). According to a joint paper by Earthlife Africa and Oxfam International (2009: 3), the bulk of GHG emissions in South Africa are as a result of energy production processes, with two main energy companies being accountable: the electricity generator Eskom and the petrochemical company Sasol. Eskom produces large quantities of GHGs through its coal-fired power stations and Sasol emits GHGs through its CTL and natural gas-to-liquid (GTL) fuel processes (Earthlife Africa & Oxfam International, 2009: 3). Figure 1.5 shows an outline of energy flows in South Africa.

**Figure 1.5: A brief outline of energy flows in South Africa, showing primary energy through transformation to end use**




Source: DME (2003, cited in Haw & Hughes, 2007)

In addition to this energy challenge, South Africa, as an emerging economy, has multiple development challenges, such as provision of low cost-housing, halving unemployment (currently at over 20%) by 2014, alleviating poverty and extending access to affordable power to 30% of the households still not electrified (Haw & Hughes, 2007; Earthlife Africa & Oxfam International, 2009: 2). The majority of people in South Africa rely heavily on expensive fossil fuels to meet their daily energy needs. In addition they are dependent on costly transport to and from workplaces due to the urban sprawl created under the apartheid regime (Haw & Hughes, 2007: 1), which has escalated in the post-apartheid era. The location of low-income South African households (Behrens & Wilkinson, 2003, cited in Mokheseng, 2008b) without private cars on the peripheries of cities has a major impact on people's travel patterns and the use of their time and financial resources.

In 2007 and 2008, South Africa had numerous power outages due to inadequate generating capacities. The blackouts in the country indicated how unstable and unreliable South Africa's electricity supply system is. According to the Department of Public Enterprises (DPE) (2007: 6), "the current reserve margin of 8-10%, which is below the global benchmark of at least 15%" (and which at some stage was below

5% before the recession) indicates the inflexibility of South Africa's generating capacity to meet large growth in electricity demand. Under the Kyoto Protocol (a global mechanism to reduce GHGs), Annex 1 countries (i.e. highly developed countries) are obligated to reduce their GHG emissions by 50% of their 1990 GHG levels (IPCC, 2007). South Africa is an Annex 3 country which means it is not yet obliged to reduce its GHG emissions under the Kyoto Protocol (Haw & Hughes, 2007: 1; Smit, 2009: 8). In December 2009, at the Copenhagen Climate Change Conference, the second commitment to Kyoto Protocol will be discussed, and South Africa, alongside China, India, Brazil, Mexico and others, may be required to significantly reduce their GHG emissions.

While both the population and economic growth rates in South Africa will further increase the electricity demand going forward, and given the above-mentioned challenges, South Africa needs to be innovative in terms of meeting and managing increased electricity demand. South Africa provides some of the best opportunities to develop renewable energy (RE) capacity to meet the country's growing energy needs. It has extremely high solar insolation levels, its coastline provides good opportunity to harness wave and tidal energy resource, and with the well established farming industry, biomass exploration offers great potential. The wind resource of the country is fairly good and can also be exploited to generate power (DME, 2003).

However, this abundance of renewable resources has to compete for their market share with South Africa's rich coal reserves and foreign oil. Inspite of recent developments – Eskom's application for an annual increase of 45% in electricity prices for the next three years, and Rio Tinto pulling out from the aluminium smelter planned for the Coega development due to inadequate generating capacity and escalating electricity prices – South Africa will still feature amongst the countries with the cheapest electricity supplies in the world, which in turn encourages the development of more energy-intensive industries. This will result in little or no attention being paid to renewable energy and energy efficiency within sectors of the economy (Haw & Hughes, 2007: 3). These energy-intensive industries depend on the stable and reliable supply of cheap energy, which includes electricity.

South Africa experienced a major power crisis in 2008 in the midst of a growth spurt partially made possible by the Accelerated and Shared Growth Initiative of South

Africa (ASGISA, 2007). Under ASGISA, one of the country's objectives is to increase the economic growth rate to 6% and maintain it until 2014. During the same year, in October 2008, the world was crushed by an economic meltdown of almost the same proportions as that of 1929, which means that it is highly unlikely that the targeted national growth rate will be achieved. The slowdown in the world economy has also reduced electricity demand by major industrial and mining firms in South Africa, resulting in a more stable and reliable power supply since October 2008. But when the economy eventually recovers, South Africa may be back to 'load-shedding' challenges. Eskom embarked on a demand-side management (DSM) programme[1] in an effort to save power by promoting energy efficiency as well as the construction of diesel or gas-fired generators as a short-term solution. A medium-term solution is the construction of more new coal-fired power stations while long-term solutions include nuclear power as an option. However, while it is true that South Africa needs to increase generating capacity, building new nuclear and coal power stations is not the only options.

As mentioned before, South Africa has the potential for renewable energy to provide in some of our energy needs, and it is critical that the use of sustainable renewable energy should be made a prominent part of the solutions to the energy challenges facing humanity in the 21st century. Some solar thermal and photovoltaic (PV) technologies are proven and can guarantee energy security through harnessing the freely available resource of solar energy towards 2050 and beyond. It is, however, very important to realise that renewable energy initiatives in South Africa are contingent on crucial policy and legislative changes. In 2003 the DME has set for itself a target of 10 000 GWh of renewable energy, which is about 4% (1 667 MW) of estimated electricity demand (41 539 MW) by 2013 (DME, 2003). It has identified solar, wind, biofuels, small-hydro, landfill-to-gas and other renewable energy sources as development potential in South Africa. Six years later not even a small fraction of that target has been achieved yet. Sectors should be identified in which most savings in cost, energy and emissions are achievable in order to indicate where policy measures should be focused and sectoral targets for renewable energy and energy efficiency can be set.

[1] Refer to http://www.eskomdsm.co.za.

### 1.1.4 The South African legislative and policy landscape

There has been a phenomenal growth in grid-connected renewable energy around the world in the past two decades, largely driven by the need to mitigate the adverse environmental impacts of fossil fuel usage, the volatility of fuel prices and the enhancement of national energy security (Sebitosi & Pillay, 2008). The application of policy support instruments to promote the dissemination of RE technologies is now a universally accepted norm (Sebitosi & Pillay, 2008), with countries and societies drafting and applying their policy frameworks depending on their different prevailing socio-economic environments. According to Sebitosi and Pillay (2008), these policies are generally categorised as investment cost reduction and/or public investment and market facilitation. An overview of South Africa's energy policies is provided in Table 1.2.

**Table 1.2: An overview of South Africa's energy policies**

| Policy | Summary |
|---|---|
| White Paper on the Energy Policy of South Africa | The National Energy Policy published by the Department of Minerals and Energy (DME) in 1998 governs development in the South African energy sector (DME, 1998). One of five key objectives for security of energy supply in South Africa identified by White Paper is "[s]ecuring supply through diversity" (DME, 1998). The White Paper on the Energy Policy's position with respect to renewable energy is based on an integrated resource planning criterion, namely "[e]nsuring that an equitable level of national resources is invested in renewable technologies, given their potential and compared to investments in other energy supply options" (DME, 2003). |
| Renewable Energy Policy of South Africa | The White Paper on Renewable Energy Policy (DME, 2003) supports the 1998 White Paper on Energy Policy and sets strategic goals for developing and implementing renewable energies in South Africa. The South African government has since set a target of "10 000 GWh (0.8 Mtoe) renewable energy contribution to final energy consumption by 2013 to be produced mainly from biomass, wind, solar and small-scale hydro. The renewable energy is to be utilised for power generation and |

| | |
|---|---|
| | non-electric technologies such as solar water heating and biofuels. This is approximately 4% (1 667 MW) of estimated electricity demand (41 539 MW) by 2013" (DME, 2003). |
| Integrated Energy Plan (IEP) | The DME (2003) commissioned the IEP to provide a framework that will create a balance between energy demand and resource availability. The objective is to supply cheap electricity for socio-economic development (DME, 2003), while considering safety, health and environmental dimensions. According to the IEP, South Africa needs to enact policy for the promotion of renewable energy and energy efficiency measures (DME, 2003). The IEP acknowledges that the new installed capacity will predominantly remain coal based, but it will have the potential for renewables, nuclear, hydro, natural gas and co-generation. |
| National Integrated Resource Plan (NIRP) | The National Energy Regulator of South Africa (NERSA) commissioned the NIRP in 2003 to "provide a long-term, cost-effective resource plan for meeting electricity demand, which is consistent with reliable electricity supply and environmental, social and economic policies" (Savannah Environmental, 2008). The NIRP's objective is to determine the most cost effective energy supply options for South Africa, provide information on investment opportunities in new electricity projects, especially renewables, and assess the security of supply (NERSA, 2003). |
| Integrated Strategic Electricity Planning (ISEP) | Integrated Strategic Electricity Planning (ISEP) is a modelling tool used by Eskom to plan its future capacity strategy. ISEP analyses electricity utilisation patterns and economic growth trends and matches them with the performance characteristics of different generation technologies and DSM options, to identify the timing, type (peaking or base load) and quantity of required new capacity options in the long-term (Savannah Environmental, 2008). Eskom's generation expansion plan would be the result of the ISEP process. The identified options would include the re-commissioning of the three mothballed coal-based power stations, namely Grootvlei, Camden and Komati, pumped storage schemes, conventional pulverised fuel (coal) power plants, |

| | |
|---|---|
| | nuclear plants and gas-fired plants, and to some extent RE technologies. The ISEP scenarios are based on an average of 4% growth in electricity demand and 6% GDP growth over a period of 20 years. |

Source: DME (1998, 2003)

### 1.1.5 The way forward

At a national level, the only real policy document South Africa has pertaining to renewable energy is the White Paper on Renewable Policy of 2003, which is now being reviewed.[2] The Western Cape provincial government has set a target of 15% RE by 2014 and the Cape Town Municipal District has considered a by-law to make it mandatory to include solar water heaters (SWHs) in new residential housing development (Sebitosi & Pillay, 2008). However, in support of the White Paper on Renewable Energy Policy, the South African Cabinet commissioned a process to examine the potential for reduction of South Africa's GHG emissions. The aim of the process was to produce the long-term mitigation scenarios (LTMSs) that would provide a sound scientific analysis from which Cabinet could draw up a long-term climate policy (DEAT, 2008b). Such a policy would give South African negotiators clear and mandated positions for their negotiations under the United Nations Framework Convention for Climate Change (UNFCCC) (DEAT, 2008b). (See Appendix A2 for a description of the LTMS process and outcomes.)

From the LTMS process four strategic options emerged to get from 'growth without constraints' (GWC) towards the goal of 'required by science' (RBS). These are:

- Start now
- Scale up
- Use the market
- Reach for the goal

[2] SA extends timeframe for renewable energy policy review to February. http://engineeringnews.co.za/article/. 2009-09-10.

The challenge is then for South Africa to scale up technologies, provide policy guidance and channel investment to achieve GHG reductions as per the RBS scenario and grow the economy with less material consumption.

According to Sebitosi and Pillay (2008), the transition to a low-carbon economy is often achieved through the application of policy support mechanisms that promote the dissemination of RE technologies. As mentioned earlier, these support mechanisms are generally categorised as investment cost reduction and/or public investment and market facilitation. These are complemented by additional instruments that include accounting for externalities such as the adverse effects of fossil fuel usage on human health (such as lung cancer from the resultant smoke, dust and local air pollution from the operation of a coal-fired power plant) through emission taxes and/or tax relief to RE investors (Sebitosi & Pillay, 2008). The success of these policies has varied over the years in different countries. Policy consistency and continuity has been identified as being critical to the success of policies. New investment suffered in countries with short-term RE incentive regimes while their renewal remained bogged down in the bureaucratic approval process (Sebitosi & Pillay, 2008). Some initiatives and associated challenges in South Africa are discussed in Appendix A3.

### 1.1.6 The South African electricity market

The South African power capacity is summarised in Table 1.3 (Smit, 2009: 9). It identifies Eskom power stations by fuel, installed capacity (MW) and the number of years in service (up to 2006) and the corresponding number of years of service left (including 2007). Eskom aims to double the current installed capacity to over 80 GW by 2025 while stabilising the reserve margin from the current 8% to 15% (Smit, 2009: 10).

**Table 1.3: Summary of South African power capacity: Eskom power stations**

| Power station | Rated output | No. of years in service (up to 2006) | No. of years of service left (including 2007) | Type of fuel source |
|---|---|---|---|---|
| Acacia Power Station (outskirts of Cape Town, Western Cape) | 171 MW (3 x 57 MW) | 30 | 10 | Gas |
| Arnot Power Station (50 km east of Middelburg, Mpumulanga) | 2100 MW (6 x 350 MW) | 31 | 9 | Coal fired |
| Camden Power Station (close to Ermelo, Mpumulanga) | 1600 MW (8 x 200 MW) | 39 | 1 | Coal fired |
| Duvha Power Station (15 km east of Witbank, Mpumulanga) | 3 600 MW (6 x 600 MW) | 22 | 18 | Coal fired |
| Drakensberg Pumped Storage Scheme (close to Bergville, in the Drakensberg, KwaZulu-Natal) | 1000 MW (4 x 250 MW) | 25 | 15 | Pumped storage |
| Gariep Hydroelectric Power Station (near Norvalspont, on the Gariep River banks, 300 m downstream from the Gariep Dam wall, Free State) | 360 MW (4 x 90 MW) | 36 (first two machines) 31 (other two machines | | Hydro electric |
| Grootvlei Power Station (close to Balfour, Mpumulanga) | 1 200 MW (6 x200 MW) | 32 | 8 | Coal fired |
| Hendrina Power Station (40 km south of Middelburg, Mpumulanga) | 2 000 MW (10 x 200 MW) | 30 | 10 | Coal fired |
| Kendal Power Station (40 km south-west of Witbank, Mpumulanga) | 4 116MW (6 x 686 MW) | 13–14 | 26–27 | Coal fired |
| Koeberg Power Station (near Melkbosstrand,25 km north-west of Cape Town, Western Cape) | 1 800 MW (2 x 900 MW) | Unit 1 = 22, 5 years Unit 2 = 21, 5 years | | Nuclear power |
| Komati Power Station (between Middleburg and Bethal, Mpumulanga) | 1 000 MW (5 x 100 MW 4 x 125 MW) | 40 | 0 | Coal fired |

| | | | | |
|---|---|---|---|---|
| Kriel Power Station (between Kriel and Ogies, Mpumulanga) | 3 000 MW (6 x 500 MW) | 27–28 | 13–12 | Coal fired |
| Lethabo Power Station (between Vereeniging and Sasolburg, Free State) | 3 708 MW (6 x 618 MW) | 16 | 24 | Coal fired |
| Majuba Power Station (between Volksrust and Amersfoort, Mpumulanga) | 4 110 MW (3 x 665 MW dry-cooled units; 3 x 716 MW wet-cooled units) | 5.75 | 34.35 | Coal fired |
| Matimba Power Station (near Ellisras, Limpopo) | 3 990 MW (6 x 665 MW) | 14 | 26 | Coal fired |
| Matla Power Station (30 km from Secunda, Mpumulanga) | 3 600 MW (6 x 600 MW) | 23.5 | 16,5 | Coal fired |
| Palmiet Pumped Storage Scheme (near Grabouw, 2 km upstream of the Kogelberg Dam wall on the Palmiet River, Western Cape) | 400 MW (2 x 200 MW) | | | Pumped storage |
| Port Rex Power Station (East London, Eastern Cape) | 171 MW (3 x 57 MW) | 26 | 14 | Gas |
| Tutuka Power Station (between Standerton and Bethal, Mpumulanga) | 3 654 MW (6 x 609 MW) | 16.5 | 23.5 | Coal fired |
| Vanderkloof Power Station (near Petrusville, under the Vanderkloof Dam, Northern Cape) | 240 MW (2 x 120 MW) | 30 | 10 | Hydro electric |
| Ankerlig Power Station (near Atlantis, Western Cape) | 588.68 MW (4 x147.17 MW) | | | Gas |
| Gourika Power Station (near Mossel Bay, Eastern Cape) | 438.87 MW (3 x 146.29 MW) | | | Gas |

Source: Eskom (2007, 2008); DPE (2007); Smit (2009)

In 2007, the Energy Intensive User Group (EIUG) developed a position paper with respect to the electricity generation supply-demand balance in South Africa at the request of the DME. The paper is about the National Generation Expansion Plan as shown in Table 1.4. In order to provide an assessment as to whether this plan will meet the future growth in electricity demand, the EIUG compared the expansion plan to a 4% annual growth in electricity demand with 2005 as a base year. The national plan to meet the expected load growth includes the following: the Eskom generation expansion plan, known DME generation expansion initiatives, Eskom's confirmed DSM programme (3 000 MW by 2012 and a total of 5 000 MW by 2024), and known private equity projects such as Mmamabula in Botswana. The capacities listed in Table 1.4 have been assumed to be net capacities by the EIUG (EIUG, 2007).

**Table 1.4: National Generation Expansion Plan**

| Plant | Camden | Grootvlei | Komati | Arnot | OCGT Eskom | OCGT DME | CCGT DME | Medupi | Bravo | Other | Pump Storage | DSM | Total Annual New | Cum Total New | ASGISA Cum growth | Mmama b-ula |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Date** | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW |
| **2005** | 340 | 0 | 0 | 20 | | | | | | | | | **360** | **360** | 0 | |
| **2006** | 340 | 0 | 0 | 40 | | | | | | | | | **380** | **740** | 1338 | |
| **2007** | 510 | 188 | 0 | 40 | 1050 | | | | | | | 400 | **1788** | **2528** | 2730 | |
| **2008** | 170 | 376 | 0 | 80 | 0 | | | | | | | 800 | **626** | **3154** | 4178 | |
| **2009** | 0 | 564 | 101 | 60 | 1050 | 0 | | | | | | 700 | **1775** | **4929** | 5684 | |
| **2010** | 0 | 0 | 215 | 60 | 0 | 1050 | 0 | | | | | 600 | **1325** | **6254** | 7249 | |
| **2011** | 0 | 0 | 316 | 0 | | 0 | 0 | 0 | | | | 400 | **316** | **6570** | 8878 | |
| **2012** | | | | | | 0 | 800 | 1380 | 1526 | | 333 | 100 | **5188** | **11758** | 10571 | 820 |
| **2013** | | | | | | | 1600 | 1380 | 763 | | 1000 | 170 | **6383** | **18141** | 12333 | 1640 |
| **2014** | | | | | | | 800 | 690 | 1526 | | 0 | 170 | **3016** | **21157** | 14164 | 0 |
| **2015** | | | | | | | 0 | 690 | 763 | | 500 | 166 | **2773** | **23930** | 16069 | 820 |
| **2016** | | | | | | | 0 | 0 | 0 | | 500 | 166 | **2140** | **26570** | 18051 | 1640 |
| **2017** | | | | | | | 0 | 0 | 0 | 0 | 500 | 166 | **500** | **26570** | 20111 | 0 |
| **2018** | | | | | | | | 0 | 0 | 0 | | 166 | **0** | **26570** | 22254 | 0 |
| **2019** | | | | | | | | | 0 | 0 | | 166 | **0** | **26570** | 24483 | 0 |
| **2020** | | | | | | | | | 0 | 0 | | 166 | **0** | **26570** | 26800 | 0 |
| **2021** | | | | | 450 | | | | 0 | 690 | | 166 | **1140** | **27711** | 29211 | |
| **2022** | | | | | 300 | | | | 0 | 1380 | | 166 | **1680** | **29391** | 31718 | |
| **2023** | | | | | 300 | | | | | 1380 | | 166 | **1680** | **31071** | 34325 | |
| **2024** | | | | | | | | | | 2070 | 1000 | 166 | **3070** | **34141** | 37036 | |
| **Total** | **1360** | **1128** | **961** | **300** | **3151** | **1050** | **3200** | **4140** | **4578** | **5520** | **3833** | **5000** | **34141** | | **37036** | **4920** |

Source: EIUG (2007)

The proposed open-cycle gas turbines (OCGTs) put out to tender by the DME, due for 2009, delayed by one year to 2010, have been included in the analysis. Eskom's board decision to double up on the 1 050 MW of OCGTs has been incorporated and included in 2009. The proposed combined-cycle gas turbine (CCGT) plant at Coega is included in the plan from 2012 as is now the earliest date by which commissioning of such plant could be realistically achieved (EIUG, 2007).

It is clear from the National Generation Expansion Plan that future South African electricity initiatives are coal based, which means that South Africa's carbon footprint is not only getting larger, but it is also getting deeper (Smit, 2009: 13). In its effort to become a key global player in decision-making processes, South Africa must at least start to show some commitment to sustainable energy future. The LTMS provide four strategic options for South Africa to shift from a carbon-based energy-intensive economy to a low-carbon energy-efficient economy.

During the writing of this thesis there have been many developments and associated challenges with regard to Eskom's expansion programme. Together with a discussion on the national reserve margin, these developments are highlighted in Appendix A4.

### 1.2 Research rationale

Eskom has previously calculated that its (thus far) unsuccessful programme to roll out 925 000 solar water heaters in higher-income households would reduce peak power demand by 578 MW (the diversity factor for this calculation is 20.8%). If it had hypothetically planned to implement a programme ten times this size and extended it to low-income households, then, assuming a roughly comparable savings rate, Eskom would save power equivalent to 5 780 MW (*Business Report*, 2009b). This is more than the output of the Medupi or Kusile coal-fired power stations currently under construction. Furthermore, Eskom has admitted that solar water heaters bearing the full South African Bureau of Standards mark of approval should be available in the near future for as little as R7 000 apiece compared to existing prices ranging from R17 000 to R35 000 (*Business Report*, 2009b). At R7 000 per unit, a large-scale SWH programme for 10 million South African households would costs in the region of R70 billion. That is a saving of R30 billion or R41 billion compared to the cost of building the Medupi or Kusile coal-fired power plant respectively. In fact, a saving of R80 billion has recently been reported,[3] probably as a result of increased

[3] Refer to: http://www.busrep.co.za/index.php?fsectionId=563&fArticleId=4756291

equipment and fuel (coal) prices. Then the potentially massive savings on household electricity, the huge savings in operation and maintenance (O&M) and fuel costs (more on this in Chapter 5) of a coal-fired power plant, and the great socio-economic and environmental benefits aren't even considered yet.

Instead of implementing a large-scale SWH programme, Eskom is planning to build a third large coal-fired power station that by the end of its construction would have probably cost twice the amount of a 10 million SWH programme.

Government officials, Eskom and politicians have beem making statements that solar PV is unviable because it is too expensive compared to coal. The reason for such statements is that the initial capital costs (procurement costs) are often used as the primary (and sometimes only) criterion for project, equipment or system selection based on a simple payback period (Barringer, 2003). However, due to life-cycle stages, the real costs of the project or equipment are often not reflected by the upfront capital costs (Hunkeler et al., 2008). The main aim of thesis is to test these statements by determining the fuel costs, operation and maintenance costs, and disposal/decommissioning costs of coal power projects and equipment and comparing them to all other initial costs, and to show that the best balance among cost items is achieved when the total life-cycle cost (LCC) is minimised (Barringer, 2003).

LCC (see Chapters 2 and 5) is the economic methodology used in this thesis to indicate that operational savings of solar water heaters and PV roof tiles installed at Lynedoch Eco-village,[4] Stellenbosch, South Africa, are sufficient to justify the upfront investment costs, which are often greater than for simple payback period methods used for small upfront capital expenditures. Large-scale deployment of SWHs and PV roof tiles would not only rein in power price increases in the future, but also make a strong case for the urgent establishment of local manufacturing capacity and a well coordinated plan to take these to every corner of the country.

As a result, this research paper discusses the feasibility of a domestic/residential solar thermal and PV system (comprising a solar water heater and relatively small size solar PV roof tile system (5 kW)) that would reduce electrical load of an average

[4] Refer to http://www.sustainabilityinstitute.net/lynedoch-ecovillage for more information.

South African household to an absolute minimum. The operational results from a 5 kW PV roof tile experiment at Lynedoch Eco-village will be used as a basis for developing a model for a million rooftops that will have a 3 to 5 kW PV system plus SWH. The focus of the million houses model will be operating costs over 40 years, on the assumption that the capital costs will be financed from coal-fired generation capacity that will no longer be needed. Basically, the life-cycle cost analysis (LCCA) of the million rooftops model is carried out. The results are compared to the LCC of coal-based electricity. The research paper proposes an alternative decision-making approach for promoting renewable energy initiatives in South Africa by setting a target for the market to relate to and provide investors and innovators with a clear strategic goal.

## 1.3 Research questions and objectives

Henning, Gravett & van Rensburg (2005) argue that the notion of research refers to finding a way to better understand and explain an issue through the texts of others (literature) and a small field of enquiry. According to Mouton (2001, cited in Kelly, 2009: 4), when formulating a research question or problem, firstly a preliminary literature review should be conducted to demarcate the field of study and show how other scholars have approached the subject before. Secondly, "units of analysis" (objects of the study) should be identified (Mouton, 2001: 51, cited in Kelly, 2009: 4). Thirdly research questions should be formulated in order to focus the research study (Mouton, 2001: 53, cited in Kelly, 2009). Yin (2009: 3) also argues that following a rigorous methodological path begins with a thorough literature review and careful and thoughtful posing of research questions or objectives.

### 1.3.1 Research questions

i. Could a domestic/residential solar thermal and PV system (comprising a solar water heater and relatively small size solar PV roof tile system (5 kW)) off-set most of the demand for electricity by the average South African household, especially in the early morning/evening peak period of electrical demand?

ii. Could operational savings justify high initial investment on a residential solar power system (PV roof tile system and SWH) over its life-span?

iii. If a million micro-power solar systems (PV and SWH) were installed on residential units;

(a) What would the total output be?

(b) What would the equivalent in coal-fired power generation be?

(c) What are the comparative costs of the two systems?

### 1.3.2 Research objectives

The following research objectives are embedded within the need for sustainable renewable energy use on a global, national and local scale and the potential of the residential sector, as a space, to implement innovative technological energy solutions. This research report explores what could be the most appropriate technological solutions to implement sustainable renewable energy, with special reference to a residential solar power system (comprising a solar water heater and solar PV roof tile system (5 kW)) at Lynedoch Eco-Village as a specific case.

This thesis has the following objectives:

i. To test the feasibility of a residential solar power system (comprising a solar water heater and relatively small size solar PV roof tile system (5 kW)) that would reduce daytime electrical demand of a South African household to an absolute minimum.

ii. To see how much energy could be saved and then consider the costs and evaluate the most cost effective ways of distributing solar roof tiles and solar water heaters, assuming that the financial resources expended on a coal-fired generation capacity (e.g. the Medupi coal project) are used to fund the mass roll-out of these micro solar systems to the rooftops of a million average South African households.

iii. To be able to use specific financial modelling to examine the life-cycle cost of two project alternatives, namely, a residential solar power system and a coal-fired power plant.

iv. To understand some of the global trends in the PV sector, and how other countries, such as Germany, Spain, USA, Japan, have supported their solar thermal and PV energy initiatives. Although the energy context of South Africa and these countries may differ, it is imperative that we learn from them and perhaps derive some value from their experiences.

v. To validate solar roof tile PV technology in the market place.

vi. To understand policy and financial realities of renewable energy, with special reference to solar PV roof tiles and SWHs.

vii. To provide recommendations with regards to policy change and investments in renewable energy initiatives, such as solar roof tiles and solar water heaters, in South Africa.

viii. To publish results in a form suitable for future guidance to policy makers, designers and potential users of solar PV roof tile systems and SWHs.

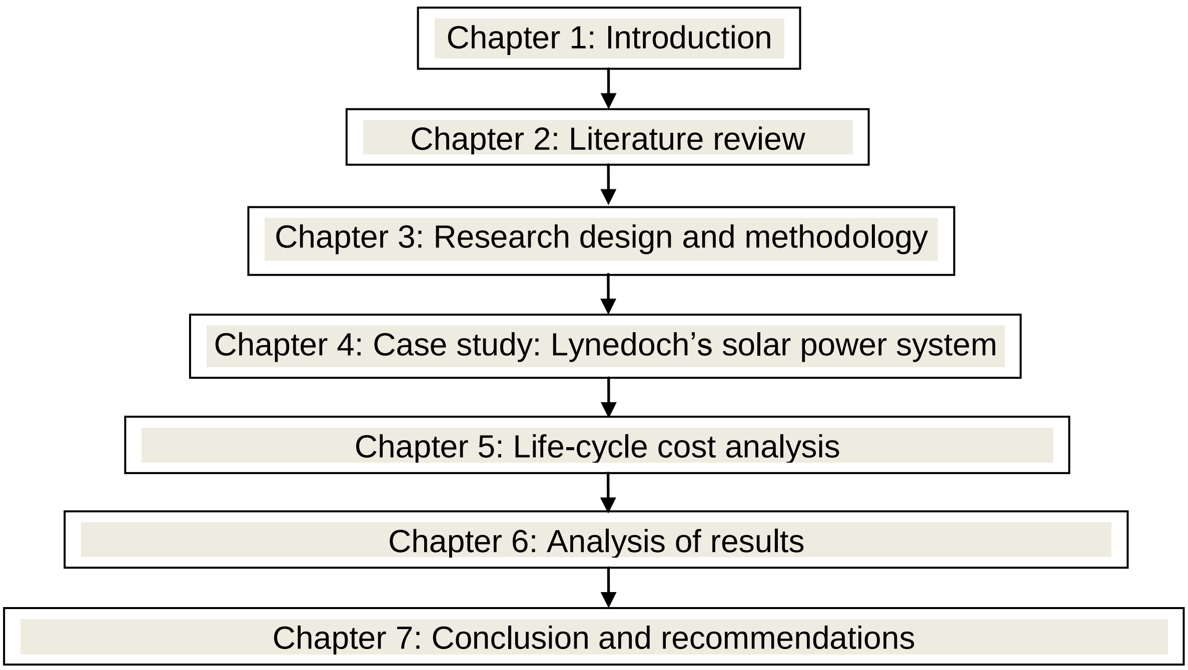
## 1.4 Significance of the study

In Section 1.1, it was clearly indicated that availability of affordable energy is vital to the development of people and economies. This critical role of energy in modern life warrants attention, particularly when there is an overwhelming global consensus that current processes of energy production and consumption are proving to cause environmental degradation, global warming, breakdown of ecosystem services and depletion of key renewable and non-renewable resource (Smit, 2009: 1; Burger & Swilling, 2009: 1), which in turn will threaten the existence of large numbers of humans and non-humans on earth. The use of fossil fuels in power generation has been found to be the most detrimental to the environment and humans (IPCC, 2007). Enhanced global warming, which has irreversible negative consequences on human experience on earth, has been proven to be caused by emissions of greenhouse gases, such as $CO_2$, from the use of fossil fuels for power generation and liquid fuel processes (IPCC, 2001; IPCC, 2007). This study is one of many that are undertaken to find alternative sustainable energy solutions to the global energy/environmental crisis. Renewable energy systems are alternatives to conventional energy systems (coal, oil, gas, nuclear and others) that allow for a sustainable energy future. This study assesses the use of RE micro-power systems, with special reference to a residential domestic solar thermal and PV system (comprising a solar water heater and relatively small size solar PV roof tile system (5 kW). The study will indicate how distributed generation (DG) from RE sources can eliminate the need to build a new coal or nuclear power station in South Africa.

The study aligns itself with the global, national and local imperatives of incorporating considerations for the environment, societies and economies in decision-making processes, with renewable energy at the centre of reliable and sustainable energy solutions for the 21st century.

## 1.5 Thesis outline

**Figure 1.6: Outline of the thesis**



# Chapter 2 : Literature review

## 2.1 Introduction

A preliminary literature review was conducted to find a way to a better understanding and explanation through literature in order to demarcate the field of study, as suggested by Henning et al. (2005) and Mouton (2001). In reviewing literature for this study, sustainable development (SD) – as an overriding objective to meet the needs of the current generation by not compromising the ability of future generations to meet their own needs (Pezzoli, 1997) – is used as a point of departure. The discussion on sustainable development is closely followed by a review of ecological design discourse and renewable energy as some of the sustainable energy options available as solutions to global energy supply and demand crisis and mitigation of climate change. Special attention is given to micro solar PV in the form of household roof tiles and solar thermal in the form of solar water heaters (SWHs) as technological options available for South Africa. The review of the literature would serve to indicate that renewable energy use is necessary and critical within the broader realm of sustainable development, and that the technology (conversion device) is mature and available and that other countries in the world are already using it.

## 2.2 Why sustainable development?

According to DEAT (2007: 18), the notion of sustainable development is often used in policy and strategy documents to refer to many different things, without real definition to mean anything specific. Mebratu (1998: 493) maintains that there is a wide variety of definitions and interpretations that are skewed towards institutional and group prerogatives rather than compounding the essence of the concept, which has been inherent in traditional beliefs and practices: nature is not ours, all species are equal and humans should be strongly committed to living within the carrying capacity of the biosphere. Central to these definitions is the widely cited definition of sustainable development that is provided in *Our common future*, a report written by Brundtland in 1987 and followed by the World Commission on Environment and Development (WCED) in 1992. It states that "sustainable development is the development that meets the needs of the present without compromising the ability of the future generations to meet their own needs" (Pezzoli, 1997). A brief history of the notion of sustainable development is discussed in Appendix A5.

It is now a global phenomenon to consider the diminishing resources that ecosystems provide in the formulation of economic and social development policies (UNDP, 2007; DEAT, 2007: 18), though the status quo still prevails in some parts of the world. Though globally adopted by relevant stakeholders (governments, organisations, businesses and civil societies), sustainable development has not been very successful in achieving its objectives (Kelly, 2009: 47). Some literature seems to suggest that the low success rate of sustainable development is due to it remaining a vague general notion of a distant future state (DEAT, 2007; Mebratu, 1998; Pezzoli, 1997; Hattingh, 2001; Sachs, 2002). Hattingh (2001: 2) argues that the notion of sustainable development is open to interpretation as it does not make clear which ethical and value judgements have been made.

A more radical and broad interpretation of sustainable development is thus needed for the purpose of this study to avoid confusion that may arise as a result of different ethical and moral values of the concept. As a result this study is positioned and aligned within a strong, egalitarian, participatory, broad and deep concept of sustainable development (see Table 2.1).

**Table 2.1: Sustainability matrix**

**Sustainability matrix**

- **Weak** *vs* **strong** SD: Nature must pay the price for the development *vs* strict limits beyond which we cannot go.
- **Non-egalitarian** *vs* **egalitarian** SD: Overconsumption by the rich at the expense of the poor *vs* defence of middle-class living standards.
- **Top-down** *vs* **participatory** SD: Policy think tanks and round tables (UN, business, and summits) *vs* grassroots mobilisation (NGOs, CBOs).
- **Narrow** *vs* **broad** SD: Green conservationist agenda *vs* SD as inclusive vision for a better future (triple bottom line).
- **Shallow** *vs* **deep** SD: Nature is important only because it is useful to human beings *vs* nature has intrinsic spiritual value.

Source: Sustainability Institute (2008)

Hattingh (2001: 21) best describes the position this study takes with regard to the sustainability matrix when he argues that there is a need for sustainable development which focuses on "structural changes in the economy, politics, institutions and individual lifestyles so as to ensure that a fairer distribution of resources can be achieved throughout the world and between generations, while staying within the carrying capacity of supporting ecological systems".

In support of what Hattingh (2001: 21) described as radical sustainable development, Sneddon et al. (2001: 255-256, cited in Smit, 2009: 27) argue that there are three mutually reinforcing objectives of sustainable development: "the improvement of human well-being; more equitable distribution of resource use and benefits across and within societies; and development that ensures ecological integrity over intergenerational timescales".

Sustainable development is thus underpinned by two factors of great importance: needs – of which the basic needs of the most vulnerable should be given the overriding priority it deserves; and limitations – caused by the mechanical, technical and social world on the ability of the ecosphere to cater for our needs today and tomorrow (Dresner, 2002: 67). As we attempt to understand better the notion of sustainable development – in which sustainable energy is central, together with other pressing issues such as alleviation of extreme hunger and poverty, climate change, urbanisation, the challenge of slums, diseases and many others – we do so by paying attention to voices that provide different perspectives on sustainable development.

### 2.2.1 Sustainability based on complex systems

Sustainability entails taking into account different agents interacting in the world of systems. This view of sustainability is based on systems theory, which holds that biological and ecological systems, weather systems and human, social and economic systems are complex subsystems contained in a very large and complex system, namely the world system (Clayton & Radcliffe, 1996: 12). According to Mebratu (1998: 494) and Macy and Young-Brown (1998: 42), the natural world is able to self-regulate via the interactions of its complex subsystems characterised by different feedbacks needed for its sustenance, and keeping balance and integrity through constant flow-through.

The concept of sustainability in development (Mokheseng, 2008c), in terms of systems theory, addresses relevant social, economic and environmental problems by looking at the economy as a highly open system that interacts with many other systems by exchanging energy and resources with them. All living systems are open systems (they exchange constant flow of material, energy and information with the environment) and this helps them to maintain their balance; hence they are self-supporting (Clayton & Radcliffe, 1996: 19; Macy & Young-Brown, 1998: 41). The second law of thermodynamics states that without energy input all systems will move from organised to disorganised states. The law further holds that, over time, even systems starting as highly ordered as possible will very likely disintegrate into less highly ordered systems (Clayton & Radcliffe, 1996: 19). The system's disorder is called the entropy of the system. Systems that are not receiving enough energy input develop a state of high entropy which is why things disintegrate, decay and die over time (Clayton & Radcliffe, 1996: 19).

The reason that life exists is that the earth continually receives energy from the sun. This energy from the sun allows entropy to be decreased, essentially for order to be created (Clayton & Radcliffe, 1996: 20). Human and economic systems are open systems which can reach a steady state, depending on them being able to maintain continuous exchanges with their environment. Pezzoli (1997: 561) warns that the high depletion rate of natural resources by humans is ultimately responsible for the high state of disorder (high entropy) of the environment. If open systems can maintain exchanges with each other, then they can create and keep a high state of order (low entropy). This means that open systems can maintain their integrity as systems, although this must always be at the expense of increased entropy elsewhere (Clayton & Radcliffe, 1996: 20). Therefore, systems theory follows a strong sustainability logic that advocates living within the carrying capacity of the environment where economic activity can be intricately balanced with other biosphere and human systems.

### 2.2.2 Sustainability based on deep ecology

The biosphere has been converted into the physical world by constructing human systems that will meet the needs and wants of humanity. This physical world has been constructed to expand human capacities and senses; hence it became the human model for the universe (Macy & Young-Brown, 1998: 40). Humans came to think of themselves as better than and superior to animals and plants, earth and water around them. They continue to think that it is their given birth right to reduce the richness and diversity of nature beyond meeting their basic and essential needs. Deep ecologists (Macy & Young-Brown, 1998; Deval & Sessions, 1985) argue that both humans and non-humans have value in themselves (intrinsic, inherent value) and that these values are independent of the usefulness of the non-human world for human purposes.

Eco-theologians and eco-feminists (Mebratu, 1998: 509; Mies & Shiva, 1993: 2) respecticely maintain that the relational balance between natural systems and human systems can be attained if human lives are shaped by genuine religious virtue, and by holistically addressing the issue of man's domination over both women and nature. Mies and Shiva (1993: 6) argue that there is a need for a new cosmology and new anthropology which recognises that life in nature (including humans) is maintained by means of cooperation, mutual care and love.

Deep ecology challenges the assumptions, embedded in Judeo-Christian and Marxist thought, that humans are the crown of creation and ultimate measure of value (Macy & Young-Brown, 1998: 46). These assumptions have led to excessive human interference with the non-human world, and the situation is worsening (Deval & Sessions, 1985). Deep ecology attempts to motivate people to deeply question their real needs and wants, and also to question their relationship with other forms of life going into the future (Macy & Young-Brown, 1998: 47). Deep ecology recognises the unaccounted eco-system services and life-support functions performed by many forms of natural capital and the considerable risk associated with their irreversible loss; hence, it is an element of deep and strong sustainability (Wackernagel & Rees 1996: 37).

### 2.2.3 Sustainability based on environmental space, justice and equity

The focus on environmental space, justice and equity is an approach to sustainability that advocates that the achievement of healthy quality of life depends on all having access to a fair share of resources essential for life (McLaren, 2003: 19). According to McLaren (2003: 20), human beings are consuming natural resources faster than the world ecosystems can tolerate and resource exploitation is further driven by economic inequalities and oppression of the poor by the rich. For example, poor countries (in the south) will have to accumulate money (foreign currency in most cases) to pay back the everlasting financial debts incurred from the wealthy (in the north). The situation has led to the establishment of management regimes for forests and minerals which encourage over-exploitation of resources by multinational investment houses – generating severe impacts which are normally larger and more damaging than those arising from the activities of the poor meeting their immediate needs (McLaren, 2003: 21).

Brundtland, in her famous report *Our common future*, identified the important elements of sustainable development as meeting basic needs, recognising environmental limits and upholding the principles of inter-generational and intra-generational equity (Dresner, 2002: 67). Dresner (2002: 68) asserts that the notion of needs is the source of Brundtland's concern for intra-generational equity and the notion of limits leads to her concern for inter-generational equity. The high rate of resource use benefits mostly, if not only, rich communities, and the environmental costs are felt mainly by poorer communities who suffer from poor quality of health and vulnerable livelihoods (McLaren, 2003: 21). According to Bartelmus (1994: 11), the environmental crisis in poor nations originates from the fight against poverty caused by pressure of the growing number of people living on vulnerable and over-exploited lands, forests and already overcrowded cities. McLaren (2003: 21) refers to this economic and social inequality as environmental injustice.

McLaren (2003: 22) states that the environmental space and equity approach to SD gives people a platform to calculate their maximum rate of natural resource use – a fair share of the maximum resource available within physical limits of the environment – whilst being aware of the minimum determined by need and human dignity. He argues that life can truly be sustainable within this space. Sustainable development (McLaren, 2003: 21; Hattingh, 2001: 11) is strongly connected to a fair distribution of resources and livelihoods between today's poor and rich nations in the world (intra-generational) and also between present and future generations (inter-generational). Sustainability based on environmental space, justice and equity puts emphasis on an egalitarian, broad and participatory approach to poverty eradication and empowerment of the previously marginalised, now and in the future.

### 2.2.4 Sustainability based on human development

In recent years, the *Human Development Report* (1998, 2007) of the United Nations Development Programme (UNDP) has indicated that more people have been fed and given shelter than ever before and that more people are enjoying the benefits of hot water, warmth, electricity and transport (UNDP, 1998: 1). However, more still needs to be done as the richest 20% of the world population consumes 86% of total resources and the most vulnerable 20% accounts for only 1.3% of total resource consumption (UNDP, 1998). The human development (HD) notion of sustainable development accepts resource consumption as an essential means to the development of humans as long as it broadens the capabilities and improves the living standards of people without negatively impacting on the health and well-being of others (UNDP, 1998: 1).

Globalisation has been blamed for contributing to increased resource use in the world (Norberg-Hodge, 2000: 2; Stiglitz, 2002: 4). Globalisation integrated trade with investment and financial markets. Consumption opportunities are available to only those with resources while many others have been marginalised through lack of income (UNDP, 1998: 6). The globalised economy requires that the poor nations export their natural resources to the rich as raw materials, that they use their best agricultural land to grow food, fibre and flowers for the rich nations, and in the process the poor are also used as cheap labour to manufacture goods for rich markets (Norberg-Hodge, 2000: 6).

Rather than exacerbating poverty for poor people, a platform should be laid where the poorer can produce more, allowing them to keep their own resources, labour and production (Norberg-Hodge, 2000: 6). This is possible through localisation.

According to Norberg-Hodge (2000: 6), localisation means making the distance between those who produce and those who consume short, wherever possible, and maintaining the healthy balance between local production and trade. Localisation would have benefits on a number of levels. It would help rural economies worldwide to come back to life, helping to stem the unhealthy tide of urbanisation. Farmers would be producing mainly for local and regional markets and not for world markets, giving them an opportunity to choose varieties in tune with local conditions and needs, thus allowing agricultural diversity to rebound (Norberg-Hodge, 2000: 6).

Production and transport would be minimised, and so would the level of greenhouse gases and pollution, resulting in a far healthier and less stressed environment. The human development approach maintains that sustainable development can be achieved if consumption fulfils the basic needs of all, strengthens human capabilities, and does not compromise the well-being of others (intra-generational justice) or limit the choices of future generations (inter-generational justice) – an element of broad, egalitarian sustainability.

### 2.2.5 Sustainability based on economic output

Sustainable development is often depicted as the outcome of economic development; it is seen as a necessary condition for sustainable living as it elevates the standard of living for the poorest, underpaid and underdeveloped people (Siggel, 2005: 1). According to Stiglitz (2002: 20), the economists' only interest is income accumulation, hence ignoring environmental concerns, social justice, human rights and democracy. Economists are not concerned with resource consumption inequalities; instead they regard them as significant for the economy to function properly and efficiently (McLaren, 2003: 26) – inequalities provide incentives by increasing overall savings and investments.

Gross domestic or national product (GDP or GNP) is used as a concise measure for economic growth, usually per capita and in real terms for development (Bartelmus, 1994: 3). In this approach to sustainability, the environment is a commodity with all environmental inputs being regarded as free goods. The question, however, is whether it is appropriate to use GDP or GNP to measure the development and standard of living of people? Dresner (2002: 73) argues that northern communities are rich and have been for many years, yet some studies indicate that people are no happier than they were half a century ago. In Japan, incomes increased fivefold to compete with those in the United States between 1958 and 1990 (Dresner, 2002: 73), yet people apparently became no happier.

Various authors (Swilling, 2005; Wackernagel & Rees, 1996: 37) argue that economists put a price on natural capital, thinking that it is just a commodity that can be replaced by human-made capital. According to Wackernagel and Rees (1996: 41), the conventional economic approach is flat-earth economics that assumes the world as extending infinitely and posing no serious threat to economic growth. Ecological economics, on the other hand, see the world as a finite sphere with all the resources coming from the earth and going back to it in degraded form (Wackernagle & Rees, 1996: 41), hence economic activity is constrained by the regenerative and absorptive capacity of the ecosphere. The economic approach is thus an element of weak and shallow sustainability as it considers the natural environment as having no intrinsic value, being just a resource to fulfil human need.

Sustainable development provides a platform for all relevant stakeholders to engage in a dialogue pertaining to environmental limits to how natural resources are used and needs and equality issues concerned with the distribution of resources (Smit, 2009: 32). Guy and Marvin (2002) argue that a major shift is required, away from the conventional approach of merely delivering more supply capacity, to a new demand-oriented paradigm of efficiently managing and conserving essential resources such as water, land, waste and energy.

For this reason a brief discussion of ecological design discourse follows before proceeding to a discussion on renewable energy as one of the solutions to bringing about sustainable development.

## 2.3 Ecological design for sustainable livelihoods

According to Van der Ryn and Cowan (1996), we live in two interpenetrating worlds. The first is the living world, which has been forged in an evolutionary crucible over a period of four billion years. The second is the world of roads and cities, farms and artefacts that people have been designing for themselves over the last few millennia. The condition that threatens both worlds – unsustainability – results from a lack of integration between them. They argue that this lack of integration between these two worlds can be addressed by the form of design that strengthens the weave that connects nature with culture (Van der Ryn & Cowan, 1996). Birkeland (2002: 14) argues that this lack of integration is a result of what she calls the “dumb design” that underpins the industrial development model, which is based on extensive use of a large base of natural resources.

Birkeland (2002: 3) further argues that the poor design of urban development externalises and conceals its negative impacts, and the rich tapestry of urban life masks a resource transfer process that harms human and environmental health, reduces secure access to food and water, destroys our life support systems, chains us to the fossil fuel economy, reduces public space and natural amenity, transfers wealth from many to the few, generates conflict over land and resources, and reduces basic life choices for future generations. According to her, conventional SD criteria and design tools that are currently promulgated by planning institutions and agencies cannot increase sustainability because they do not design for the infrastructure that allows nature to regenerate, flourish and deliver ecosystem services and goods sustainably.

Birkeland (2002) maintains that the negative impact of the poor design of urban development on the environment and communities could be reversed by resource transfer through what she calls “positive development”. This positive development would improve human and ecological health, resilience and viability, increase natural capital, biodiversity and ecosystem goods and services, increase secure access to food and water, enhance urban space for both people and natural processes, transform our infrastructure from fossil fuel driven to solar powered, help correct imbalances in power and wealth, conserve open space, wilderness and natural resources, and increase life quality and substantive life choices for present and future generations. The barriers to the design for positive development are not technical or financial – they are purely as a result of polarisation of power, biased mindsets, institutional norms and marginalisation of design (Birkeland, 2002).

Guy and Marvin (2002), based on their understanding of the design of urban infrastructure, argue from the angle of urban environmental flows that a shift is required away from the conventional approach of delivering more supply capacity to a new demand-oriented paradigm of efficiently managing and conserving essential resources. They further argue that the shape and form of policy strategies necessary to bring about this shift is underpinned by a shared, almost orthodox, vision of what shapes material flows through cities. These authors maintain that the planning of infrastructure networks tends to be conceived as the rational management of resource flows through cities, regions and states with little regard to the dynamic, contextually contingent strategies of infrastructure suppliers and users (Guy & Marvin, 2002). They argue that the orthodox has been established around two related views of urban environmental processes. The first is a production-focused image that concentrates on physical places as its objects of analysis and intervention, while the second is a consumption-focused image that concentrates on the social shaping of environmental choice (Guy & Marvin, 2002).

Rather than viewing the realms of production and consumption as somehow autonomous we must become sensitive to their interconnections (Guy & Marvin, 2002). They maintain that we need to develop an alternative analytical framework which recognises infrastructure systems as socio-technical networks that offer a new understanding of the interrelationships between physical production processes shaping the construction of cities and the changing social dynamics of urban consumption. This is the new paradigm that projects a network-focused image that is sensitive to political, cultural, economic and physical interconnections between supply and demand of essential resources (Guy & Marvin, 2002). It is the image of the city of which physical networks are intimately tied to everyday life.

Technical systems are integral to our daily lives (Guy & Marvin, 2002). We as consumers, therefore, are undeniably parts of these systems – when they are reshaped, parts of our lives are reshaped (Guy & Marvin, 2002). Therefore, the paradigm shift requires an understanding of the changing strategies of the suppliers of networked services and a coherent understanding of how these strategies may reshape contexts of consumption (Guy & Marvin, 2002). In this paradigm, for example, sociological analysis of energy use could replace conventional descriptions of universal barriers to energy efficiency innovation based on apathy, ignorance or lack of financial interest, with an analysis of how the changing social organisation of energy production and consumption creates new opportunities for more efficient use of energy (Guy & Marvin, 2002).

According to Guy and Marvin (2002), the whole rationale of infrastructure provision and use has, until recently, been one of predict and provide, a supply-oriented logic facilitating infrastructure provision. The objective has been to maximise supply capacity through network expansion justified through extrapolated models of demand. The high capital costs of network expansion and the need for maximum access has meant that economies of scale has been pursued, encouraging a move towards "standardization of products and homogenization of patterns of behaviour" (Guy & Marvin, 2002). This supply-oriented logic of the provision of national infrastructure networks framed and even actively shaped social patterns of consumption (Guy & Marvin, 2002), thereby limiting environmental innovation to engineering interventions and/or the persuasion of consumers to conserve resources. Birkeland (2002) argues that the design of infrastructure, building systems and construction processes determines the demand upon the industry to provide materials and products downstream in the market. She maintains that in the context of built environment people have limited choices to lead sustainable lifestyles (Birkeland, 2002). They are trapped within the vicious circle of unsustainable resource use promulgated by physical and institutional design failure. She further argues that the design of infrastructure and built environment has locked us into manufactured environments that limit personal choices and will rather continue driving excessive consumption and waste into the future.

The new paradigm is to replace vertically integrated industries dedicated to mass production techniques, standardisation and homogenisation with new high technology based on advances in microelectronics (Guy & Marvin, 2002). This paradigm shift can be seen emerging in the British energy sector, where privatisation and liberalisation of utility networks has revolutionised the provision and use of essential resources. Shifting from spatially homogenised, technically standardised logic of nationalised infrastructure systems, utility companies are, wherever profitable, developing infrastructure networks that more accurately match local market need. At the same time technological developments in advanced metering technologies is rapidly expanding consumer choice over utility services – enhancing the power of utility customers to influence utility strategies (Guy & Marvin, 2002).

Having looked at the discourse of sustainable development for improving human well-being, maintaining ecological integrity and achieving equal distribution of life-sustaining resources, as well as the discourse of ecological design for infrastructure networks that emphasise consumer service and choice, the next section will focus on global trends in renewable energy (RE) as one of the solutions to mitigate climate change, rein in increasing fuel prices and enhance energy security.

## 2.4 Why renewable energy?

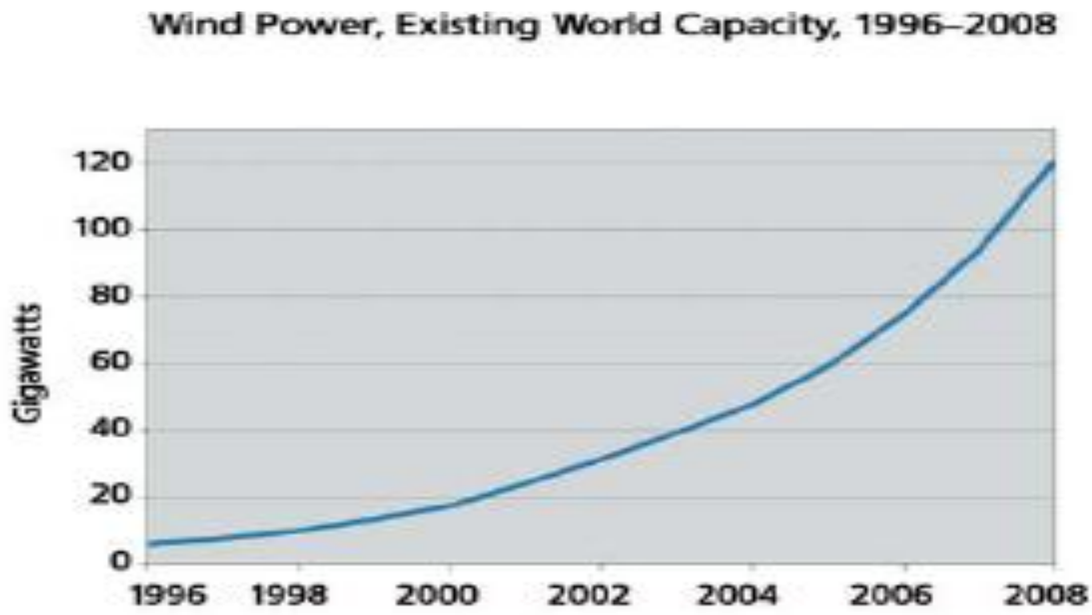
### 2.4.1 Background and context

Diminishing oil reserves and the volatile oil price, increasing concerns about global warming and climate change, and an attempt to conserve energy resources by promoting sustainable and efficient use have begun to make way for resources and technologies that were previously not part of global industrial economic development models.

Turbulent times lie ahead as international bodies, industry stakeholders and policy makers debate what environmental policies should be and which economic policies will be feasible while national governments worry about energy security. Coalitions will be formed to create and drive their own blueprints for their energy futures. As a result market-driven efficiency measures will emerge more quickly, and market-driven $CO_2$ management practices will spread even more quickly. According to the 2008 Shell Energy Scenarios, carbon trading markets will become more efficient and $CO_2$ prices will strengthen (Shell, 2008). The level of atmospheric $CO_2$ will be constrained to a sustainable level below 550 parts per million (ppm) by volume as larger take-up of cleaner and renewable energy such as wind and solar energy is adopted.

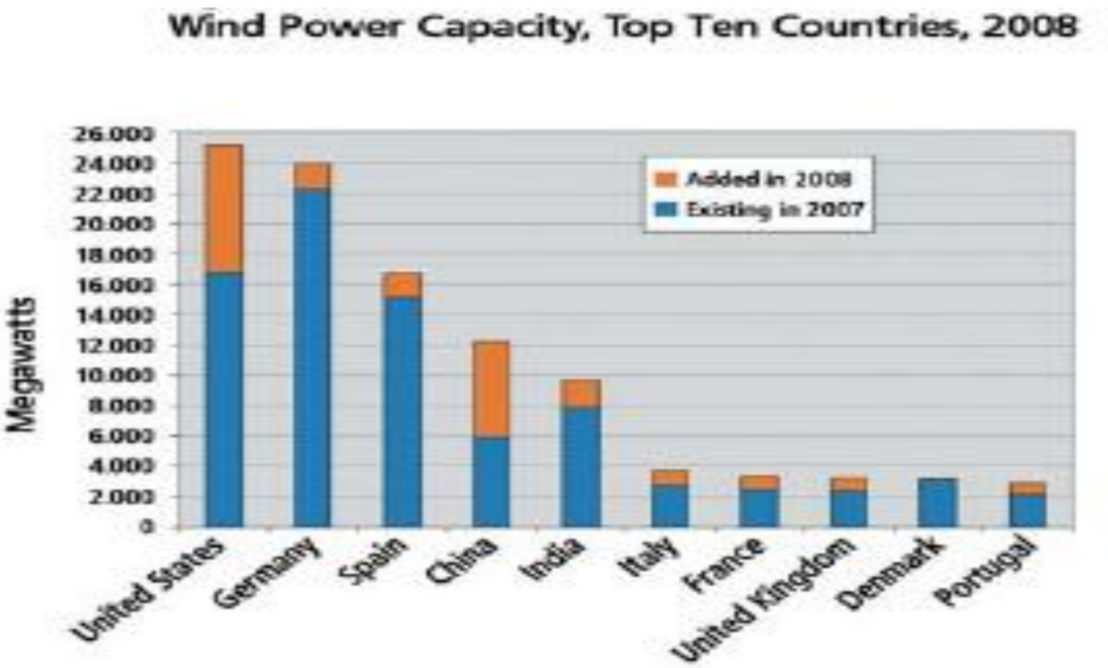
Since 1995, investment and capacity building in the renewable energy sphere have increased at the back of support policies and increased awareness regarding environmental and climate change issues. According to the Renewable Energy Policy Network (REN21, 2009), renewable energy markets grew robustly in 2008. Among new renewables (excluding large hydropower), wind power was the largest addition to renewable energy capacity. See Figures 2.1 and 2.2.

**Figure 2.1: Wind power – existing world capacity (1996-2008)**




Source: REN21 (2009)

**Figure 2.2: Wind power capacity – top ten countries (2008)**

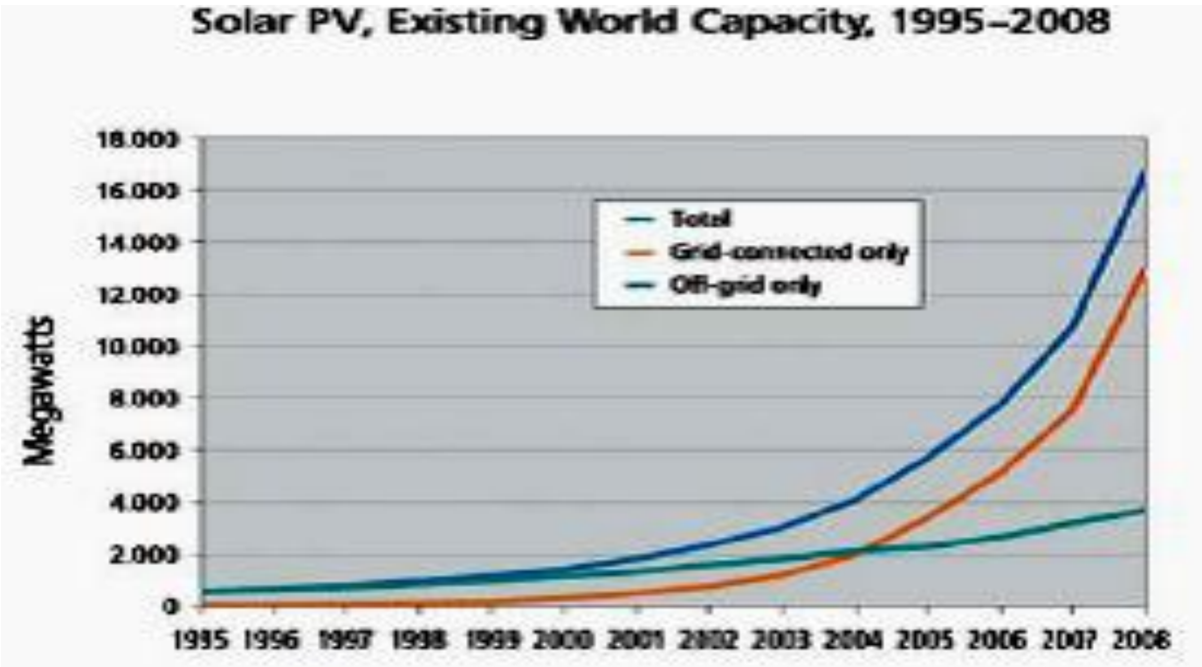



Source: REN21 (2009)

Existing wind power capacity grew by 29% in 2008 to reach 121 GW, more than double the 48 GW that existed in 2004 (REN21, 2009). The 2008 increase was led by high growth in the strongest markets, namely the United States (8.4 GW added), China (6.3 GW), India (1.8 GW) and Germany (1.7 GW).

Grid-connected solar photovoltaics (PV) continued to be the fastest-growing power generation technology, with a 70% increase in existing capacity to 13 GW in 2008 (REN21, 2009). See Figure 2.3. Annual installations of grid-connected solar PV reached an estimated 5.4 GW in 2008. Spain became the market leader, with 2.6 GW of new capacity installed, representing half of global installations and a five-fold increase over the 500 MW added in Spain in 2007. Other leading markets in 2008 were United States (310 MW added), South Korea (200-270 MW), Japan (240 MW) and Italy (200-270 MW). Markets in Australia, Canada, China, France and India also continued to grow (REN21, 2009).

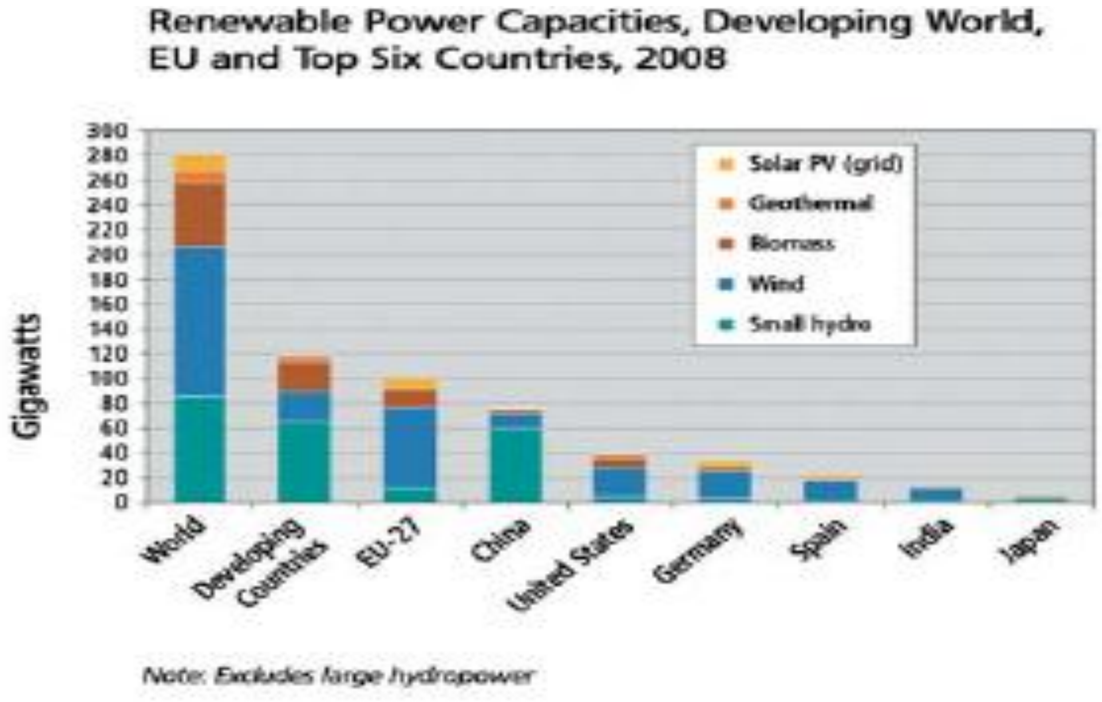
**Figure 2.3: Solar PV – existing world capacity (1995-2008)**




Source: REN21 (2009)

Overall, renewable power capacity expanded to 280 GW in 2008, a 75% increase from 160 GW in 2004 (REN21, 2009), excluding large hydropower (see Figure 2.4). The top six countries were China (76 GW), United States (40 GW), Germany (34 GW), Spain (22 GW), India (13 GW) and Japan (8 GW). The capacity in developing countries grew to 119 GW, or 43% of total, with China (small hydro and wind) and India (wind) leading the increase.

**Figure 2.4: Renewable power capacities – developing world, EU and top six countries (2008)**




Source: REN21 (2009)

The ever-growing wind and solar power industry would probably stimulate a surge in electric transport – powered by battery, fuel-cell or hybrid technologies, as we are yet to see the cleaner energy technologies taking shape in the transport sector. Going forward to 2050 we need these kinds of investments in the renewable energy sphere in order to reduce greenhouse gas emissions while promoting economic growth and energy security for the benefit of all.

In the midst of economic crisis, organisations such as the Renewable Energy and Energy-Efficiency Partnership (REEEP), with its finance initiative, the Renewable Energy Finance Forum (REFF), continue to host conferences that bring together financiers, investors and renewable energy project developers who engage in a high-level debate regarding the future of renewable energy going forward to 2050, prospects for the economy and the impact of a credit crunch on financing possibilities for renewable energy projects worldwide. REFF conferences help achieve technological and cost breakthroughs in the renewable energy sphere by looking closely at the latest global policy developments and the role of the credit market and interest rates in determining levels of project financing in renewable energy in both developing and developed countries. The downturn of the business cycle since 2007 has resulted in a slowdown of global investment flows into renewable energy initiatives. However, capacity in renewable electricity is expected to grow, with wind and PV being the dominant technologies in 2050. Table 2.2 shows renewable electricity capacity from 2003 to 2050.

**Table 2.2: Global renewable electricity generation capacity in MW (2003-2050)**

| | **2003** | **2010** | **2020** | **2030** | **2050** |
|---|---|---|---|---|---|
| **Hydro** | 728 000 | 854 800 | 994 190 | 1 091 490 | 1 257 300 |
| **Biomass** | 48 030 | 110 000 | 211 310 | 305 780 | 504 610 |
| **Wind** | 30 280 | 156 150 | 949 800 | 1 834 290 | 2 731 330 |
| **Geothermal** | 10 170 | 20 820 | 40 780 | 70 380 | 140 010 |
| **PV** | 560 | 22 690 | 198 900 | 727 820 | 2 033 370 |
| **Solar thermal** | 250 | 2 410 | 29 190 | 137 760 | 404 820 |
| **Ocean energy** | 240 | 2 250 | 13 530 | 28 090 | 63 420 |
| **Total** | 817 000 | 1 169 120 | 2 437 700 | 4 195 610 | 7 134 860 |

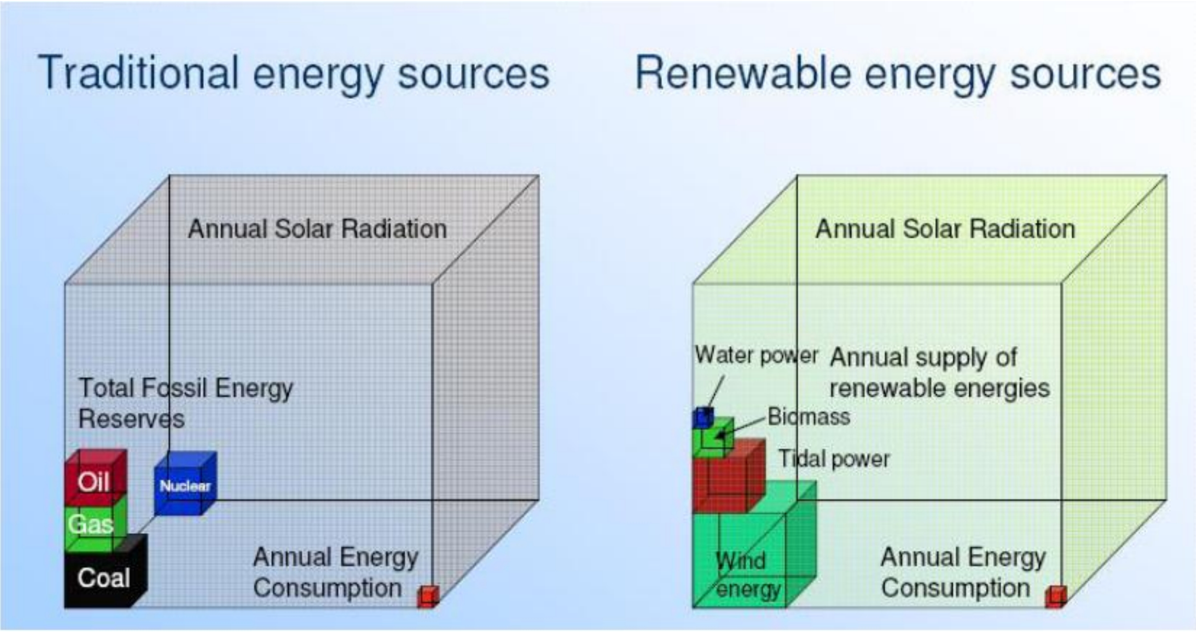
Source: WEC (2007)

### 2.4.2 Global solar energy

Solar energy, the radiant energy from the sun, is the most abundant permanent energy resource available on earth. According to the WEC (2007), the sun radiates as much as 3.8 x $10^{23}$ kW of power and of this total only 1.8 x $10^{14}$ kW is intercepted by the earth. About three-fifths of that intercepted by the earth (or 1.08 x $10^{14}$ kW) reaches the earth's surface, and the rest is reflected back into space and absorbed by the atmosphere. The WEC (2007) maintains that even if only 0.1% of solar energy reaching the earth's surface could be converted at an efficiency of only 10% it would still amount to four times the world's total generating capacity of about 3 x $10^{3}$ GW.

Put differently, the annual solar radiation reaching the earth's surface is estimated at 3 400 000 EJ, 7 556 times more than the world's total annual primary energy consumption of 450 EJ (WEC, 2007). The WEC (2007) argues that this annual solar radiation is in an order of magnitude greater than all the estimated (discovered and undiscovered) non-renewables, including all fossil fuels and nuclear power (see Figure 2.5), hence the need to shift focus to PV and solar thermal power.

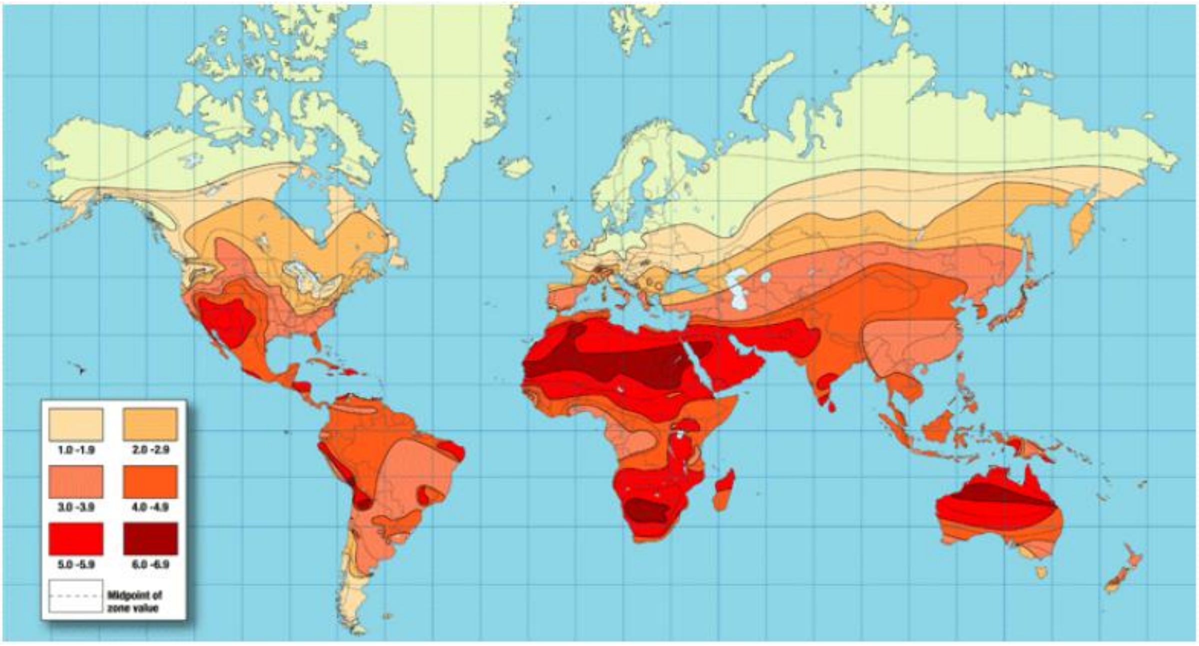
**Figure 2.5: Annual solar radiation greater than all estimated renewables and non-renewables (discovered and undiscovered)**




Source: Swanepoel (2008a); Spencer (2009)

Figure 2.6 shows the global solar insolation in kWh/m$^2$/day, and as can be seen, Southern Africa has some of the best sun in the world.

**Figure 2.6: World solar insolation map – kWh per m$^2$ per day**




Source: Spencer (2009)

### 2.4.3 Global solar photovoltaics

Photovoltaics were first used in the US space programme to power satellites in the late 1950s (Lawley, 2003). As their price started to fall they were increasingly used in terrestrial applications to provide electricity for domestic and industrial applications in remote areas where there was no supply of electricity (Lawley, 2003). Some utilities started using PV in large grid-connected solar applications in the 1980s. There was increasing use of grid-connected PV in 1990s, especially in rooftop programmes: first in Germany through their 1 000 Rooftops Programme, then in California in the PV Pioneer Program and in Japan's New Sunshine Programme (Lawley, 2003).

It is well known that the world's primary energy demand will increase exponentially in the coming decades, driven mainly by population and economic growth. Renewable energy will be part of a solution in a worldwide scramble for economic and energy security. Going forward to 2050, the PV demand is going to increase substantially at the back of supporting policies and awareness regarding green issues and sustainable development. Table 2.3 shows the estimated regional distribution of PV electricity by 2050.

**Table 2.3: PV electricity production by region in 2050, assuming a PV share of 28% in total intermittent renewable energies**

| Countries | Annual PV electricity production (TWh/yr) | Share of electricity demand (%) |
|---|---|---|
| Western Europe | 121 | 5 |
| United States | 332 | 10 |
| Canada | 62 | 12 |
| Japan | 68 | 9 |
| Australia | 16 | 10 |
| **Total OECD countries** | **599** | **9** |
| **Former centrally planned European economies** | **539** | **10** |
| **Total industrialised countries** | **1 139** | **9** |
| Latin America | 92 | 3 |
| Africa | 59 | 3 |
| Middle East | 168 | 10 |
| China and planned economies | 623 | 10 |
| South-east Asia | 621 | 10 |
| **Total developing countries** | **1 562** | **8** |
| **Total world** | **2 701** | **9** |

Source: Johansson et al. (1993)

The scenarios shown in Table 2.3 is painted on the assumption that policy strongly supports the deployment of PV and that serious commitment is made to energy efficiency and mitigating of greenhouse gases. Under this optimistic scenario solar power could meet the electricity needs of 10 to 11% of the world's population in 40 years (Johansson et al., 1993).

The solar energy industry is projected to grow to more than 179 GW in 2030, with even greater penetration moving towards 2050 (Solar Generation IV, 2007). With human development as one of the priorities of sustainable development the solar energy industry would contribute immensely to the employment prospects of mid 21$^{st}$ century job seekers. Table 2.4 indicates that solar PV would be reducing annual $CO_2$ emissions by just above 1 billion tonnes (equivalent to the emissions for the whole of India in 2004, or emission output from 300 coal-fired power plants). The cumulative $CO_2$ savings from solar PV electricity generation would have reached a level of 6.7 billion tonnes in 2050.

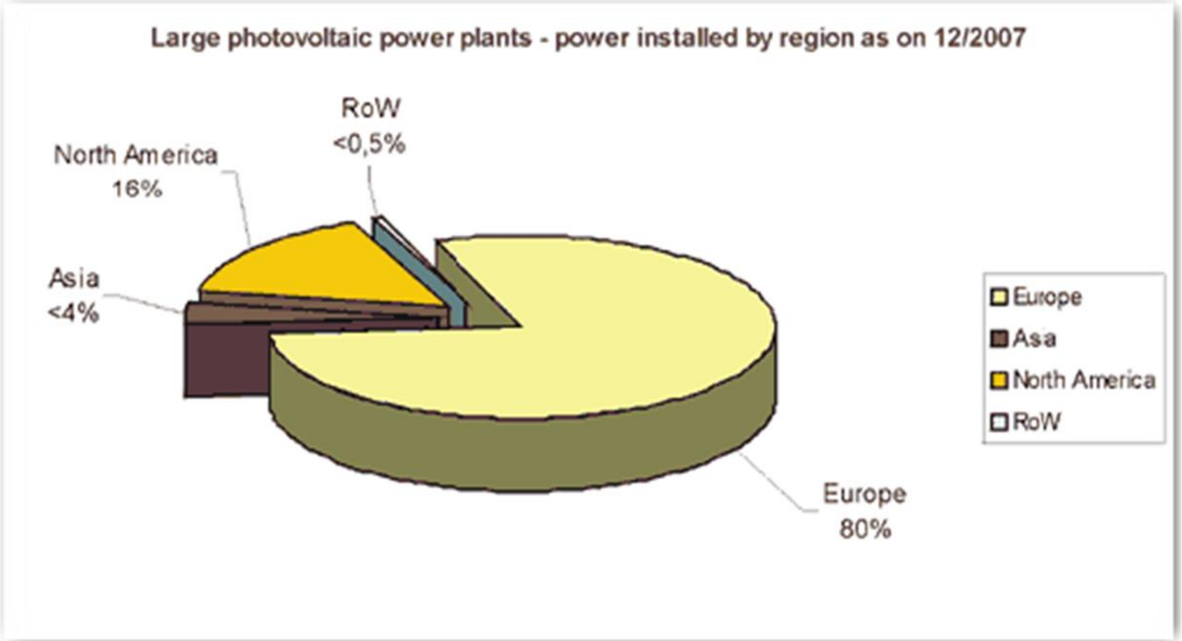
**Table 2.4: Solar generation scenario for global PV market up to 2050**

| **Current situation** | | **Scenarios** | | |
|---|---|---|---|---|
| | 2006 | 2010 | 2020 | 2050 |
| Advanced scenario | | | | |
| Annual installations (GW) | 1.5 | 5.6 | 44 | 179 |
| Cumulative capacity (GW) | 6.6 | 28.9 | 241 | 1 272 |
| Electricity production (TWh) | 8 | 25 | 320 | 1 802 |
| PV contribution to electricity consumption – business as usual | 0.05% | 0.14% | 1.83% | 6.41% |
| PV contribution to electricity consumption – alternative scenario | 0.05% | 0.18% | 1.93% | 9.39% |
| Grid-onnected people (million) | 5 | 15 | 157 | 776 |
| Off-grid connected people (million) | 10 | 61 | 966 | 2 894 |
| Employment (thousand) | 74 | 271 | 1 840 | 6 329 |
| Market value (billion €) | 9 | 25 | 113 | 318 |
| Annual $CO_2$ savings (million tonnes) | 5 | 15 | 192 | 1 081 |
| Cumulative $CO_2$ savings (million tonnes) | 20 | 61 | 898 | 6 671 |

Source: Solar Generation IV (2007)

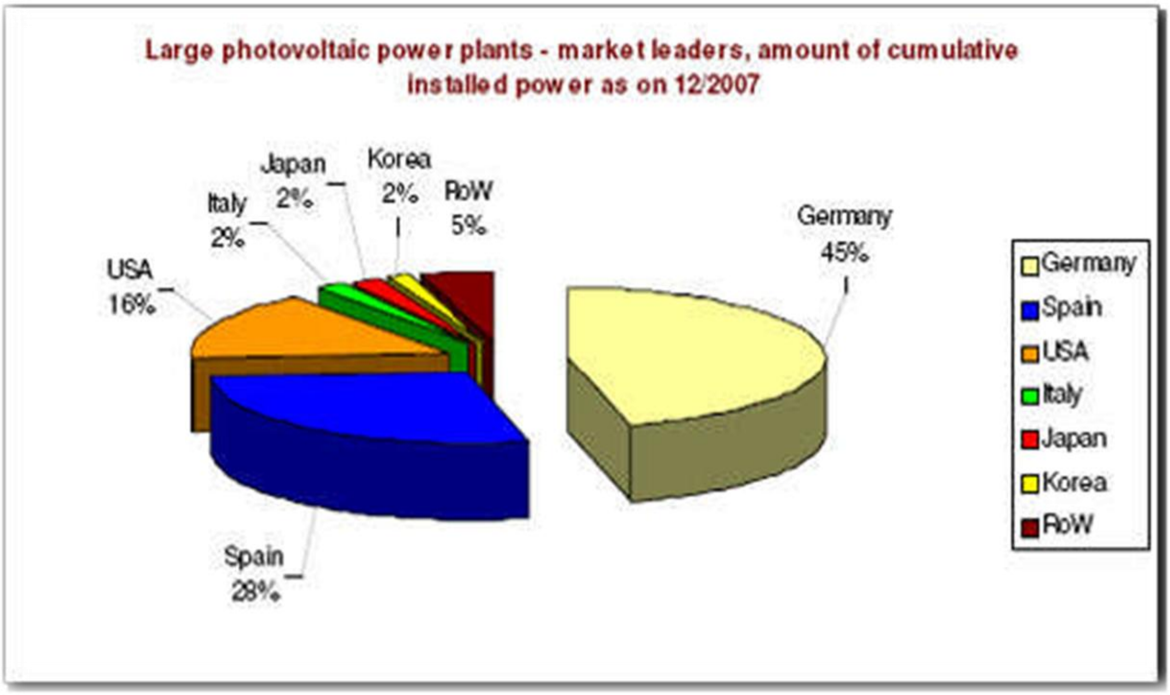
According to Lenardic and Hug (2007), 80% of large PV plants in the world are installed in Europe (700 MWp), with Germany hosting nearly 50% of them, followed by Spain. The North America's market share is 16% (142 MW) and Asia's share accounts for less than 4% (34 MW) according to Figure 2.7.

**Figure 2.7: Large PV power plants by region**




Source: Lenardic and Hug (2007)

**Figure 2.8: Large PV power plant market leaders in terms of cumulative installed capacity**




Source: Lenardic and Hug (2007)

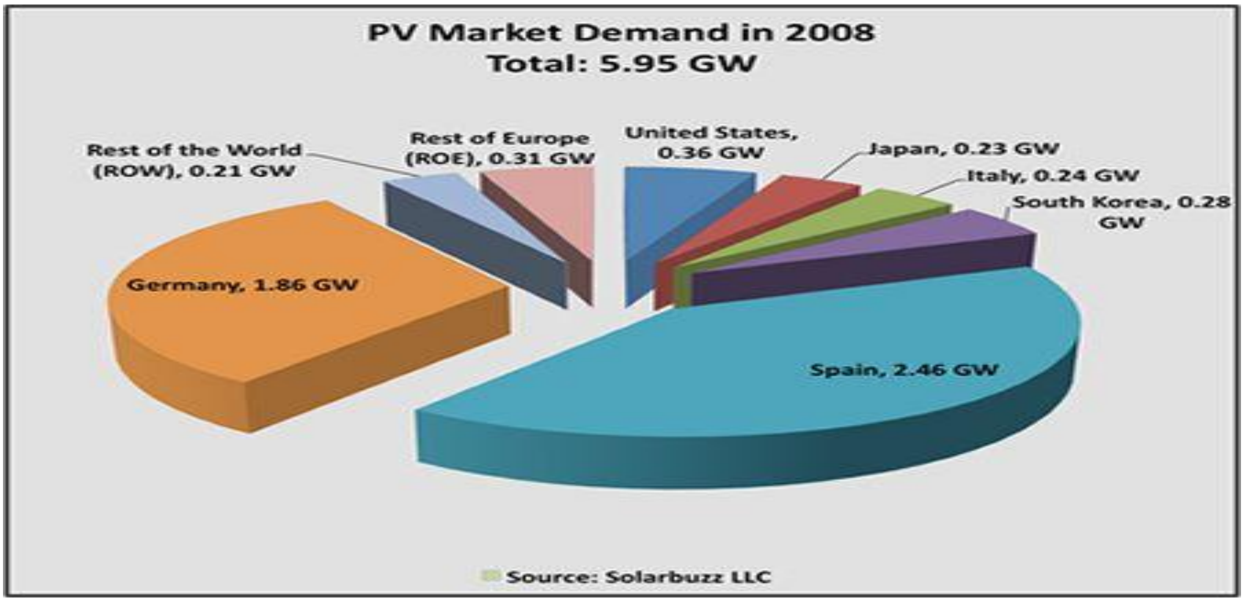
**Table 2.5: PV power market share by countries with more than 1 MWp cumulative PV power installed (December 2007)**

| **Country** | **Power (MWp)** | **Market share (%)** |
|---|---|---|
| Germany | 400 | 45 |
| Spain | 245 | 28 |
| USA | 142 | 16 |
| Italy | 17 | 2 |
| Japan | 17 | 2 |
| Korea | 13 | <2 |
| Portugal | 12 | <1.5 |
| Netherlands | 9 | 1 |
| Switzerland | 5 | <1 |
| Belgium | 3 | <0.5 |
| Australia | 2 | <0.5 |
| China | 2 | 0.2 |
| Austria | 1.5 | <0.2 |
| Czech Republic | 1.4 | <0.2 |
| Philippines | 1.1 | <0.1 |
| Reunion | 1 | <0.1 |

Source: Lenardic and Hug (2007)

According to Solarbuzz (2009), global solar PV market installations reached a record high of 5.95 GW in 2008 (more than the 5.6 GW that several studies had projected), growing by 110% over the previous year. Europe accounted for 82% of world demand in 2008. Spain's demand share grew by 285%, taking over first place from Germany in the market ranking, while the US retained its number three spot from 2007. Korea became the fourth largest PV market following rapid growth in 2008, closely followed by Italy and Japan. In total, 81 countries contributed to the 5.95 GW of global solar PV market installation (Solarbuzz, 2009).

**Figure 2.9: Global PV market demand in 2008**




Source: Solarbuzz (2009)

On the supply side, world solar cell production reached a consolidated figure of 6.85 W in 2008, up from 3.44 GW a year earlier (Solarbuzz, 2009). Overall capacity utilisation rose to 67% in 2008 from 64% in 2007. Meanwhile, thin film production also recorded solid growth, up 123% in 2008 to reach 0.89 GW. China and Taiwan continued to increase their share of global solar cell production, rising to 44% in 2008 from 35% in 2007 (Solarbuzz, 2009).

Polysilicon supply to the solar industry grew by 127% in megawatt terms, sufficient to substantially ease supply limitations in 2008. US polysilicon production accounted for 43% of the world's supply. Average global wafering capacity grew to 8.30 GW (up 81%) (Solarbuzz, 2009).

In dollar terms, the weighted 2008 average global factory gate crystalline module price increased by a modest 3% over 2007, notwithstanding the significant fall in the fourth quarter of 2008 (Solarbuzz, 2009). Preliminary first quarter 2009 data shows a decrease of up to 24% (manufacturer dependent) compared to the 2008 global weighted average. Meanwhile, the new report quantifies the global inventory build during the first quarter of 2009.

The PV industry generated $37.1 billion in global revenues in 2008, while successfully raising over $12.5 billion in equity and debt – up 11% on the prior year (Solarbuzz, 2009). Many countries have made significant progress in the development of PV industries, especially community-scale PV systems (ranging from 1 kW to 5 kW). A table summarising countries with community-scale PV systems is presented in Appendix A6.

### 2.4.4 Solar thermal energy, with special reference to solar water heating

#### 2.4.4.1 Global solar water heating

According to Holm (2005), more than 100 million $m^2$ (70 GWth) of SWHs have been installed worldwide, reducing $CO_2$ emissions by 18 million tonnes per year. Table 2.6 provides the ranking in absolute terms.

**Table 2.6: Global ranking of solar thermal energy in operation**

| | Water collectors | | | Air collectors | | Total area | Total capacity |
|---|---|---|---|---|---|---|---|
| Country | unglazed | glazed | evacuated tubes | unglazed | glazed | [m²] | [kW$_{th}$] |
| 1. China | 0 | 11 200 000 | 20 800 000 | 0 | 0 | 32 000 000 | 22 400 000 |
| 2. USA | 22 944 375 | 1 445 340 | 551 372 | 0 | 226 557 | 25 167 644 | 17 617 400 |
| 3. Japan | 0 | 11 755 008 | 311 481 | 0 | 0 | 12 066 489 | 8 446 500 |
| 4. Turkey | 0 | 8 130 000 | 0 | 0 | 0 | 8 139 000 | 5 691 000 |
| 5. Germany | 665 000 | 3 149 000 | 542 000 | 0 | 46 000 | 4 396 000 | 3 007 200 |
| 6.Israel | 0 | 3 900 000 | 0 | 0 | 0 | 3 900 000 | 2 730 000 |
| 7. Australia | 2 000 000 | 1 198 000 | 0 | 0 | 0 | 3 198 000 | 2 238 600 |
| 8. Greece | 0 | 2 990 000 | 0 | 0 | 0 | 2 990 000 | 2 093 000 |
| 9. Austria | 580 873 | 1 739 045 | 28 439 | 0 | 0 | 2 348 357 | 1 643 800 |
| 10. Switzerl | 233 529 | 275 698 | 16 642 | 825 000 | 0 | 1 350 869 | 945 600 |
| South Africa | 500 000 | 250 000 | 0 | 0 | 0 | 750 000 | 525 000 |
| Global [%] | 51,27 | 23,75 | 23,33 | 1,36 | 0,28 | 100 | >70000000 |

Source: (Holm, 2005)

China, the country with the largest population in the world, has the highest number of SWH systems. Market penetration is better reflected if ranking is expressed in square metre (or kWth) per 1 000 inhabitants (Holm, 2005). See Table 2.7.

**Table 2.7: Global ranking in m² and kWth per 1 000 inhabitants**

| Country | $m^2$ per 1 000 inhabitants | kW per 1 000 inhabitants |
|---|---|---|
| 1. Israel | 608 | 426 |
| 2. Greece | 298 | 209 |
| 3. Austria | 220 | 154 |
| South Africa | 16 | 11 |

Source: (Holm, 2005)

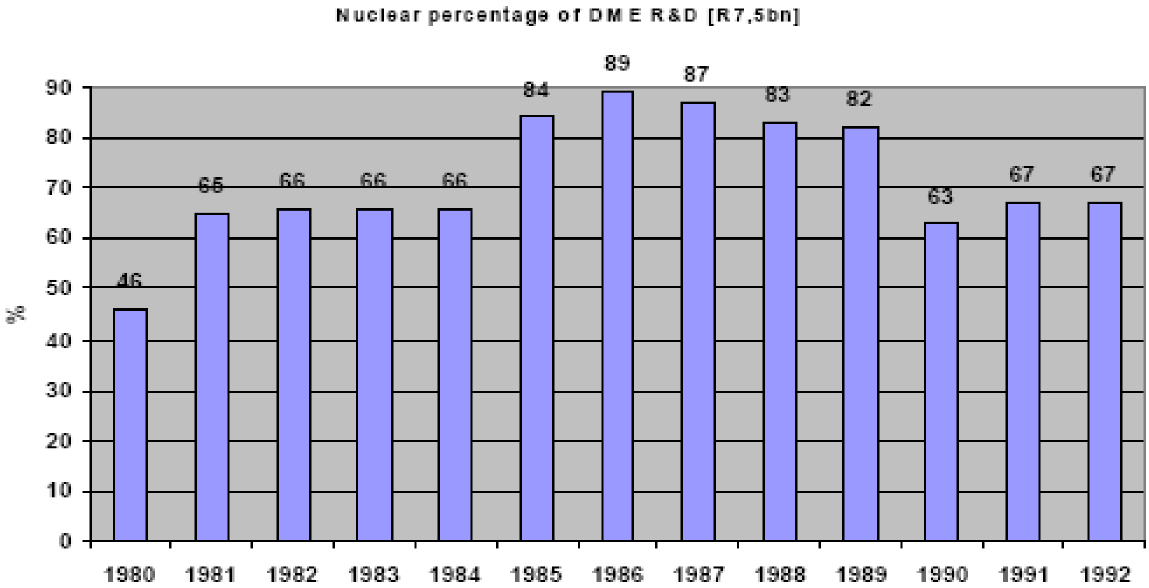
Israel, Greece and Austria have a mere fraction South Africa's solar radiation. However, their per capita use of SWHs is respectively 38, 19 and 14 times higher, while their electricity prices are only respectively 1.6, 1.3 and 2.4 times higher than South African process (Holm, 2005). Mandatory SWHs on all buildings less than 27 m high in Israel led to a market penetration in excess of 80% over 20 years, and the same regulation in Spain led to a ten-fold increase in SWHs in Barcelona since 1999 (Holm, 2005).

Holm (2005) argues that the global use of SWHs is driven by the socio-economic need for job creation, environmental concerns, energy security, national economy and peak demand reduction. The main barriers of lacking awareness and higher initial capital costs are more readily overcome where national governments legislate supportive policies (Holm, 2005). Of these, short-term input-related tax incentives and rebates to manufacturers have been least successful. Long-term performance-related incentives work better, and long-term mandatory regulations have produced the highest national benefit, cost reduction and market penetration.

### 2.4.4.2 Overview of the South African solar thermal industry

In line with the rest of the world, South Africa reacted to the energy crisis of 1970 by spending the bulk of public research and development (R&D) funding on the nuclear industry (Holm, 2005). See Figure 2.10.

**Figure 2.10: Percentage of public R&D budget spent on nuclear industry in South Africa**




Source: Holm (2005)

The trend continues today: a large proportion of R&D funding has been assigned to pebble bed modular reactors (PBMRs), while a small fraction is envisaged for R&D on coal, energy efficiency and renewable energy. According to Holm (2005), the tax money spent on the nuclear industry produced only 3.3% of South Africa's primary energy. He further argues that if the tax money was spent on the installation of a SWH on each house in South Africa the country would have been the world champion of installed SWHs, resulting in the creation of many local job opportunities, reduction in pollution and a reduction of about 18% in the electricity peak demand (Holm, 2005).

### 2.4.5 The cost of generating electricity

#### 2.4.5.1 Introduction

"In order to make sensible decisions about energy policy, policy makers need to be able to compare the costs and benefits of different types of electricity generating technologies on a like-for-like basis" (Parsons Brinckerhoff (PB) Power, 2006). In 2004 PB Power was commissioned by The Royal Academy of Engineering to undertake the underlying analytical work on technology costs, fuel costs, O&M costs and other costs associated with the production of electricity from a wide range of electricity generating technologies. Since 2004, significant changes had occurred in relation to electricity production in the UK: gas prices had risen considerably and the long-term security of supply had become a major issue of concern; advanced coal technologies started receiving more attention; the growth rate of renewables continued to fall short of the target; and nuclear power was under significant scrutiny (PB Power, 2006). In January 2006, the UK government launched its Energy Review to assess the progress made against the goals of the 2003 White Paper on Energy Policy and identify the options for further steps to achieve them (PB Power, 2006).

As a contribution to the Energy Review, PB Power re-examined the work it carried out for The Royal Academy of Engineering in 2004 and updated some of the assumptions it made at that time regarding capital costs of generating plants, fuel costs and discounts rates. The results of their latest study are presented in summary form below. Firstly, the methodology adopted in their study is discussed, followed by a discussion of the key sensitivities that have been analysed.

PB Power (2006) has utilised costs and prices apparent in the power generation market since 2004 for plant costs, O&M and carbon allowances set in the National Allocation Plan. The carbon and fuel pricing was referenced to the UK's department of Trade and Industry (DTI) long-term forecasts then. The analysis was carried out in real terms with 2006 being the base year, i.e. all construction for projects was assumed to have commenced in 2006 (PB Power, 2006).

#### 2.4.5.2 Process and methodology

A discounted operational cash flow model was adopted by PB Power to calculate the lifetime costs of electricity generation from the various technologies on a long-run marginal cost basis (PB Power, 2006). According to PB Power (2006), this is a widely used method for the analysis of power system costs. The comparisons made were cost comparisons that excluded any associated revenues that may have been received by the electricity generator (PB Power, 2006).

The capital investment in the generation technology was assumed to be financed ‘on balance sheet’ by market participants, which therefore removed the need for sensitivities relating to project/debt equity structures (PB Power, 2006).

The data used was based on information owned by PB Power through its involvement in the power industry, acting either for project developers, project financiers or project operators. The data relates to UK projects and was referenced wherever possible to independent external sources in the public domain (PB Power, 2006).

The calculation of lifetime costs of electricity generation did not take into account taxation or capital allowances and were intended to provide an indication of the costs of electricity production from the different technologies at the point of plant connection to the electricity grid (PB Power, 2006). Whilst the point of connection of a power generator to the electricity grid does affect the total costs of providing that power to the electricity market, the costs that arise due to transmission and distribution losses and the use of system charging applied by transmission and/or distribution network operators were not included in PB Power’s analysis. PB Power (2006) believed that it allowed for a fair comparison between technology types.

PB Power also excluded any revenues associated with support mechanisms such as the renewable obligation and the climate change levy exemption as these are subsidies designed to accelerate the development of sub-commercial or immature technologies (PB Power, 2006).

#### 2.4.5.3 Sensitivities

#### (a) Discount rate

Recognising that the electricity market has restructured significantly with the introduction of British Electricity Trading and Transmission Arrangements (BETTA) in April 2005 and the continued consolidation of independent power generation capacity within vertically integrated companies, PB Power (2006) decided to increase the base discount rate assumption of 7.5% they had initially used in the study of 2004. In their re-assessment of the work they carried out for The Royal Academy of Engineering in 2004, PB Power (2006) used a base discount rate of

10% because they believed it closely reflected the balance sheet expectations of the vertically integrated utilities. According to PB Power (2006), within any market there are risks for investors that are dependent on technology, regulatory/legislative uncertainty and input pricing over the project life. They maintained that the assumed discount rate recognises such market risks to a degree (PB Power, 2006). PB Power carried out the sensitivity analysis using discount rates of 7.5% and 12.5% to provide an indication of the effect of changes in the perception of potential investors (PB Power, 2006).

PB Power further argued that the discount rate appropriate to a specific project is dependent on the maturity of the technology, the residual risks within the project from un-contracted output or fuel supplies, and certain conditions relating to the site itself (ground conditions, grid access and others). Therefore, whilst generic assumptions can be made for a given technology type, these can only provide an indication of the relative costs of different technologies at a given point in time (PB Power, 2006).

#### (b) Capital costs

Capitals costs are the engineering, procurement and construction (EPC) costs of building a typical power plant within each generic technology type. According to PB Power (2006), the capital costs are sensitive to the following factors:

- Site-specific requirements relating to supporting infrastructure
- The duration of construction of the project (this affects the interest on the capital incurred during the construction period)
- Price variations due to equipment supply and demand in the market at any given time
- Development, financing and legal fees (project ‘soft costs’)

There is no correct answer pertaining to the cost of a given technology; rather the costs will lie within a range that is representative of what can be expected in a typical competitive tendering process at a given point in time (PB Power, 2006). The capital costs used by PB Power in their 2006 cost review were based on the information available to PB Power through its involvement in power generation projects globally, with specific emphasis on UK activities (PB Power, 2006). Their internal database of specific average capital costs was referenced to external independent reports on capital costs wherever possible to support the assumptions they used in their analysis (PB Power, 2006).

PB Power (2006) carried out the capital cost sensitivity analysis that reflected market expectations of the range of capital cost outcomes for each technology in the market. The capital cost sensitivity inputs are presented in Table 2.8.

**Table 2.8: Summary of capital cost sensitivities**

| **Technology** | **Specific capital cost (£/kW)** | **Market expectations** | |
|---|---|---|---|
| | | Low (£/kW) | High (£/kW) |
| Coal PF | 687 | 618 | 860 |
| Coal CFBC | 611 | 550 | 765 |
| Biomass BFBC | 1 744 | 1 570 | 2 000 |
| Coal IGCC | 1 000 | 800 | 1 250 |
| Gas OCGT | 366 | 330 | 410 |
| Gas CCGT | 340 | 275 | 375 |
| Wind (onshore) | 824 | 596 | 1 070 |
| Wind (offshore) | 1 236 | 892 | 1 375 |
| Wave | 2 850 | n/a | n/a |
| Tidal | 2 200 | n/a | n/a |
| Nuclear | 1 050 | 1 000 | 1 200 |

Source: PB Power (2006)

### (c) Fuel costs

The three main primary energy sources for electricity generation in the UK are coal, gas and nuclear. According to PB Power (2006), there was a significant movement in fuel prices in the period 2004 to 2006. This trend is summarised in Table 2.9.

**Table 2.9: Movements in fuel pricing between 2004 and 2006**

| Pricing date | Electricity (£/MWh) | Coal ($/tonne) | Gas (p/therm) | Nuclear (£/MWh) |
|---|---|---|---|---|
| March 2004 | 21.25 | 70.00 | 24.25 | 4.60 |
| March 2006 | 50.83 | 61.00 | 55.18 | 4.60 |

Source: PB Power (2006)

The price of gas had more than doubled in the two years leading to 2006. The annual contract price for gas as at 2 March 2006 was in the region of 57p/therm[5] and this value was projected to hold relatively steady at 55p/therm up to the summer of 2008 (PB Power, 2006). However, there was a body of opinion that saw longer-term pricing reverting back towards the levels of 2004. To reflect this longer-term view, PB Power referenced their gas pricing to the published DTI high, medium and lower price tracks of the time, and these were escalated into 2006 real values for their study.

The movements in the coal price between 2004 and 2006 were largely attributed to a shortage of shipping capacity pushing up the transportation proportion of the coal costs (PB Power, 2006). During the time of the review the coal price appeared to have reverted to the levels seen in early 2004 – around $60/tonne. PB Power used the DTI published coal price tracks as a reference for the required long-term coal pricing, taking the central price track as the base case for their study (PB Power, 2006). The DTI prices were escalated to 2006 real prices.

According to PB Power (2006), most studies propose a nuclear fuel cost of about £4/MWh. During the time of the review there was a debate in the industry about the sustainability of uranium supply and the resultant prices, but the fuel cost component of the total cost of generation is relatively small (PB Power, 2006). A 10% increase in input uranium prices results in a variation in electricity generation cost of just 0.2% (PB Power, 2006). In addition to the front-end fuel preparation costs there is a potential range of costs associated with the back-end waste processing and disposal costs. A  study in the US estimated that fuel waste disposal costs would be covered by a charge of 0.1 US cent per kWh, equivalent to 0.06 pence per kWh (PB Power,

[5] Penny (p) is a British coin; 100 pence = 1 British Pound. Therm is a unit of heat equivalent to 100 000 British thermal units (Btu).

2006). This would therefore bring the total fuel costs to 0.46 pence per kWh, which PB Power used in their analysis.

### (d) Operation and maintenance costs

For the review, O&M costs were based on PB Power's internal database of project costs. As with the capital costs the data was supplemented with independent external sources. The O&M costs included the following:

- Long-term service agreements
- Routine maintenance costs
- Cost of consumables
- Nuclear decommissioning costs

### (e) General and administration costs

These costs were also based on PB Power's internal database of project costs, and as with the capital costs were supplemented with independent external sources. The costs included the following:

- Staff
- Administrative overheads
- Business rates
- Plant insurances

### (f) Carbon emissions

According to PB Power (2006), the element of uncertainty surrounding carbon pricing that existed in 2004 was no longer an issue in 2006. The National Allocation Plan for the first phase of the EU Emissions Trading Scheme (EU ETS) (to the end of 2007) provided power generation plants with carbon credits for 95% of their annual carbon emissions. The remaining credits had to be purchased from other participants in the carbon market (PB Power, 2006). The allowance levels for the second phase of the EU ETS were still in the process of being developed during the review, and it was for that reason that PB Power provided sensitivities relating to a variation in the level of free allocation provided to power generation plants. PB

Power (2006) therefore used the market-based carbon price that fell within the DTI's longer-term carbon credit cost estimates that ranged from €10/tonne to €40/tonne. The sensitivity inputs are summarised in Table 2.10.

**Table 2.10: Carbon allowance sensitivities**

| Carbon allowance (% annual emissions) | | Carbon price | |
|---|---|---|---|
| | | (€/tonne $CO_2$) | (£/tonne $CO_2$) |
| Base case | 95% | 25.80 | 17.72 |
| Case A | 85% | - | - |
| Case B | 75% | - | - |

Source: PB Power (2006)

**(g) Standby energy**

Standby energy represents the costs incurred by an electricity generator in replacing energy that it is contracted to supply but which it fails to supply because of a forced outage of its power plant (PB Power, 2006). This element of the costs is intended to provide an indication of the extent to which technical reliability (based on calculations of typical forced outage rates) of the various plant types contribute to their overall costs of generation (PB Power, 2006). When a generator fails to produce electricity due to forced outage, it will need to purchase replacement electricity for its lost output in order to meet its contractual obligations. The cost of the replacement energy is assumed to come from a generation plant that is already operating on the system but which has the capability to provide additional energy at short notice.

PB Power considered the forced outage scenario in their analysis by including the cost incurred by the generator to buy its lost output from a reserve generator. According to PB Power (2006), the reserve generator is assumed to be a coal plant and the plant cost assumptions relating to the provision of standby energy are those used in the analysis for coal PF plant.

**(h) System integration costs**

In the study done by PB Power (2006), it was indicated that the wide-scale integration of intermittent electricity generation sources, such as wind power, had inherent risks with respect to the short-term predictability of wind farm output given the potential rate of change of turbine output with wind speed (PB Power, 2006). According to PB Power (2006), findings from several studies have indicated that the range of additional system costs arising from connection of significant wind generation into transmission systems falls between 0.03p/kWh and 0.3p/kWh when the costs are spread across all electricity consumption in the market. The value of 1.6p/kWh was reported when the additional costs were recovered solely from wind generation output.

**(i) Exchange rates**

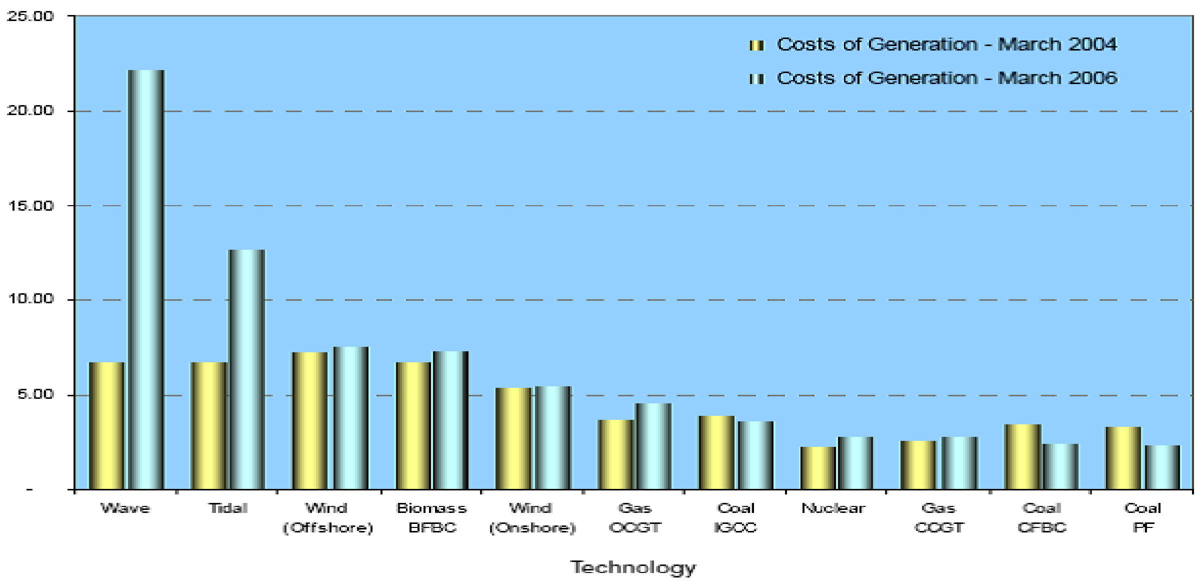
PB Power (2006) used the following exchange rates in deriving the capital, fuel, O&M and carbon costs in GBP:

- GBP:EUR 1:1.456
- GBP:USD 1:1.735

#### 2.4.5.4 Comparison and review of electricity generation costs

Figure 2.11 shows the electricity generation costs for all technologies in p/kWh from March 2004 to March 2006.

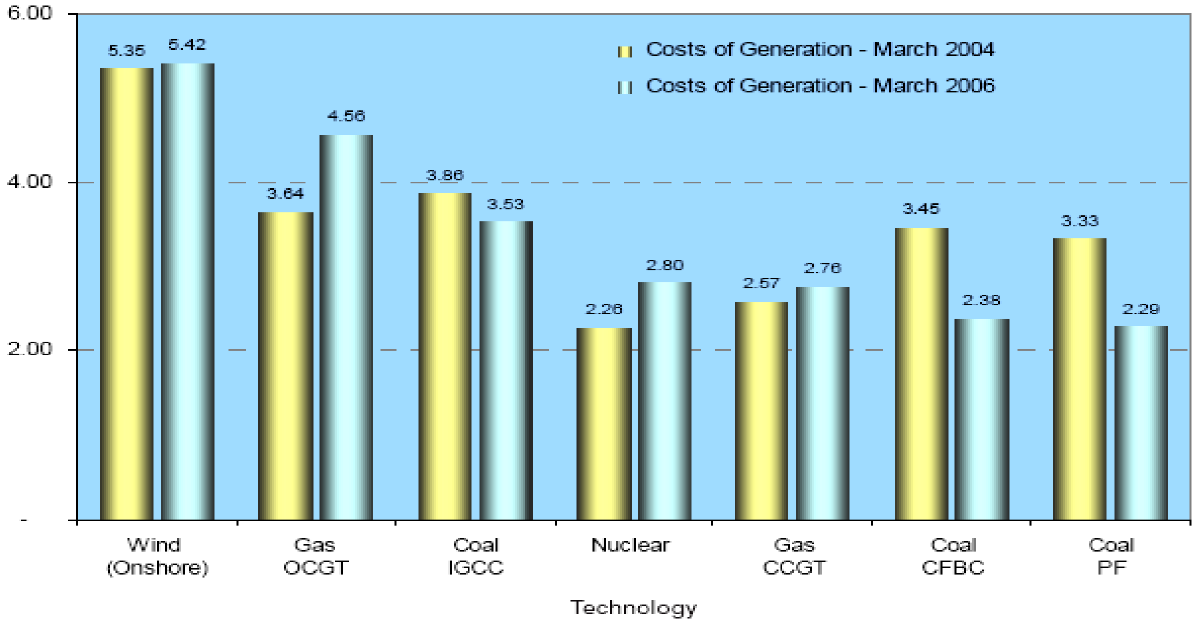
**Figure 2.11: Comparison of electricity generation costs for all technologies – March 2004 and March 2006 in p/kWh**




Source: PB Power (2006)

Figure 2.12 shows comparison of electricity generation costs for main technologies in p/kWh from March 2004 to March 2006.

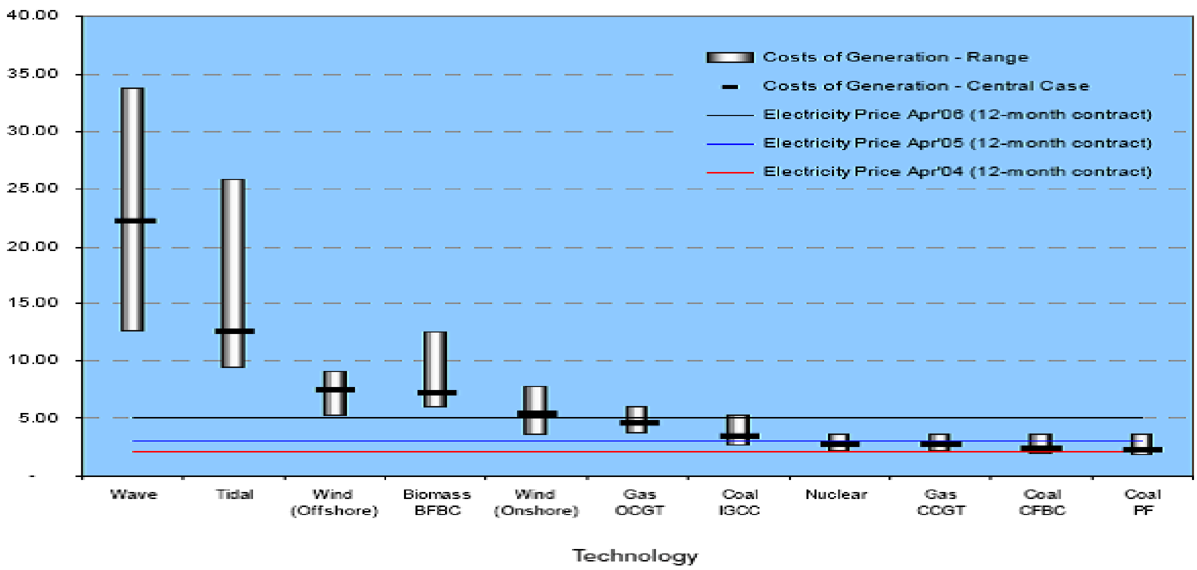
**Figure 2.12: Comparison of electricity generation costs for 'main' technologies – March 2004 and March 2006 in p/kWh**




Source: PB Power (2006)

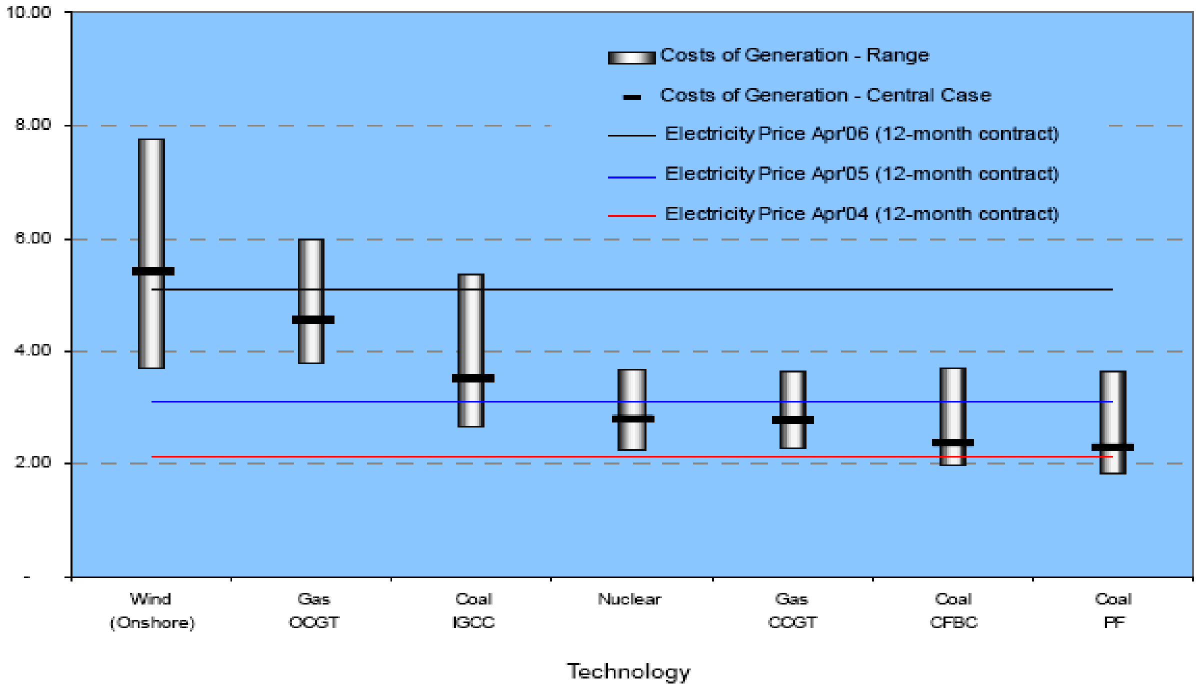
Figures 2.13 and 2.14 show the review of electricity generation costs for all technologies and main techonoligies respectively.

**Figure 2.13: Review of electricity generation costs for all technologies – range of costs in p/kWh**




Source: PB Power (2006)

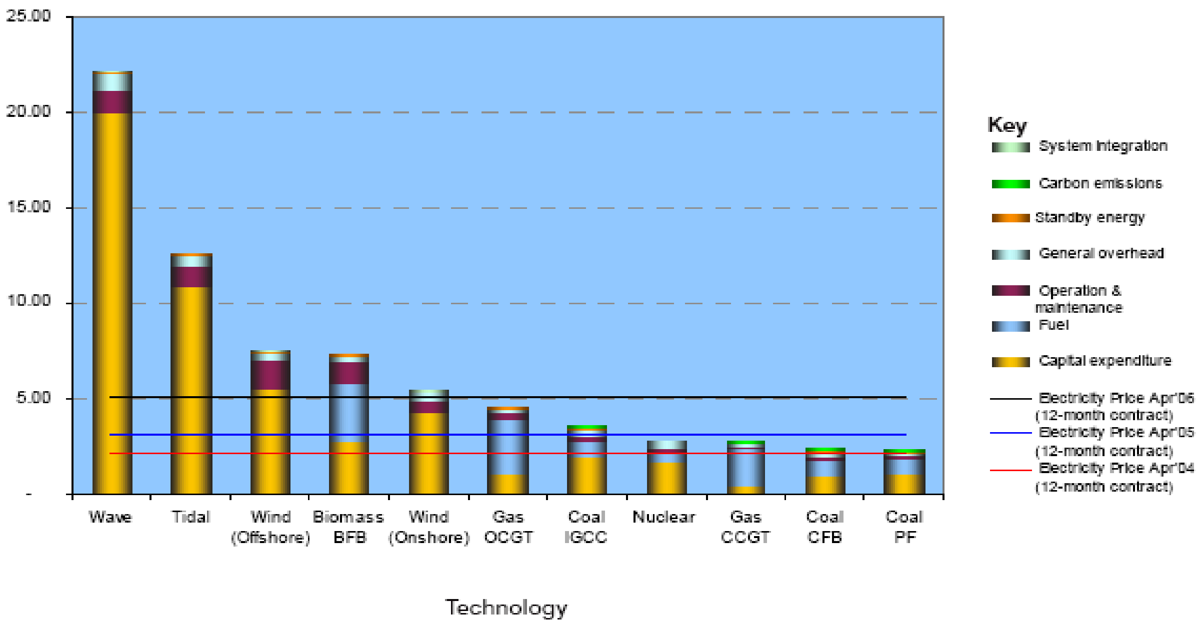
**Figure 2.14: Review of electricity generation costs for 'main' technologies – range of costs in p/kWh**




Source: PB Power (2006)

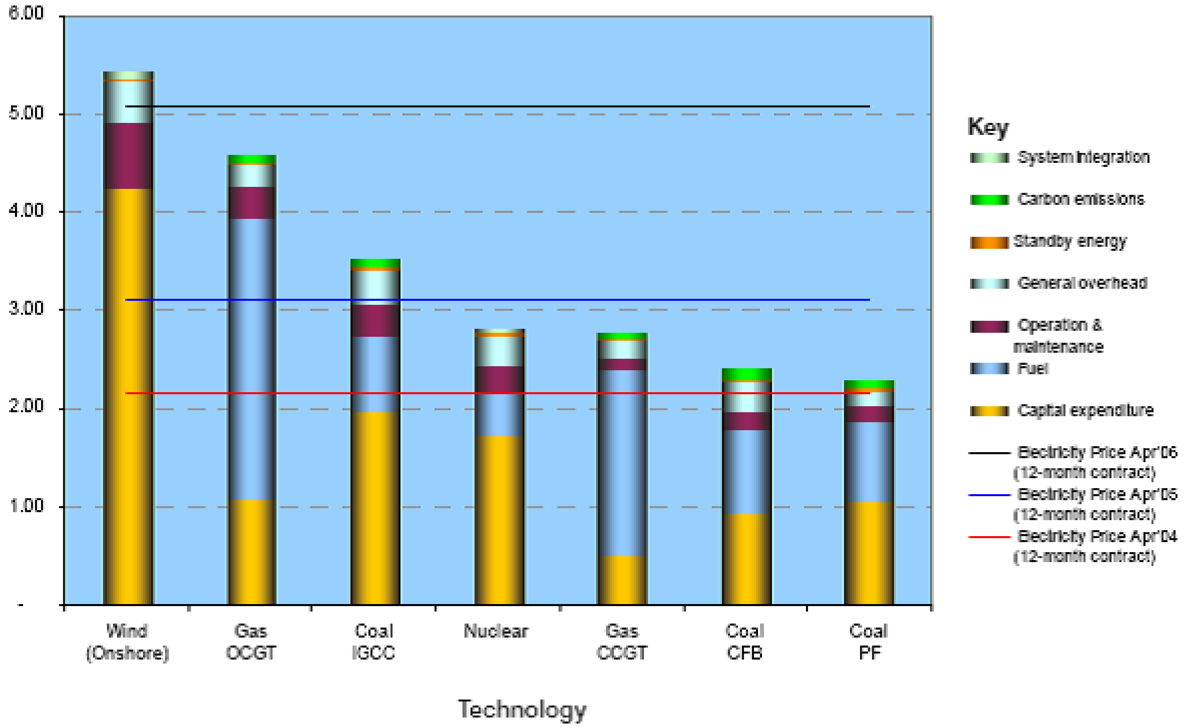
Figures 2.15 and 2.16 shows cost breakdown in p/kWh for all technologies and main technologies respectively.

**Figure 2.15: Review of electricity generation costs for all technologies – cost breakdown in p/kWh**




Source: PB Power (2006)

**Figure 2.16: Review of electricity generation costs for 'main' technologies – cost breakdown in p/kWh**




Source: PB Power (2006)

### 2.4.6 Life-cycle cost analysis methodology

#### 2.4.6.1 Introduction to life-cycle approaches

The objective of this research is to demonstrate that a life-cycle approach rather than the more traditional once-off capital cost approach generates results that demonstrate that sustainable living through the use of solar-powered communities can be affordable for both households and the tax base of the country or city. This has been achieved by collecting data on the life-cycle costs of coal-fired power stations as well as residential solar power systems (comprising a SWH and a PV roof tile system). Conclusions were reached by measuring and comparing the 40-year life-cycle cost effectiveness of the two alternatives. The results are expressed as net present values (NPVs), using a discount rate of 9%. (Discount rate will be discussed in more detail in Chapter 5.)

According to (Burger & Swilling, 2009), several life-cycle methodologies are used in response to the global demand for tools to determine the material and energy content of particular production and consumption processes, as well as environmental impacts. Burger and Swilling (2009) argue that a life-cycle approach is necessary because it has become imperative to take into account the full capital and operational costs of a given production or consumption process over the life-cycle of the process. They further argue that without this kind of analysis it will not be possible at the design stage to determine which process will contribute most towards achieving a more sustainable socio-ecological regime, or alternatively, which one will do the least damage.

However, Burger and Swilling (2009) maintain that a wide range of life-cycle methodologies have emerged for different purposes. These included the following: life-cycle assessment (LCA), material input per unit of service (MIPS), environmental risk assessment (ERA), material flow accounting (MFA), accumulative energy requirements analysis (CERA), environmental input-output analysis (env.IOA), life-cycle cost analysis (LCCA), total cost accounting (TCA), cost-benefit analysis (CBA), cost effectiveness analysis (CEA) and analytical tools for eco-design. The analysis and discussion of these methodologies is not within the scope of this thesis. Suffice it to say that a LCCA approach has been adopted in this thesis because this makes it possible to compare the conventional approach of more supply of mega-power capacity to a more demand-oriented approach of distributed micro-power across the life-cycle. The essence of this approach (Wrisberg et al., 2002, cited in Burger & Swilling, 2009) is that it does not quantify benefits like CBA does. LCCA determines the least costly option of attaining a predefined target after the fundamental decision process has been finalised (Burger & Swilling, 2009). CBA, by contrast, is used to assess viability of an investment by quantifying the future realisation of costs and benefits, generally through discounted cash-flow analysis (Burger & Swilling, 2009). Burger and Swilling (2009) argue that an investment is viable if the present value of all benefits exceeds the present value of all costs. The net present value (NPV) should therefore indicate a positive return. A detailed discussion of LCCA, the approach adopted in this thesis, follows in the next section.

#### 2.4.6.2 Life-cycle cost analysis

Life-cycle cost analysis (LCCA) is a method for assessing the total cost of system/facility or equipment ownership. It takes into account all costs of acquiring, operating, maintaining and disposing of a system (Barringer, 2003; Fuller, 2008; Hunkeler et al., 2009). Often the purchase price or initial cost does not reflect the real cost, either to the decision maker or cost bearer. This is due to the life-cycle stages, up and downstream from production or purchasing, contributing to the cost of ownership (Hunkeler et al., 2009). According to Fuller (2008), in addition to LCCA, there are other measures of economic evaluation, such as savings-to-investment ratio, internal rate of return and payback period, which can be used to determine cost effectiveness. But LCCA is especially useful when project alternatives that fulfil the same performance requirements, but differ with respect to initial costs and operating costs, have to be compared in order to select the one that maximises net savings (Fuller, 2008). For example, in this thesis, LCCA will help determine whether the installation of a residential solar power system (comprising PV roof tile and SWH) on the roof of a million or more houses – which may increase initial cost but result in dramatically reduced operating and maintenance costs – is more cost effective than the development of a new coal-fired power plant.

**(a) The costs**

There are numerous costs associated with acquiring, operating, maintaining and disposing of or decommissioning of a facility/system and/or equipment. According to various authors (Barringer, 2003; Hunkeler et al., 2009; Fuller, 2008), these costs fall into the following categories:

- Initial costs – purchase, acquisition and construction costs

Initial costs may include capital investment costs for land acquisition, construction or renovation and for the equipment needed to operate a facility (e.g. power station).

- Fuel costs – energy, water and other costs

According to Fuller (2008), the operational expenses for energy, water and other utilities are based on consumption, current rates and price projections. Energy prices are assumed to increase or decrease at a rate similar to or different from general price inflation. The energy price escalation needs to be considered when estimating future energy costs. Water costs should be handled much like energy costs.

- Operation, maintenance and repair costs

Operation, maintenance and repair (OM&R) costs are often more difficult to estimate than other costs (Fuller, 2008). The author argues that operating schedules and standards of maintenance vary from project alternative to the other. In this case it is therefore important to use expert judgement when estimating these costs.

- Replacement costs

The number and timing of capital replacement of a power system, for example, depend on the estimated life of the system and the length of the study period. It is recommended that the same sources that provide cost estimates for initial investments are used to obtain estimates of replacement costs and expected useful lives (Barringer, 2003; Fuller, 2008). Barringer (2003) and Fuller (2008) maintain that a good starting point for estimating future replacement costs is to use their (replacement) cost from the base year. The LCCA method will escalate base-year amounts to their future time of occurrence.

- Residual values – resale or salvage values or disposal or decommissioning costs

The residual value of a system (or component) is its remaining value at the end of its life/study period, or at the time of its replacement during the study period. Fuller (2008) argues that, as a rule of thumb, the residual value of a system with remaining useful life can be calculated by linearly prorating its initial costs. For example, for a solar water heater with an expected useful life of 25 years, which was installed 10 years before the end of the study period, the residual value would be approximately [(25-10)/25] = 3/5 or 60% of its initial cost.

- Other costs – finance charges (loan interest payments), non-monetary benefits or costs

Finance charges are usually included in the contract payments negotiated with the energy service company or utility. Non-monetary benefits or costs (often referred to as externalities) are project-related effects for which there is no objective way of assigning a value in real monetary terms. Examples of non-monetary effects may be the benefits derived from the fresh air as a result of not building a coal-fired power station, or from an expected but hard to quantify productivity gain in a workplace due to improved natural lighting and ventilation. These effects, by their nature, are external to the LCCA, but if they are significant (like polluted air due to the operation of a coal-fired power plant) they should be considered in the final investment decision and included in the project documentation (Fuller, 2008).

Fuller (2008) argues that only those costs within each category that are relevant to the decision and significant in amount are needed to make a valid investment decision. He further argues that costs are relevant when they are different for one alternative compared with another; costs are significant when they are large enough to make a credible difference in the LCC of a project alternative. All the costs are entered as base-year amounts in today's money; the LCCA method escalates all the amounts to their future year of occurrence and discounts them back to the base year to convert them to present values (Fuller, 2008).

**(b) The parameters for present value analysis**

- Discount rate

According to Fuller (2008), in order to be able to add and compare cash flows that are incurred at different times during the life-cycle of a project, they have to be made time equivalent. In order to do this, the LCC method converts them to present values by discounting them to a common point in time, usually the base year. The interest rate used for discounting is a rate that reflects an investor's opportunity cost of money over time, meaning that an investor wants to achieve a return at least as high as that of his/her next best investment. Hence, the discount rate represents the investor's minimum acceptable rate of return. Fuller (2008) argues that the discount rate for energy and water conservation projects – the real discount rate, not including the general rate of inflation – should be determined annually by the relevant stakeholders (e.g. government agencies or private entities).

- Cost periods

According to Fuller (2008), the cost period can refer to the length of the study period, service period or contract period. Since this thesis focuses on operational costs, all cost periods would be the service period over which operational and maintenance costs and benefits are evaluated. This service period will be equivalent to the life span of the project alternatives starting with the base year, i.e. the year to which all cash flows are discounted.

- Discounting convention

All annually recurring cash flows (e.g. operational costs) are discounted from the end of the year in which they are incurred. All single amounts (e.g. replacement costs) are discounted from the year they occur (Fuller, 2008).

**(c) Life-cycle cost calculation**

After identifying all costs by year and amount and discounting them to present values, they are added to arrive at the total life-cycle costs for each alternative. Fuller (2008) gives the following formula for total LCC:

LCC = I + R + E + W + OM&R + O – r

- LCC = Total LCC in present value (PV) money of a given alternative
- I = PV of investment costs (initial costs) (if incurred at base year, they need not be discounted)
- R = PV of capital replacement costs
- E = PV of energy costs
- W = PV of water costs
- OM&R = PV of non-fuel operation, maintenance and repair costs
- O = PV of other costs
- r = PV of residual value (resale or salvage value) less disposal costs

The project alternative with the lowest LCC shows cost effectiveness compared to other project alternatives.

**(d) Uncertainty assessment in life-cycle cost analysis**

Various authors (Barringer, 2003; Fuller, 2008; Hunkeler et al., 2009) argue that the decision about project-related investments (e.g. power projects) typically involve a great deal of uncertainty about their costs and potential savings. LCCA greatly increases the likelihood of choosing a project that saves money in the long term. Yet there may be some uncertainty associated with the LCC results. These authors argue that LCCAs are usually performed in the design process when only estimates of costs and savings are available, rather than real money amounts. They further maintain that uncertainty in input values means that actual outcomes may differ from estimated outcomes. Different techniques can be used to assess uncertainty of input variables but there are two that often form part of the LCCA, namely sensitivity analysis and break-even analysis.

- Sensitivity analysis

Sensitivity analysis is the technique recommended for energy and water conservation projects. It is useful for the following:

  - To identify which of the uncertain input values has the greatest impact on a specific measure of economic evaluation (e.g. LCCA)
  - To determine how variability in the input value affects the range of a measure of economic evaluation
  - To test different scenarios to answer 'what if' questions

To identify critical parameters, arrive at estimates of upper and lower bounds, or answer 'what if' questions, simply change the value of each input up or down, holding all others constant, and recalculate the economic measure (e.g. LCCA) to be tested (Fuller, 2008).

- Break-even analysis

Fuller (2008) maintains that decision makers sometimes want to know the maximum cost of an input that will allow the project to still break even, or conversely, what minimum benefit a project can produce and still cover the costs of the investment. To do this break-even analysis is performed.

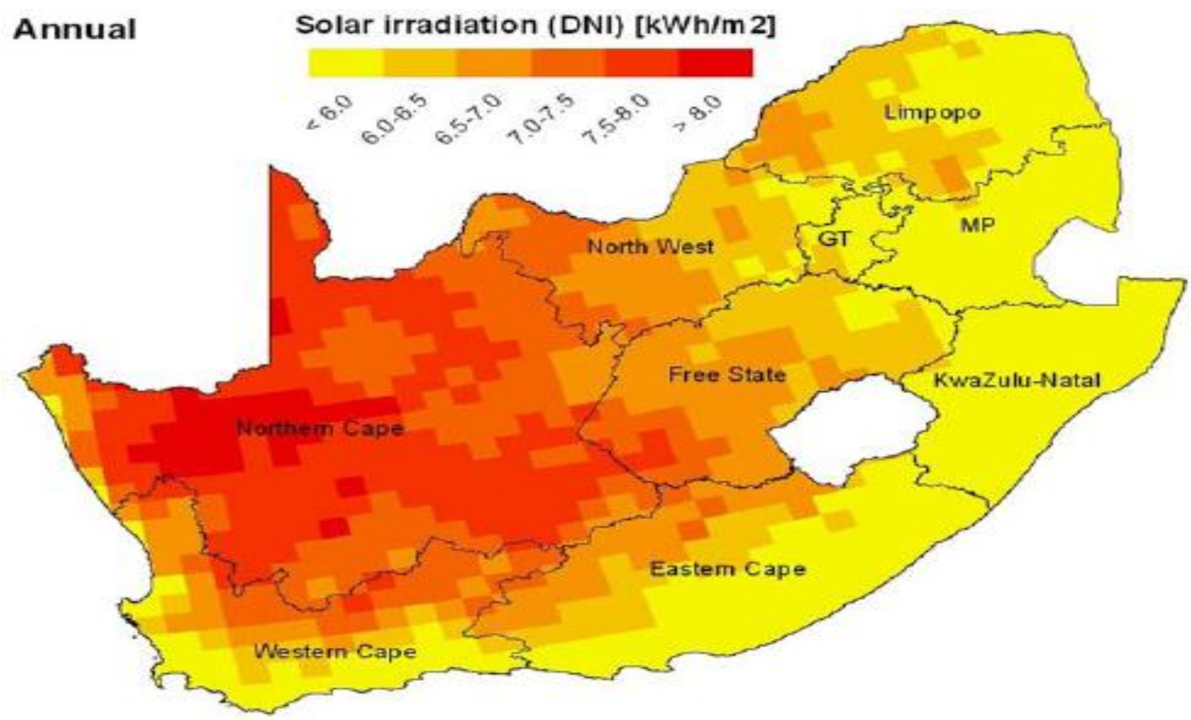
**(e) Why LCCA?**

Authors such as Barringer (2003), Fuller (2008) and Hunkeler et al. (2009) argue that LCCA can be applied to any capital investment decision in which relatively higher initial costs are traded for reduced future cost obligations. LCCA provides a significantly better assessment of the long-term cost effectiveness of a project than an alternative economic method that focuses only on first costs or on operation-related costs in the short-term. In order words, the balance between all cost items of the project alternative is achieved through LCCA.

### 2.4.6 South African solar power resource

The solar radiation that South Africa receives ranges from around 1 450 kWh/m$^2$ to about 1 950 kWh/m$^2$ per year, compared to Europe which on average receives 910 kWh/m$^2$ per year. According to Fluri (2009), South Africa receives some of the best solar radiation in the world (see Figure 2.17).

**Figure 2.17: Average daily direct normal irradiation in kWh/m$^2$ for South Africa for the whole year**




Note: GT and MP in the map represent Gauteng and Mpumalanga respectively

Source: Fluri (2009)

The Northern Cape every year records some of the highest aggregates of sunny days a year worldwide. Upington (in the Northern Cape) has one of the highest solar values in the world with a direct normal insolation (DNI) level of approximately 2 900 kWh/m$^2$ per year (see Table 2.11).

**Table 2.11: International solar potential relative to South Africa**

| Location | Site latitude | Annual DNI ($kWh/m^2$) | Relative solar resource |
|---|---|---|---|
| South Africa | | | |
| Upington, Northern Cape | 28 °S | 2 995 | 100% |
| United States | | | |
| Barstow, California | 35 °N | 2 725 | 92% |
| Las Vega, Nevada | 36 °N | 2 573 | 87% |
| Albuquerque, New Mexico | 35 °N | 2 443 | 83% |
| International | | | |
| Northern Mexico | 26-30 °N | 2 835 | 96% |
| Wadi Rum, Jordan | 30 °N | 2 500 | 85% |
| Ouarzazate, Morocco | 31 °N | 2 364 | 80% |
| Crete | 35 °N | 2 293 | 78% |
| Jodhpur, India | 26 °N | 2 200 | 74% |
| Spain | 34 °N | 2 100 | 71% |

Source: Eskom (2007)

Most areas in South Africa average more than 2 500 sunshine hours per year, and average solar radiation levels range between 4.5 and 6.5 kWh per $m^2$ in one day (Create Acceptance, 2007). Looking at it another way, the annual daily solar radiation average for South Africa is about 220 $W/m^2$, compared with about 150 $W/m^2$ for parts of the US, and about 100 $W/m^2$ for Europe and the United Kingdom. South Africa is endowed with adequate solar energy that should be tapped for energy security and mitigation of climate change.

According to Fluri (2009) five out of the nine provinces of South Africa, i.e. Northern Cape, North West, Free State, Eastern Cape and Western Cape, include areas with an annual average DNI higher than 7.0 $kWh/m^2/day$, but in North West Province these areas are located too far from transmission lines. Due to these climatic variations around the country, solar power installations in aforementioned provinces will perform better than in other provinces. For example, the cost of producing a kilowatt-hour will be lower in Northern Cape than in Kwazulu Natal.

## 2.5 Closing remarks

Chapter 2 featured a discussion of the discourse of sustainable development for improving human welfare, maintaining ecological integrity and achieving equal distribution of life-sustaining resources, as well as the discourse of ecological design for infrastructure networks that emphasise consumer service and choice. It was stated that the negative impacts of the poor design of urban development on the environment and communities could be reversed by resource transfer through positive development. A shift is required away from the conventional design approach of delivering more supply capacity, to a new demand-oriented paradigm of efficiently managing and conserving essential resources. The chapter then looked at the global developments in the renewable energy sector to provide perspective on the global renewable energy market, with special focus on solar PV and SWH systems. The processes and procedures adopted in other countries in determining the costs of generating electricity were discussed. A life-cycle cost analysis (LCCA) was briefly discussed, since this methodology was used to generate the findings of this research study.

Chapter 2 concluded by giving a brief overview of South African solar resources. It was pointed out that South Africa receives some of the best solar radiation in the world.

# Chapter 3 : Research design and methodology

## 3.1 Introduction

To achieve the objectives of this study (see Chapter 1), different research methods are adopted, which are detailed in this chapter. In Chapter 2 subject literature was employed to assess the processes and approaches that other countries have adopted in determining the costs of generating electricity. It included a review of renewable energy within the realm of ecological design, with special reference to solar PV and thermal technology as possible solutions to achieve sustainable development.

According to Yin (2009: 4), there is no formula to knowing which research method to use; the choice depends largely on the research questions. When to use which method depends on three conditions: (a) the type of research questions posed, (b) the extent of control a researcher has over actual behavioural events, and (c) the degree of focus on contemporary as opposed to historical events (see Table 3.1).

**Table 3.1: Relevant situations for different research methods**

| | **(a)** | **(b)** | **(c)** |
|---|---|---|---|
| **METHOD** | **Form of research questions** | **Requires control of behavioural events?** | **Focuses on contemporary events?** |
| **Experiment** | How, why? | Yes | Yes |
| **Survey** | Who, what, where, how many, how much? | No | Yes |
| **Archival analysis** | Who, what, where, how many, how much? | No | Yes/No |
| **History** | How, why? | No | No |
| **Case study** | How, why? | No | Yes |

Source: Yin (2009)

The research questions for this study (see Chapter 1) have taken the form of 'what' and 'how' questions? These questions are exploratory in nature and are guided by both quantitative and qualitative methods so as to ensure "solutions that are not informed by the 'one-dimensional mapping' of a singular approach" (Smit, 2009: 63). The research methods outlined in Table 3.1 are exploratory in nature.

Yin (2009: 9) asserts that if research questions focus mainly on 'what' questions, one of two possibilities arises. Firstly, some type of 'what' questions are exploratory, such as the following: "To what extent can solar PV roof tiles' investment value be magnified by energy efficiency measures and/or ecological design for community building?" This question justifies conducting an exploratory study, the goal being to "develop pertinent hypotheses and propositions for further inquiry" (Yin, 2009: 9). According to Yin (2009), any of the five research methods in Table 3.1 can be used for an exploratory study. Secondly, 'what' questions can take the form of a 'how many' and 'how much' line of inquiry. These are more likely to favour survey or archival analysis (Yin, 2009).

On the other hand, 'how' and 'why' questions are more explanatory and are likely to lead to the use of case studies, histories and experiments (Yin, 2009). The following serves as an example of such a question: "How can alternative financial sources, such as carbon finance, certified emissions reductions (CERs) and renewable energy certificates (RECs), be used to make an investment financially viable?"

Kelly (2009: 11) says that a researcher should make explicit his/her research assumptions and reasons for using specific methods and tools for collecting information.

According to Mouton (2001: 56, cited in Kelly, 2009: 10), the research design outlines the kind of study to be undertaken and the kind of results that are expected, whereas research methodology is about the processes, procedures, tools and methods that are used to gather and process information.

## 3.2 Research design

As discussed in Chapter 1, this research report investigates the feasibility of a domestic/residential solar thermal and PV system (comprising a solar water heater and relatively small size solar PV roof tile system (5 kW)) that would reduce electrical demand of an average South African household to an absolute minimum. A 3.3 kW PV roof tile system and a 300 litre SWH were installed at the new crèche built at Lynedoch Eco-village, Stellenbosch, South Africa. Because of the installation of a 1.7 kW PV roof tile system a year earlier at the guesthouse at Lynedoch Eco-village, the total PV roof tile capacity at Lynedoch is 5 kW. The aim is to use the operational results from the 5 kW PV roof tile experiment at Lynedoch as a basis for developing a model for a million households that will have a 5 kW PV system plus a SWH. The focus of the million households model is operating costs over 40 years, on the assumption that the capital costs are financed from coal-fired generation capacity that will no longer be needed. Basically, the life-cycle cost effectiveness analysis (LCCA) of the million households model is carried out. The results are compared to the life-cycle costs of coal-based electricity.

The energy use of the new crèche was monitored as well as the energy savings due to the energy production by solar PV roof tiles and the SWH. The crèche’s energy savings per month/year were recorded and the scenario for total savings for a million or more houses was created. Based on the average cost of municipal electricity (55c/kWh), the savings in monetary terms were determined.

Exploratory research such as this attempts to achieve the following (Smit, 2009: 66):

- Test the feasibility of undertaking an extensive study
- Satisfy the curiosity of the researcher and desire for better understanding
- Develop methods to be employed in any subsequent study
- Determine priorities for future research
- Develop new hypotheses about an existing phenomenon

## 3.3 Unit of analysis

Lynedoch Eco-village,[6] founded by Eve Annecke (director of Sustainability Institute), "is the first ecologically designed socially mixed community", and is situated in Stellenbosch near Cape Town, South Africa. At Lynedoch, where the Sustainability Institute is located, a new crèche for local children has been equipped with a solar PV roof tile system and SWH (see Chapter 4). This system was sized to provide power that would offset some of the household electrical load. The crèche is an old building that was designed to conform to the usual energy consumption patterns, with no particular orientation suited to ecological design. The solar PV roof tile system is grid interactive, producing direct current (DC) that is converted to alternating current (AC) and then fed directly into the local electricity distribution system.

## 3.4 Research methods

The research methods outlined below explains how the research process was undertaken. This involved identifying the key data sources from which decisions about the research process were justified as well as data used to generate the findings of the study (Smit, 2009: 69).

The use of excel spreadsheets, assumptions/inputs into spreadsheet, and financial modelling to evaluate life-cycle cost effectiveness of a residential solar system (PV and SWH) and a coal-fired power plant were adopted in this study. Interviews with the founders and staff of the Sustainability Institute were carried out. Interviews with other stakeholders (engineers, planners, policy makers and many others) in the renewable and sustainable energy field were also conducted. The researcher worked closely with the Sustainability Institute, based at Lynedoch, and Peter Sieckmann, consulting engineer, on the technical aspect of the system. The researcher also had the opportunity to gain hands-on experience in installing some of the operational parts (sun-slates, inverters etc.) of the solar PV roof tile system.

[6] Refer to http://www.sustainabilityinstitute.net/lynedoch-ecovillage for more information.

Two powerful research tools were used in this study. Firstly, the Stellenbosch Research Group (SRG), comprising five master's students and their supervisors, was employed. This group met every fortnight, at which time one member would present an update on his/her research; feedback from these sessions had been very helpful. Secondly, brainstorming sessions with a panel of experts in the field of energy/electricity, especially sustainable and renewable energy, were key sources of data.

Literature on the most popular and successful policy, market and financial interventions in the countries that have made major progress in sustainable and renewable energy was studied. Once this was done, the appropriate contextual interventions were explored for South Africa to deploy solar PV roof tiles. The general literature search on the subject was conducted through the Internet, as well as through a search of the publications on the subject. The main subjects that were researched were renewable energy, in particular the solar PV sector in countries such as Germany, USA, Spain, Japan and Korea, which have made significant progress in renewable energy, with particular emphasis on solar rooftop systems. California, for example, signed a bill in 2006 to distribute a million rooftops by the end of 2016.

Furthermore, a search was carried out on issues of planning processes and decision making in energy matters. A thorough search was also conducted on more specific reports and studies on the subject carried out by various organisations and authorities.

Material studied include official documents published by governments, including the South African government, regulatory authorities and government agencies, both printed and electronic, such as policy documents and reports. Journal articles on renewable energy initiatives were also useful. Proceedings from various national and international seminars and conferences on renewable energy, in particular solar PV, were studied as well. Reports and other material from national and international organisations and independent agencies were also used. Various publications are available from international agencies, such as the WEC, IEA, EIA, WWF and UN agencies.

A meeting with a panel of experts on issues such as sustainable resource use and management and renewable energy technologies were scheduled to help brainstorm the parameters of the financial modelling exercise. The panel consisted of Prof. Mark Swilling (University of Stellenbosch and Sustainability Institute), Peter Sieckmann (experienced consulting engineer), Riaan Meyer (research engineer at CRSES, University of Stellenbosch), Frank Spencer (sustainable energy engineer), Allen Morgan (electrical engineer) and many other experts in the field of RE.

Excel spreadsheets were used to evaluate the life-cycle cost (LCC) of a residential solar power system (comprising PV roof tile and SWH) and a coal-fired power plant.

## 3.5 Closing remarks

Chapter 3 described the research methodology, research design, unit of analysis and research methods that formed the research process of this thesis.

It was explained that an exploratory research design was used in this study. Then the processes, procedures, tools and methods that were used to gather and process information were discussed. The most important methods of research adopted in this thesis were the following: the use of excel spreadsheets to evaluate the cost effectiveness of a residential solar system (PV and SWH) and a coal-fired power plant using the LCCA approach, interviews, research group discussions and brainstorming sessions with expert panels. It was established that the unit of analysis, a new crèche for local children at Lynedoch Eco-village, has been equipped with a solar water heater that produces thermal energy for water heating and a PV roof tile system that is grid interactive, producing direct current that is converted to alternating current and then fed directly into the local electricity distribution system.

# Chapter 4 : Case study: Lynedoch's solar power system

## 4.1 Introduction

The objective of studying the Lynedoch solar power system (PV roof tile system and SWH) is to accumulate the knowledge to test the operational viability within the South African context with a view to replicate and take this pilot project to every corner of the country. In other words, this chapter aims to establish what lessons can be gained from the Lynedoch pilot project that will influence the way a national system for a million or more residential solar power systems (PV roof tile system and SWH) will be designed and built. However, it is important to first provide background knowledge on solar insolation, solar system energy output, specifications of the power system, and how the typical system works before investigating the lessons that could influence the design of a national system.

## 4.2 Solar insolation and PV energy output

The intensity of the sun's rays reaching the earth is referred to as the solar insolation and is expressed in $W/m^2$ (Swanepoel, 2008). The processes that occur in the atmosphere (reflection, scattering, absorption and many others) influence the nature of the spectrum that reaches the surface of the earth. This is shown by the effect of the azimuth angle of the sun, which is expressed in the notation AMx (Air Mass x), where x = 1/cos (azimuth angle). The path length of the sun through the atmosphere increases with the increase in the azimuth angle (Swanepoel, 2008). Thus, the notation AM0 refers to the insolation in the outer space near the earth and AM1 to the insolation on the surface of the earth at sea level when the sun is perpendicular to the site below (Swanepoel, 2008). AM1.5 refers to the insolation when the azimuth angle is 48.2°. It was agreed internationally to define a reference solar spectrum as follows:

> A standard solar spectrum has an intensity of 1 000 $W/m^2$ and the spectral distribution is that of AM1.5.
>
> Swanepoel (2008b)

The power output of PV systems is measured in Watts peak (Wp) under standard test conditions (STC) of solar intensity of 1 000 W/m$^2$, temperature of 25 °C and a sunlight spectrum defined as corresponding to atmospheric conditions known as AM1.5 (Lawley, 2003; Swanepoel, 2008b).

According to Lawley (2003), the energy (electricity) output from a PV system varies mainly with insolation levels and to a minor extent with PV module temperature. The internationally accepted measure of a PV system's energy (electricity) output is in terms of kWh of AC electricity produced in a year per kWp of system capacity (abbreviated kWh/kW). This measure includes the conversion losses from DC to AC electricity and allows for daily and seasonal changes in the insolation levels over the year.

### 4.3 The description of the solar power community

| | |
|---|---|
| PV community name: | Lynedoch Eco-village |
| Kind of urban area: | Residential – urban |
| Building type in community: | House – pre-school/crèche building |
| New/Retrofit/Added: | New community – building integration |
| Type of project: | Demonstration project |
| Start of operation (1.7 kW): | September 2008 |
| Start of operation (3.3 kW): | May 2009 |
| Start of operation (SWH): | August 2009 |
| City, municipality: | Stellenbosch, Lynedoch |
| Country: | South Africa |

**PV roof tile system and SWH characteristics**

| | |
|---|---|
| Total PV power: | 5 kW (3.3 kW + 1.7 kW) |
| SWH: | 300 L Atlantic Solar Coastal |
| Number of houses/buildings: | 1 of 2 |
| PV power per unit: | 3.3 kW/crèche + 1.7 kW/guesthouse |
| SWH: | 2 x (150 L) pre-feeding each other |
| Energy yield per year: | 2 008 kWh/kW (estimated/calculated) |

| | |
|---|---|
| Capacity factor | 23% |
| SWH savings: | Estimated 40% of monthly consumption |
| Main PV system type: | Grid-connected – demand side |
| SWH system type: | Solar collectors |
| SWH application type: | Flat plates – demand side |
| Main PV application type: | Inclined roof – integrated: PV roof tiles |
| Main PV module type: | PV roof tile |
| Main PV cell type: | Crystalline silicon – multi |
| PV module manufacturer/brand: | Atlantis roof tile |
| Inverter manufacturer/brand: | SMA |
| SWH manufacturer/brand: | Atlantic Solar |
| Investment for PV systems: | R68.80/W (excluding installation costs) |

The Sustainability Institute is the owner of the building and solar system, and the user of PV electricity and solar hot water. A 3.3 kW PV roof tile system was installed at the new crèche together with a solar water heater. A 1.7 kW PV roof tile system was installed at the guesthouse a year before the installation of the 3.3 kW system. A 3.3 kW PV roof tile system is described in the next sections to provide details of the design, operation and performance of the system. Operational and other details of a 1.7 kW PV roof tile system are not given here but since it is exactly the same but half the size of a 3.3 kW PV roof tile system the operational, maintenance and performance details are similar to that of a 3.3 kW PV roof tile system. Lynedoch is thus powered by a 5 kW (3.3 kW + 1.7 kW) of PV roof tile capacity, which together with a 300 litre SWH system make up the residential solar power system which is the focus of this thesis.

## 4.4 The PV roof tile system

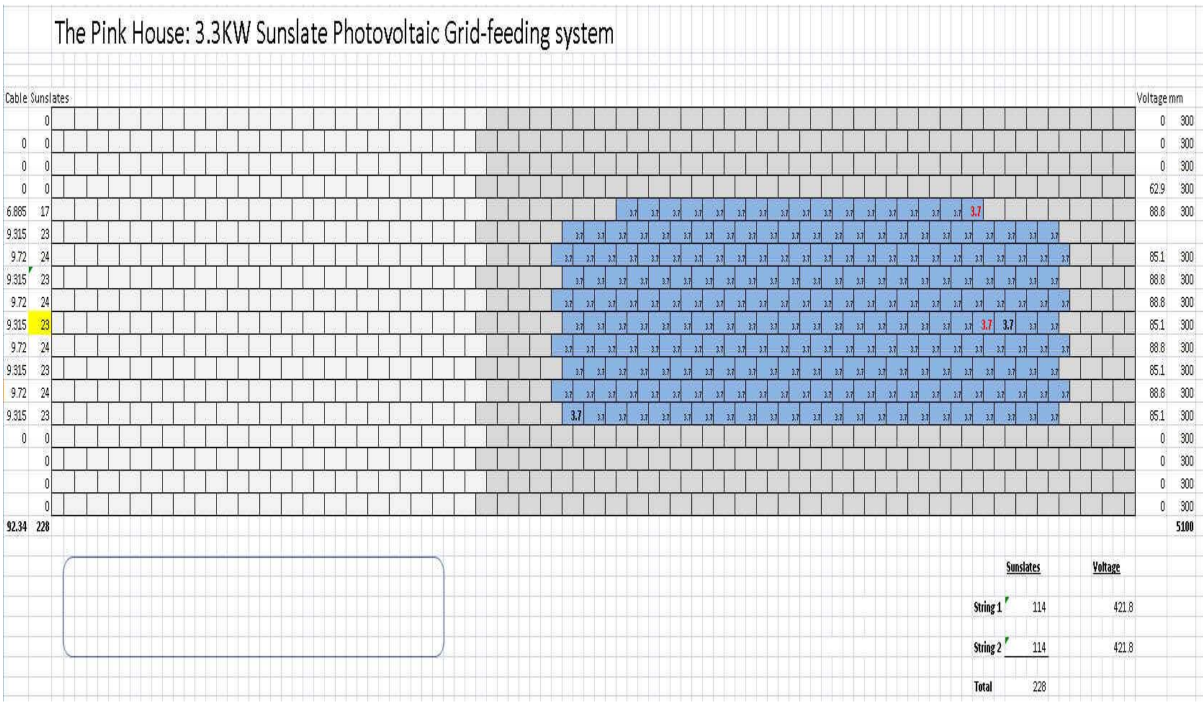
### 4.4.1 The design of the PV roof tile system

Figures 4.1 and 4.2 show that a PV roof tile system was installed on the far right of the roof (indicated by blue shading) and a solar water heater on the far left.

**Figure 4.1: A 3.3 kW PV roof tile system installed at the new crèche at Lynedoch Eco-village**

Source: Sustainability Institute (2009)

**Figure 4.2: Design of a 3.3 kW PV roof tile system at Lynedoch Eco-village**




Source: Sieckmann Engineering (2009)

### 4.4.2 PV system operation and performance

The 3.3 kWp solar PV system consists of 228 poly-crystalline modules integrated into roof tiles (see Figure 4.2). The 114 modules (sun-slates) are connected in series to generate 400 V DC (1 596 Wp) at their rated voltage (14 W/module) under STC. Two strings, each having 114 sun-slates, are then connected in parallel to keep voltage at 400V and into one inverter of 3.82 kVA capacity. The AC output from the inverters is connected to the single phase of the three phases of the grid. Electricity produced by the PV system is fed directly into the grid. A communication cable is installed to record electrical data (power, voltage, current, power factor, etc.) and a weather station would be installed to record meteorological data (radiation, temperature, wind speed, rain fall, humidity, etc.). However, there are no sensors installed to measure the temperature of the PV modules. The annual net electricity generated from the solar PV system was monitored and recorded as from May 2009. For the calculation of the life-cycle energy use, emissions and cost, an average annual electricity generation of 2 008 kWh/kW is calculated and used. The average net conversion efficiency of the solar PV roof tile system (solar radiation to AC power output) under STC is 11% based on the manufacturer’s specifications while the measured efficiency of the inverter is about 92%. Figure 4.3 shows the installation of 3.3 kW PV roof tile system. The builders of the new crèche were also the installers of the PV roof tile system, supervised by an experienced professional.

**Figure 4.3: Builders installing solar PV roof tiles at Lynedoch Eco-village**

**Table 4.1: Overview of the 3.3 kW PV roof tile system at Lynedoch Eco-village**

| **System overview** | | | |
|---|---|---|---|
| **PV manufacturer** | | **Inverter** | |
| Atlantis | | Sunny Boy SB 3300 | |
| Sun-slates: | 14 W | Number 1 | |
| Angle of inclination: | 30° | Max. efficiency: | 95.2% |
| Azimuth angle: | 180° | Max. DC power:<br>Max. AC power: | 3.82 kW<br>3.6 kW |
| Module x String: | 114 x 2 | Grid voltage/frequency: | 230 V/50 Hz |

Source: Sieckmann Engineering (2009)

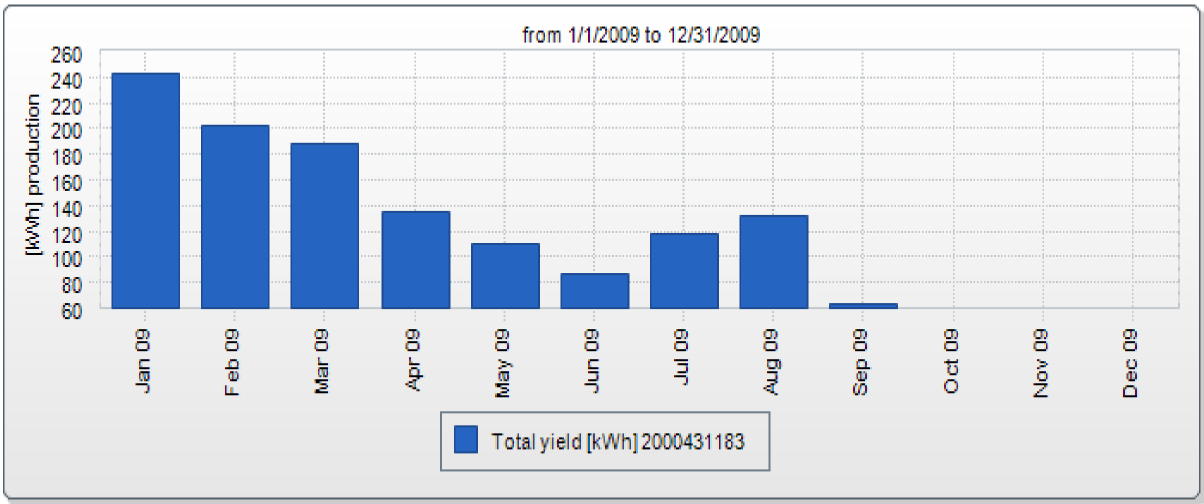
**Table 4.2: Technical data of the 3.3 kW PV roof tile system at Lynedoch Eco-village**

| **Technical data** | | | |
|---|---|---|---|
| PV peak power: | 3.3 kW | Nominal power ratio: | 120% |
| Total number of modules: | 228 | Yearly energy yield*: | 6 625 kWh |
| Area of PV generator: | 29.0 $m^2$ | Energy usability factor: | 100% |
| Number of inverters: | 1 | Performance ratio*: | 92% |
| Max. DC power of inverter: | 3.82 kW | Specific energy yield*: | 2 008 kWh/kWp |
| Max. AC power of inverter: | 3.60 kW | Cable losses (% in PV energy): Not considered (very minimal) | |
| *Note: The calculation of the yield is based on estimated values and a mathematical model. The real yield can deviate due to contamination or different efficiencies of the modules. | | | |

Source: Sieckmann Engineering (2009)

The energy yield of a 3.3 kW PV system is an estimated value based on mathematical modelling. The actual yield was monitored on the web using SMA monitoring technology. However, as will be discussed in Section 4.6, it was found that the data logger was unplugged, which resulted in the loss of some critical data. Figures 4.4, 4.5 and 4.6 show the actual performance thus far of the PV roof tile system, although the results may not be a true reflection of the system's performance due to the loss of critical data.

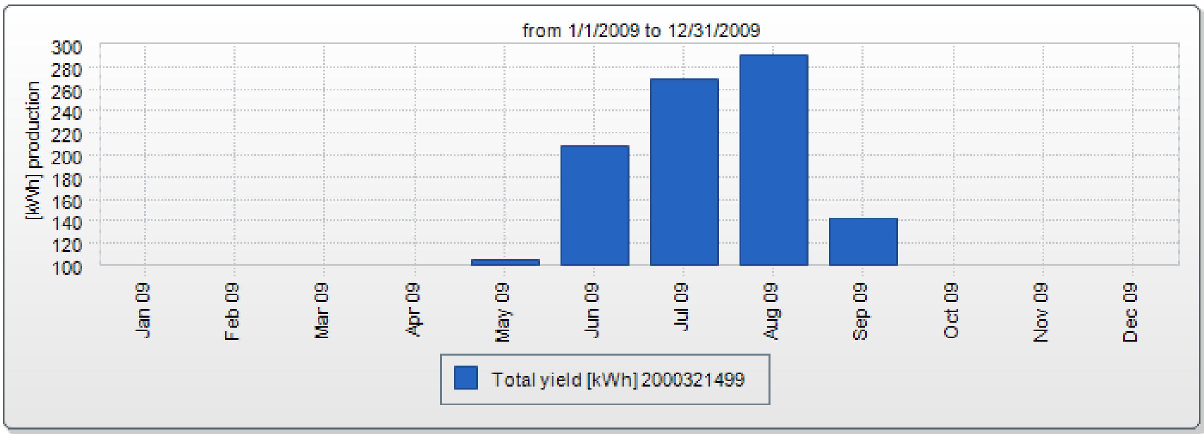
**Figure 4.4: Energy yield for the 1.7 kW PV roof tile system at Lynedoch's guesthouse for the period 1/1/2009-31/09/2009**




Source: Sieckmann Engineering (2009)

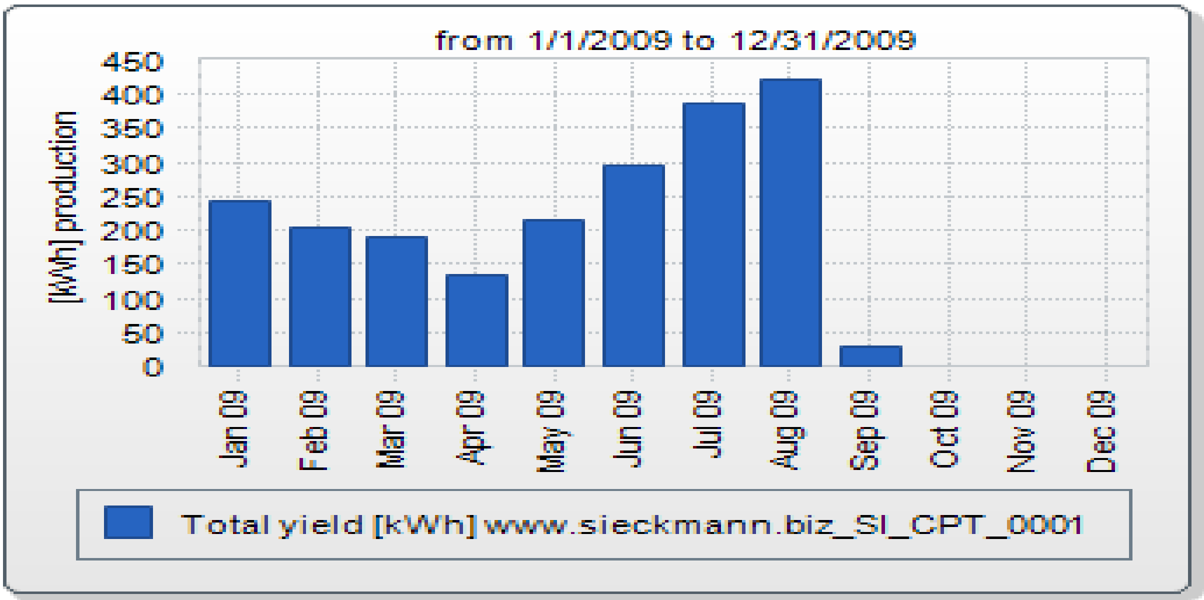
Figure 4.4 shows the energy yield from the 1.7 kW PV roof tile system for the period January 2009 to September 2009, while Figure 4.5 shows the energy yield from the 3.3 kW PV roof tile system for the same period. Figure 4.6 shows the monthly energy yield from the 5 kW PV roof tile system (the combination of the 1.7 kW and 3.3 kW PV roof tile systems).

**Figure 4.5: Energy yield of the 3.3 kW PV roof tile system at Lynedoch's new crèche for the period 1/1/2009-31/09/2009**




Source: Sieckmann Engineering (2009)

**Figure 4.6: Energy yield of the entire 5 kW system for period 1/1/2009 to 31/09/2009**




Source: Sieckmann Engineering (2009)

The actual energy yield from the entire system (5 kW) for the period January 2009 to 15 September 2009 was 3 051 kWh. The carbon dioxide emissions reduction amounted to 3 661 kg for the same period, using Eskom's emission factor of 1.2 kg $CO_2$/kWh for coal-based electricity. But it is important to remember that the 1.7 kW PV roof tile system was commissioned in September 2008, while the 3.3 kW PV roof tile system was only commissioned in May 2009. So, the actual energy yield for the same period would have been much higher than 3 051 kWh had the 3.3 kW PV roof tile system been operational since January 2009. Therefore, using the actual monthly average of 152 kWh generated by the 1.7 kW PV roof tile system and the actual monthly average of 257 kWh generated by the 3.3 kW PV roof tile system, the actual annual energy yield of the entire 5 kW PV roof tile system is 4 906 kWh. This will be used in comparison with the estimated energy yield of 10 038 kWh from the 5 kW PV roof tile system in Chapter 5.

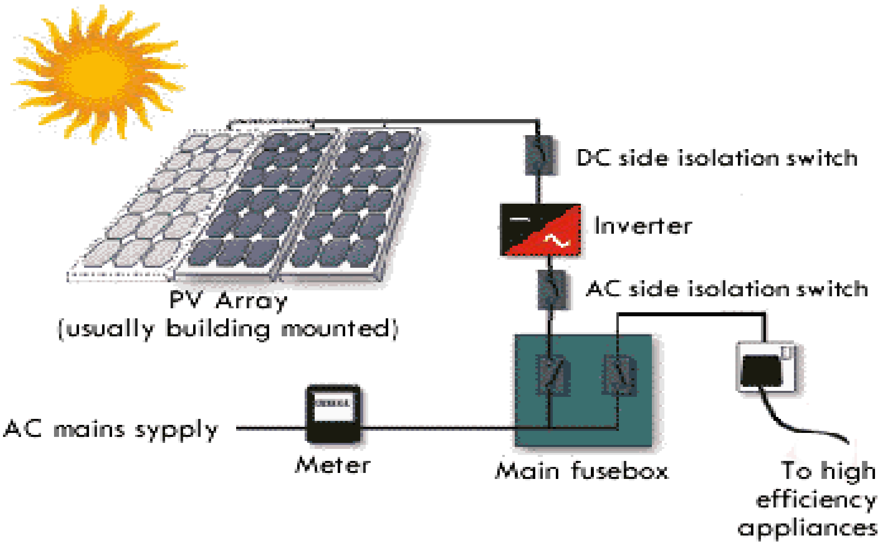
Using Eskom's emission factor of 1.2 kg $CO_2$/kWh for coal-based electricity, the estimated annual carbon savings from the 5 kW PV roof tile system amount to 12 046 kg $CO_2$ and the actual annual PV carbon savings amount to 5 887 kg $CO_2$.

For a 300 litre SWH, an average monthly electricity saving of 300 kWh[7] are realised for an average Cape Town household that uses 750 kWh[8] a month. That is an annual electricity saving of 3 600 kWh. This equates to annual savings of 4 320 kg $CO_2$. Together, the residential solar power system (PV and SWH) generates carbon savings totalling 16 366 kg $CO_2$.

### 4.4.3 How does a typical PV system work?

Figure 4.7 shows a diagram of grid-connected PV system, followed by a brief discussion on how a typical system works

**Figure 4.7: A diagram of a typical grid-connected PV system**




- **PV array:** This converts sunshine into electricity (both direct and diffuse radiations), so it works even on the cloudy days.
- **Inverter:** This converts direct current generated by the rooftop system into alternating current that can be used by the household or fed into the grid.
- **Main fuse box:** For safety reasons, AC is fed into the mains of the building via a fuse box.

[7] Based on 35 to 40% monthly electricity savings. See http://www.engineeringnews.co.za/article/eskom-to-promote-sustainable-use-of-water-and-energy-2009-03-18.
[8] Accessed from: http://www.capetown.gov.za/en/EnvironmentalResourceManagement/EnergyEfficiency/Documents/SLH%20energy%20audit%20pp%2044-47.pdf

- **Meter:** Especially for grid-connected systems, spare electricity generated during the day flows out to the grid and is sold to the local electricity supplier. Fitting an electricity meter will measure electricity fed into the grid.**Battery:** For off-grid systems batteries are used to store electricity generated by the rooftop system during the day to use when needed.

A sloping rooftop is an ideal site, because modules are simply mounted using frames, but a flat rooftop can also be used for maximum power output. Roof conditions vary greatly and several key factors should be considered when mounting a PV system onto a roof. The most important of these factors are the following:

- **Geographic orientation** – northern or southern hemisphere: PV systems maximise power output on south-facing roofs in the northern hemisphere and north-facing roofs in the southern hemisphere (up to 95% efficiency).
- **Azimuth:** The path length of the sun through the atmosphere increases with the increase in the azimuth angle (see Section 4.2).
- **Tilt/angle of inclination:** The angle from the horizontal formed by an inclined roof or mounted PV system on flat surface.
- **Available area:** The more surface area available, the greater the power potential. Systems can be small to fairly large. For grid-connected system the required area could range from 8 $m^2$ to several hundred square meters.
- **Shadowing:** The roof shouldn't be shadowed by tall trees or neighbouring buildings. Even small shading can cause significant loss of energy.

Rooftop systems can be roof mounted. PV modules are fixed on frames above the existing tiles or integrated with the roof. PV modules are an integral part of the building structure, replacing conventional roof tiles in new buildings or re-roofing (e.g. the Lynedoch project).

## 4.5 Solar water heater

### 4.5.1 The design of the SWH system

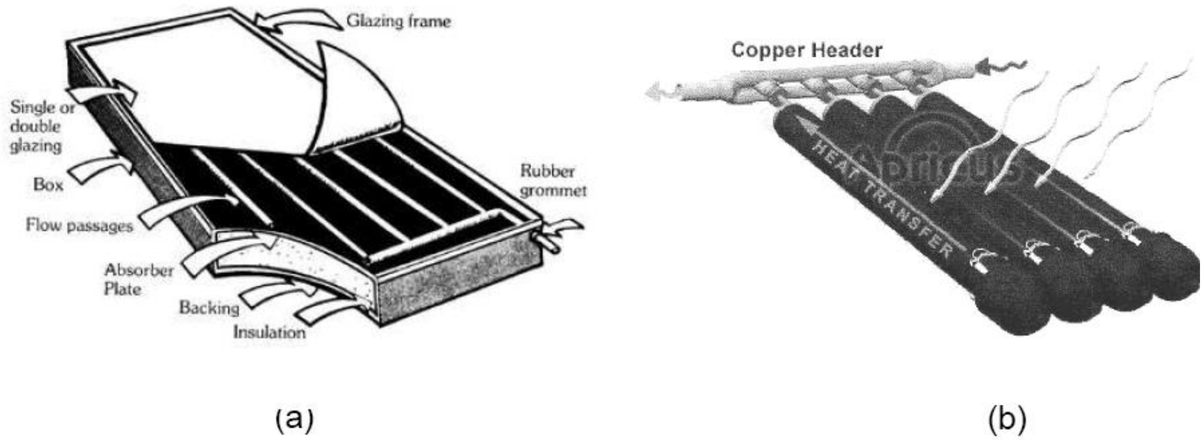
The solar water heater installed at Lynedoch crèche is a 300 litre Atlantic Solar Coastal system consisting of a twin 150 litre system pre-feeding each other. There is a 2.5 m$^2$ solar collector with a 150 litre direct solar geyser. The components of the system are a collector (2 000 mm x 1 250 mm), eight risers with fins and tempered glass, geyser, fibreglass and geyser 'xstream'.

The system was installed close-coupled externally on the eastern side of the solar PV array on the north-facing slope of the roof. All the plumbing is located on the western side of the building. This means that reticulation to the point of installation was required. A geyser-wise timer with thermostatic control was installed and power was connected to one geyser only. Electricity would be supplied to a 20 amp isolator in the roof which is connected to a 20 amp circuit-breaker. Finally, the 400 kPa pressure valve was installed to balance water pressure at the point of installation.

### 4.5.2 How does a typical SWH system work?

There are basically two main types of solar water heaters (SWHs), as shown in Figure 4.8.

**Figure 4.8: Two main types of solar water heaters.**




Source: Swanepoel (2008b)

A flat-plate system (Figure 4.8(a)) comprises an insulated, weatherproof box containing a dark absorber plate under a transparent glass cover. A few rows of copper pipes are attached to the dark absorber plate. Glass has the useful optical property that it is transparent in the visible region of the electromagnetic (EM) spectrum but absorbs and reflects EM radiation in the far infrared region of the spectrum (Swanepoel, 2008b). The energy from the sun thus enters the box but radiation from the heated dark absorber inside the box cannot escape. This leads to an increased temperature inside the box – a phenomenon known as the greenhouse effect. This heat energy is absorbed by the metal plate covered with a selective absorber coating. Copper pipes are in thermal contact with this plate and the circulating water inside the pipes is heated.

An evacuated tube system (Figure 4.8(b)) consists of rows of parallel glass tubes. Glass-glass tubes consist of two glass tubes that are fused together at one end. The inner tube is coated with a selective absorber coating. The air is withdrawn from the space between the two glass tubes to form a vacuum that eliminates conductive and convective heat losses. Glass-metal tubes consist of a single glass tube of which the inside is a flat or curved aluminium plate that is attached to a copper heat pipe (Swanepoel, 2008b). The heat is collected inside the glass tube and transported to a heat exchanger by a means of a heat pipe (a sealed copper pipe). The solar water heating systems generally consist of the following components: (i) a solar collector, (ii) a storage vessel, (iii) a heat exchange fluid in the case of indirect systems, and (iv) a pump in the case of an active system.

Solar water heaters can be classified as either passive or active systems. Passive systems depend on natural convection to circulate the water through the collectors. According to the North Carolina Solar Center (2002), an initiative supported by the US Department of Energy in cooperation with North Carolina State University, the integral collector storage and thermosiphon systems are passive systems. In brief, the thermosiphon is the upward movement of heated water by natural convection. When the fluid in the collector is heated, it becomes less dense and rises to the top of the collector and into either a heat exchanger (indirect systems) or storage tank (passive systems). Active systems use electrically driven pumps and valves to control the circulation of the heat transfer fluid. This allows greater flexibility than passive systems since the hot water storage tank does not have to be above or near the collectors.

All solar water heating system can be characterised as either direct or indirect, depending on whether household water is heated directly in the collector or via a heat exchanger. In direct systems, the fluid that is heated directly in the collector is potable water, which flows directly to the tap. In indirect (closed-loop) systems, the heat transfer fluid is treated water – a non-freezing liquid such as an anti-freeze solution, hydrocarbon oil or silicone (North Carolina Solar Center, 2002). Here, the heat transfer fluid absorbs heat from the collector (absorber plate/tube) and then transfers it to the potable water through a heat exchanger such as a coil, either inside or wrapped around the storage tank. Here is the brief discussion on how SWH systems work:

- Both systems (flat plates and evacuated tubes) absorb energy from the sun's rays.
- The thermal energy is then transferred to an anti-freeze liquid that is pumped through the collectors in active and indirect systems or thermal energy is transferred to the potable water circulating, either by pump or thermosiphoning, directly through the collectors in direct systems.
- Once heated, the liquid is then pumped (active systems) or thermosiphoned (passive systems) to solar coils in the base of the domestic hot water tank located in the house (active systems) or either attached to the top of the collector or placed very near to the collector (passive systems).
- While passing through the solar coils, the thermal energy in the liquid is transferred to the water in the tank (indirect systems).
- The heated water in the tank rises to the top of the water tank ready for domestic use.
- The liquid in the solar coils, which is now cooled, is pumped back or thermosiphoned to the solar collectors to be replenished with new thermal energy, and thus the cycle continues.
- If there is not enough solar power, in winter for example, the electrical element will top up the thermal energy as in conventional geysers (Swanepoel, 2008b).

## 4.6 Outcomes and lessons from the Lynedoch pilot project

As mentioned earlier the objective of studying the Lynedoch solar system is to test the operational viability of the system within the South African context in order to gain knowledge and perhaps influence the way in which a national system for a million or more solar rooftops systems could be designed and built. The following are some of the lessons learnt from the Lynedoch project. These are based on the researcher’s personal experience with the project and interviews with the relevant stakeholders.

The new crèche at Lynedoch was installed with solar roof tiles which are not the usual PV modules that are stuck on top of the roof. The reason for this is that the installer and the owner of the PV roof tile system had hoped that the cost of the PV array will be cross-subsidised by the cost of the roof. In other words the installer and the owner of the system had hoped that the combined cost of a roof-integrated PV array (e.g. PV roof tiles) and the roof would be less than the cost of a normal roof plus a normal PV array. For example, the cost of the 5 kW PV roof tile system that was bought and imported from the US is R343 979.99. This is just the cost of the modules (PV roof tiles), excluding installation, inverter, and import and storage costs. The breakdown of system costs (for both the 5 kW PV roof tile system and the 300 litre SWH system) is provided in Chapter 5. It amounts to R68.80/W installed at the new crèche and guesthouse. The PV roof tiles are heavier than normal roof tiles and as a result the roof had to be reinforced to withstand the extra weight. Here follows the breakdown of the cost of the roof that was reinforced as provided by the builders of the crèche:

| | |
|---|---|
| • Laminated beams | R42 484.80 |
| • Pine rough | R20 947.90 |
| • Screws | R2 160 |
| • Nails wire | R942.20 |
| • Ridges | R929.79 |
| • Corrugate roofing | R6 008.97 |
| • Nails roof | R697 |
| • Fascia board | R4 356 |
| • Guttering | R3 709.82 |
| • Graphite fastener | R2 037 |
| **Total** | **R84 273.48** |

The following is the cost breakdown of a normal roof as provided by the builders of the crèche:

| | |
|---|---|
| • Pine rough | R21 828.31 |
| • Screws | R2 160 |
| • Nails wire | R942.20 |
| • Ridges | R929.79 |
| • Corrugate roofing | R1 216.97 |
| • Nails roof | R697 |
| • Fascia board | R4 356 |
| • Guttering | R3 709.82 |
| • Graphite fasteners | R2 037 |
| **Total** | **R37 877.09** |

The reinforced roof costs more than double the price of a normal roof, with laminated beams contributing to this high cost. So the extra cost incurred by the reinforced roof is R84 273.48 – R37 877.09 = R46 396.39. This is too costly, and it means that a much lighter PV roof tile should be designed and manufactured that can easily go onto a normal roof structure that is not as expensive. This is a challenge as well as an opportunity for the PV industry to drive innovation in this area.

The following are some of the lessons that were learnt from personal experience in the Lynedoch pilot project whilst working with Peter Sieckmann, the renewable energy consultant who installed the PV roof tile system at Lynedoch. Most of the information was collected through personal communication and interviews with the various people who, in one way or another, are part of the Lynedoch pilot project. Here simply referred to as Sustainability Institute (2009)

- PV roof tiles installed at Lynedoch are only better than usual PV modules that are just stuck on top of the roof from an anti-theft point of view. The PV roof tiles have the advantage of being difficult to steal. Furthermore, the modules do not have sought-after aluminium frames. In other words, the thief will have to steal the roof material which is certainly a lengthy and tedious process. The usual PV modules are better than PV roof tiles in terms of cost and efficiency.

The cost of the PV roof tile is already too expensive, even before adding the cost of import, storage and installation. The glass laminate may contribute to the high cost. The efficiency of the PV roof tile is that of a normal mono-crystalline PV module (about 15 to 19%). However, the module itself has been glued to a dark substrate, i.e. the tile itself. The problem with this is the reduced cooling during higher temperatures as dark substrate absorbs heat, which then result in reduced efficiency. The measured efficiency of the Lynedoch PV roof tile is 11% compared to 19% of a normal PV module – that is a 42% drop in efficiency.

- The Lynedoch pilot project uses SMA inverter technology in its electronic configuration. According to Peter Sieckmann, SMA is the only sensible solution since it is the only technology that can scale from kW to MW. He substantiates this by further arguing that the SMA grid-feed inverter technology has some important features that makes it a leading technology:

    - High IP rating (IP65), i.e. can be mounted outside
    - High safety measures
    - World-class certification
    - High efficiency, up to 98% for transformer-less modules
    - Patented efficient cooling system
    - High-quality system components and manufacturing processes
    - Patented frequency shift power control (FSPC) capabilities for off-grid applications – which allows AC coupling, a distinctive feature of SMA
    - Excellent product support

  So far, no problem with the functioning of the PV roof tile system at Lynedoch has been reported, probably as a result of the way it is has been configured electronically.

- PV systems maximise power output on north-facing roofs in the southern hemisphere (up to 95% efficiency), so performance should be good. Although the orientation of the roof is not perfectly north, there were no performance problems at the time of writing this thesis. The communication cable installed as part of the system is feeding electrical data (regarding power, voltage, current, power factor etc.) into the website, and the system performance can be monitored on the internet. However, this has proven to be problematic since the data logger was unplugged for two weeks – which means that the performance could not be monitored as well as it should have been. The cause of the problem was not system's failure but human error.

- The roof of the crèche where the PV roof tiles are installed is inclined, forming an angle with the horizontal. Peter Sieckmann argued that a sun sensor had to be installed in order to establish a baseline. The sun sensor measures the levels of temperature on the PV roof tiles. In addition to this, a weather station that measures meteorological data (radiation, temperatures, wind speed, rain fall, humidity and others) would have completed the process of establishing a baseline.

- Builders were interviewed to find out how they found the installation process of the PV roof tiles, and from their perspective the installation was straight forward. However, according to Peter Sieckmann, special handling and some knowledge of electricity is required during the construction process. Sieckmann pointed out that this knowledge can easily be transferred to a standard electrician, as was the case with the Lynedoch pilot project. Furthermore, there are a few additional steps required compared to normal roof tiles. As a result it took the builders longer than it was originally planned to install the PV roof tile system. According to Elijah, the supervisor of the builders, he would have charged for extra hours spent on the installation of the PV roof tiles had he known that it was going to take them that long. The other factor that contributed to the longer installation process is the fact that the installation did not take place in one session. Weather conditions were not favourable for at least two days, and that meant that installation had to be postponed.

- The solar water heater (SWH) has been installed on the eastern side of the PV roof tiles (on the left side of the PVs when viewing the roof). Neither the researcher nor the professional installer of the PV roof tiles (Peter Sieckmann) knew about the installation of the solar water heater. Neither did the two (researcher and installer) know if it was planned or not. The solar water heater was installed on the side with the tiles without the PV. If the whole roof was covered with PV roof tiles there would not have been space available for a SWH, and since the north-facing roof is ideal for both PV and SWH, the decision to install a SWH would probably have been reversed or a new location for the SWH found. If the space had been created for a SWH on the right side of the PV roof tiles when viewing the roof, thus creating a shadow on the PV roof tiles, the performance of the PV roof tiles was going to be greatly affected. Even small shading can cause significant loss of energy, so the roof should not be shadowed by tall trees, neighbouring buildings or even a SWH. There are two strings of PV roof tiles that are connected in parallel, but the modules (PV roof tiles) of each string are connected in series, which means any shadow on any of these modules would mean total failure of the entire string. If the entire roof was populated with PV roof tiles, at least double the electrical power would have been produced – the more surface area available, the greater the power potential. But the advantage of the interface between the PV roof tiles and the SWH is that cost per watt is reduced, because the SWH magnifies the investment value of the PV roof tiles.

- Neither the researcher nor the installer of the PV roof tile system at Lynedoch is aware of any complications regarding the installation thus far. In an interview with Gyro Valentyn, the programme coordinator at Lynedoch, she maintained that no maintenance issues or any sort of complications are known as yet. As mentioned earlier, the installer is also not aware of any complications except that the data logger located in the guesthouse was unplugged (unintentionally maybe) by either a cleaner or a guest. Since the web-box was unplugged critical data has been lost that shows exactly how much the actual savings in terms of kWh and $CO_2$ emissions are. According to Sieckmann, even if the data logger was unplugged for only a few minutes, critical data would still have been lost, but it would not have been as bad as when it was unplugged for several weeks, which was the case with the

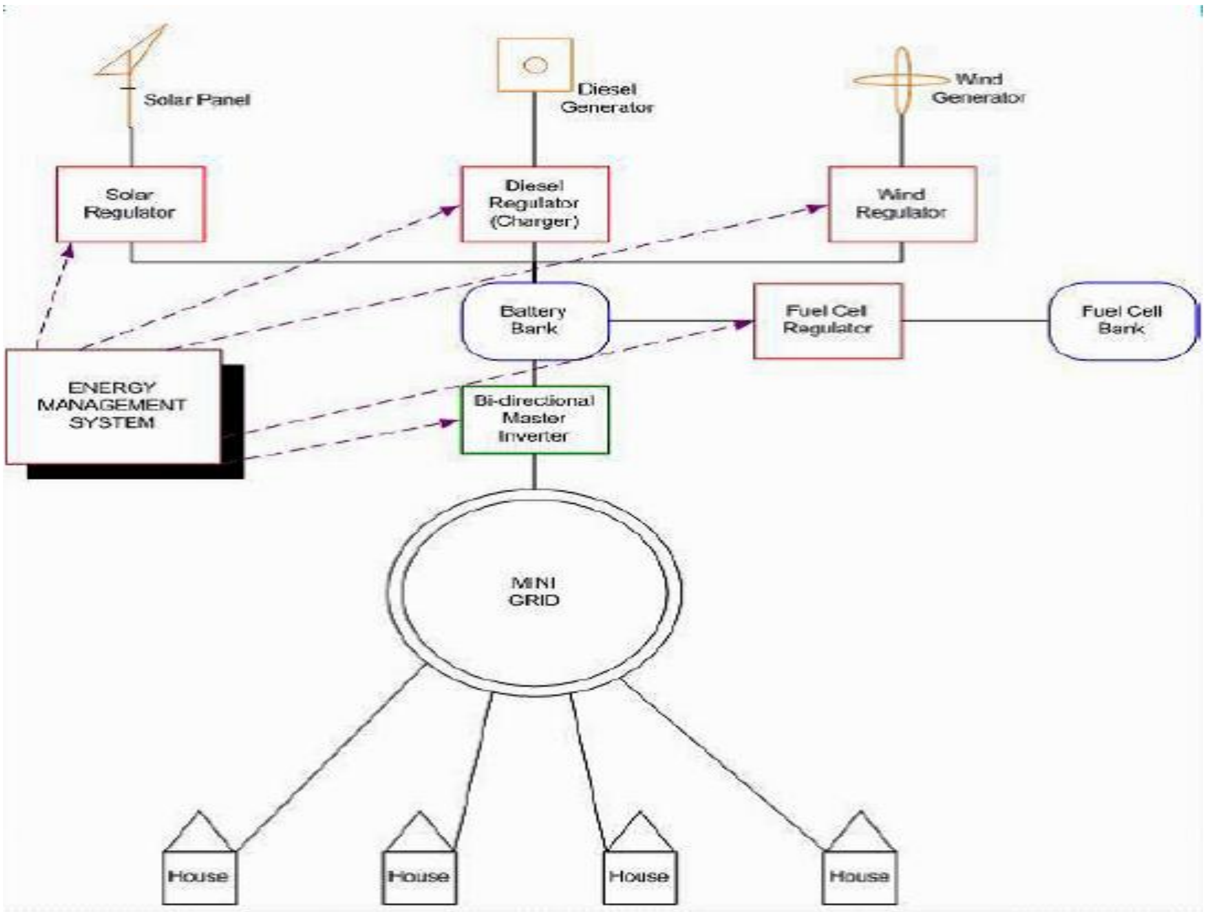
Lynedoch pilot project. The director of the Sustainability Institute, Eve Annecke, has since been notified of the issue.

- An interview was conducted with the operators of the new crèche, headed by Edith Swarts, to find out if the PV roof tiles and SWH made any difference in their lives. In summary, there is now hot water available due to the installation of a SWH. There was no hot water available in the old crèche and most often there was a need to shower the kids that came from local farm families that did not have hot water. Now with the availability of hot water, the kids are clean and increased levels of concentration can be observed. According to Edith, the water is always warm in the mornings and hot in the afternoons. However, they are not aware of any energy savings since they do not pay the electricity bills – the Sustainability Institute pays these. Gyro Valentyn, Rene Human and Shaun Claasen, all staff of Sustainability Institute, were contacted to provide information on electricity savings after the installation of both PV roof tiles and SWH, but apparently there was no electric meter installed at the old crèche and or in the new one. This means that they could not provide information about savings in kWh, $CO_2$ and money. However, electricity savings can be estimated and the SMA monitoring device can provide the actual savings in kWh as well as $CO_2$.

It is important to note that the Lynedoch system is also a de facto mini-grid. In other words, electricity enters the Lynedoch Eco-village through one meter and then all users buy electricity via a pre-paid meter system. This means that surplus electricity generated by the PV roof tiles at the new crèche and guesthouse is actually bought by the other users within the Lynedoch Eco-village, thus creating a differential between what Lynedoch pays the local utility and the revenue generated from the users.

According to IEA PVPS (2009), a mini-grid is defined as the interconnection of small, modular generation sources to AC distribution systems. These mini-grids may be powered by a combination of PV, wind, micro-hydro, fossil-fuel generators and other sources. They typically supply multiple users, and they may be interconnected with (or be part of) the distribution grid of the local electric utility. The Lynedoch PV roof tile system operates within this kind of mini-grid. Mini-grids (see Figure 4.9) could range from an individual household to a larger system connecting a number of users. However, the connection of mini-grids to the distribution network often raises issues of system control and coordination, sustainability and the role of local electric utilities in different jurisdictions (IEA PVPS, 2009). The main technical issues regarding grid-connected PV systems are discussed in Appendix A7.

**Figure 4.9: Mini-grid system connecting a number of users**




Source: Spencer (2009)

## 4.7 Closing remarks

This chapter started with a discussion of solar insolation and PV energy output. This was followed by a description of the solar power community at Lynedoch Eco-village, after which the residential solar rooftop power system (comprising a 5 kW PV roof tile system and a 300 litre SWH) was discussed.

The lessons learnt from the Lynedoch pilot project were then discussed. Here it was mentioned that the new crèche at Lynedoch was installed with solar PV roof tiles and not the usual PV modules that are stuck on top of the roof. The reason for this is that the installer and the owner of the system had hoped that the combined cost of a roof-integrated PV array (e.g. the PV roof tiles) and a roof would be less than the cost of a normal roof plus a normal PV array. However, this was not the case.

The chapter also highlighted that the Lynedoch case is a de facto mini-grid. This means that surplus electricity generated by the PV roof tiles at the new crèche and guesthouse is actually bought by the other users within Lynedoch Eco-village, thus creating a differential between what Lynedoch pays the local utility and the revenue generated from the users.

# Chapter 5 : Life-cycle cost analysis

## 5.1 Introduction

*“It’s unwise to pay too much, but it’s foolish to spend too little”*

*– John Ruston*

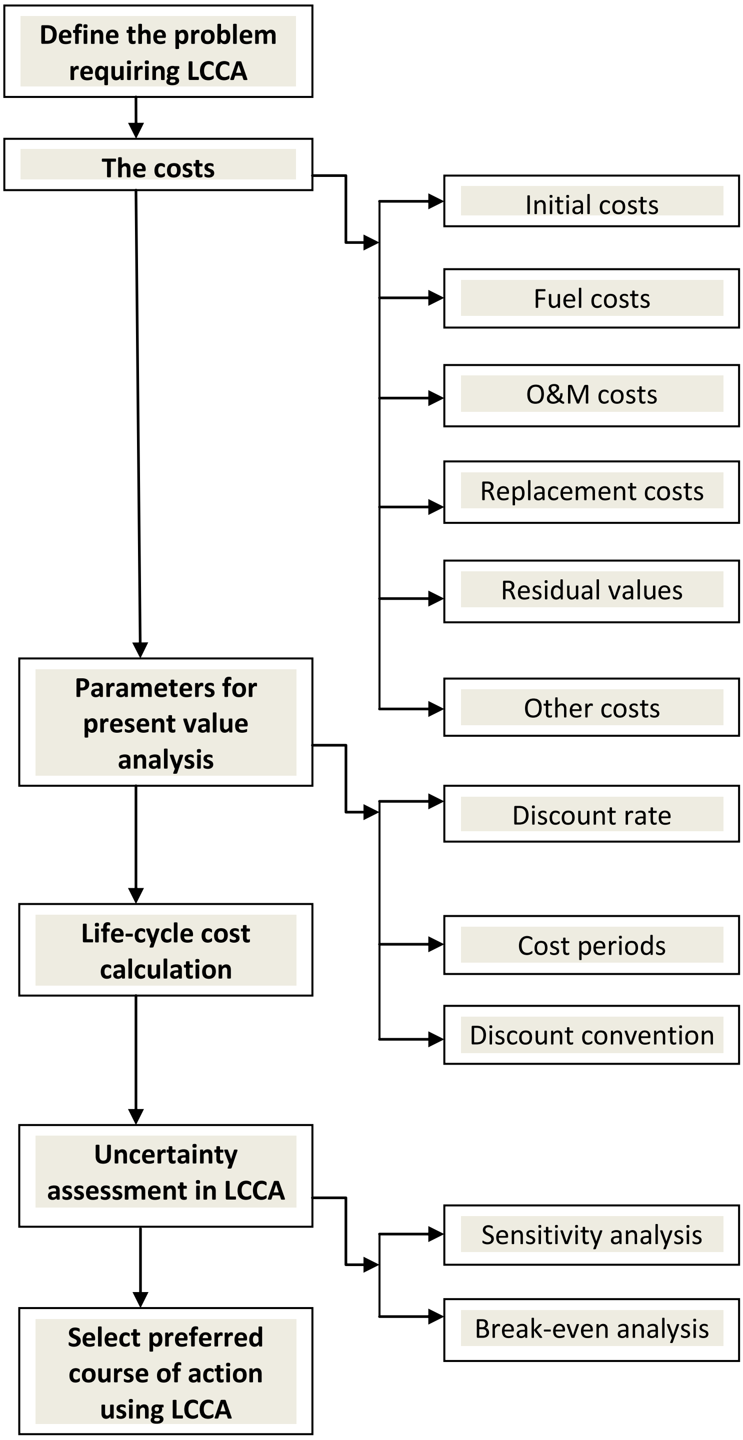
The quote above neatly summarises the operating principle of life-cycle cost analysis (LCCA). According to Barringer (2003), it is wise to consider and use life-cycle cost (LCC) for capital expenditures above $10 000 to $25 000. He further argues that high upfront capital costs are only the tip of the iceberg and the damaging part of the iceberg is the bulk of other costs related to the life-cycle costing for equipment, projects and systems (Barringer, 2003).

This chapter discusses the process that was followed in the life-cycle cost analysis of the Lynedoch solar project (5 kW PV roof tile system and SWH) and a coal-fired power station. Every appropriate cost is included in the LCC; appropriateness according to Barringer (2003) changes with each specific case which is tailored to fit the situation. A detailed discussion of the LCCA process is presented in Chapter 2.

The spreadsheet model for measuring the NPV of LCC of different project alternatives requires as inputs the identified capital expenditure and operating expenditure cost items, each with its base year (2009) amount, the year in which the expenditure starts, the year in which the expenditure ends and the price escalation expected for that item. Further inputs required are the discount rate and the life-cycle duration. The spreadsheet-model was designed to test NPVs of life-cycle costs for both residential solar power rooftop systems (PV and SWH) and a coal-fired power plant for 40 years due to the design working life of 40 years for a coal-fired power plant and 25 years for a residential solar power rooftop system which will be replaced at the end of its useful life. For both project alternatives the NPVs of LCC is in terms of kWh.

## 5.2 What does the LCCA process entail?

### Figure 5.1: Life-cycle costing process




Source: Fuller (2008); Barringer (2003)

The following sections will cover: a definition of the problem requiring LCCA; a description of what was included in the measurement of the cost profiles of different project alternatives and how the measurement was executed; the actual measurement of data collected on the coal-fired power plant; the actual measurement of data collected on the residential solar power alternative; and an interpretation of the results and formulation of recommendations.

**(a) Define the problem**

Initial capital costs (procurement costs) are often used as the primary (and sometimes only) criterion for power projects such as a coal-fired power plant. Due to life-cycle stages, often the real costs of the coal projects or any other power project are not reflected by the upfront investment capital (Hunkeler et al., 2008; Barringer, 2003; Fuller, 2008; Burger & Swilling, 2009). LCCA was therefore used in this thesis to choose an investment alternative to a coal-fired power plant in terms of the lowest long-term cost during the useful life of the project. LCCA will serve to indicate that operational savings are sufficient to justify the investment costs of residential solar power rooftop systems (PV and SWH), which are often greater than those of coal-fired power plants in terms of the project's functional unit (e.g. cost/kWh).

The multiple residential solar rooftop power systems (comprising PV and SWH), a demand-side management option, is proposed as an alternative to a coal-fired power plant, a supply-side option. The overriding objectives of the demand-side management option over its useful life are to:

- Leverage electricity savings
- Reduce greenhouse gases
- Reduce overall local pollution
- Reduce carbon footprint
- Improve electricity demand-side management
- Improve access to affordable and reliable energy services
- Promote technology and skills transfer
- Promote large-scale deployment of residential solar PV and SWH
- Increase employment opportunities

### (b) The costs

According to Burger and Swilling (2009), cost effectiveness analysis is a technique for investment appraisal prescribed in the South African National Treasury directives. The National Treasury (2006, cited in Burger & Swilling, 2009) expresses the following intention:

> It is the intention of the National Treasury to progressively require more detailed analyses as funding requests are becoming larger compared to available resources. Under these circumstances it is appropriate to prioritise requests which can demonstrate the largest benefits to our country.

Since the 2007 Medium Term Expenditure Framework (MTEF) (Burger & Swilling, 2009), all new infrastructure projects or programmes require some form of appraisal to demonstrate advanced planning. Such appraisal may include needs analyses, options analyses, cost-benefit analyses, life-cycle cost and affordability analyses (Burger & Swilling, 2009). Burger and Swilling (2009) maintain that cost effectiveness analysis (CEA) was identified by the National Treasury as a tool that can help to ensure efficient use of investment resources in sectors where it is difficult to value benefits in monetary terms. CEA was specifically identified as useful for the selection of alternative projects with the same objective (quantified in physical terms), and it is most commonly used in the evaluation of social projects, e.g. in the health and education sectors (Burger & Swilling, 2009; National Treasury, 2006). It is therefore appropriate to use life-cycle cost analysis (LCCA) in this thesis to evaluate the long-term cost of socio-economic and environmental sustainability of a coal-fired power station and a million or more residential solar power systems. Acquiring and assembling cost details of different cost items is often challenging, and as a result the more thorough the data collection process, the better the LCC model (Barringer, 2003; Fuller, 2008).

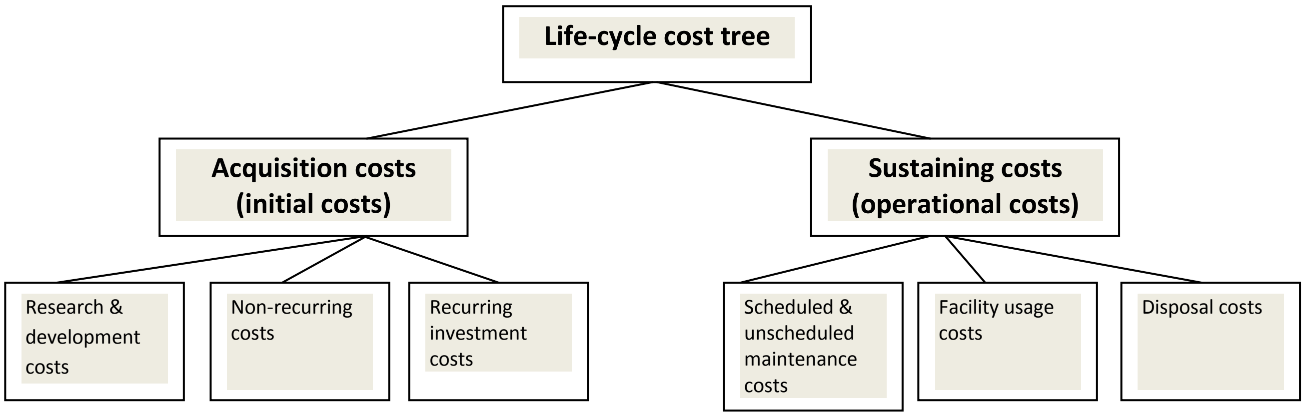
Cost items for the two alternatives were divided into capital expenditure items incurred in the base year and operating expenditure items incurred from year one. The main sources of data on the capital and operating cost items relating to a coal-fired power plant and a residential solar power system (PV and SWH) are summarised in Table 5.1.

**Table 5.1: Main sources of data on the capital and operating cost items relating to the two project alternatives**

| Project alternative | Sources of data |
|---|---|
| **Coal-fired power plant** | Dipuo Peters, Minister of Energy, in her Budget Vote Speech of May 2009 |
| | Eskom Annual Report (2008) |
| | Department of Public Enterprises (DPE, 2008) |
| | Department of Minerals and Energy (DME, 2009) |
| | Engineering News |
| | Mining Weekly |
| | miningmx.com |
| | Sustainability Institute (SI) |
| **Residential solar power system (PV and SWH)** | Sieckmann Engineering (installer of PV system) |
| | Atlantic Solar (installer of SWH) |

According to Barringer (2003), the basic tree for LCC combines acquisition costs (initial costs) and sustaining costs (operational costs) as shown in Figure 5.2.

**Figure 5.2: Top level of life-cycle cost tree**




Source: Barringer (2003)

Acquisition and sustaining costs for projects have their own branches on the cost tree (Barringer, 2003). Each of the three branches of acquisition and sustaining costs has its own sub-branches that are not shown in the LCC tree (see Figure 5.2). For example, R&D costs under acquisition costs will include programme management, advanced R&D, engineering design, equipment development and testing, and engineering data. Under sustaining costs, scheduled and unscheduled maintenance costs will include labour, materials and overheads, replacement, transportation and others (Barringer, 2003). For the purpose of this thesis, acquisition and sustaining costs for a residential solar power system (PV and SWH) and a coal-fired power plant are outlined in the next paragraphs with the actual cost details.

For a 5 kW PV roof tile system, acquisition costs for project management, engineering design, on-site visits, engineering data, installation, travel allowance and system commissioning were incurred. The same acquisition costs incurred for a PV system were also incurred for a SWH. For a residential solar power system (PV and SWH), sustaining costs were incurred for labour, operation and maintenance and replacement.

For a 4 800 MW coal-fired power plant (e.g. the Medupi coal project), acquisition costs for programme/project management, engineering design, engineering data, facilities and construction were incurred. Sustaining costs were incurred for labour, materials, overheads, maintenance, operations, transportation, energy (fuel), facilities, on-going training costs and carbon emissions. The decommissioning costs for a coal-fired power plant are not included in the calculation of a LCC of coal-based electricity. The LCC of both project alternatives is based on upfront capital (including replacement costs) and operating costs over the life of the project.

- Initial costs – purchase, acquisition and construction costs

The capital cost items determined for a coal-fired power plant included plant costs totalling R100 billion, transmission costs totalling R2 billion, fixed annual costs totalling R28.8 million and other direct costs (10% of EPC) totalling R10 billion. The total initial costs for a 4 800 MW coal-fired power plant totalled just over R112 billion. The capital cost items calculated for a solar power rooftop system included: (1) a 5 kW PV roof tile system totalling R343 979.99, import and storage costs totalling R16 318.36, installation costs totalling R85 913.64, extra cost for the reinforced roof totalling R46 396.39 (see Chapter 4). The total initial costs for a 5 kW PV roof tile system was R492 608.38, excluding replacement costs; (2) a 300 litre SWH system totalling R13 286, a generic domestic external plumbing kit totalling R2 500, a pressure control valve totalling R495, a geyser timer totalling R963, installation/labour totalling R2 310, and a fuel allowance totalling R125. The total initial cost for a 300 litre SWH system was R19 679. Altogether the initial costs for a solar power rooftop system (comprising a 300 litre SWH and a 5 kW PV roof tile system) totalled R512 287.38. All these initial capital costs are entered into the spreadsheet as if incurred in the base year, Year 0, i.e. as a one-year capital project taking place during 2009.

- Fuel costs – energy, water and other costs

The fuel cost items measured for a coal-fired power plant included coal costs totalling R175/tonne, sorbent costs totalling R125/tonne and water costs totalling R7/kL.[9] Based on annual consumption of: 14 600 000 tonnes of coal, the annual total cost of coal is R2 555 000 000; and 730 000 tonnes of sorbent, the annual total cost of sorbent is R91 250 000; and 49 953 024 kL of water, the annual total cost of water is R349 671 168 in the 2009 base year. Life-cycle price escalation used for fuel cost items is 15% for coal, sorbent and water, keeping in mind ever-increasing resource shortages over the next 40 years. The price of coal in particular is going to be under severe upward pressure as demand, bolstered by Indian and Chinese markets, outstrips global supply. In fact, according to Bongani Nqwababa, former CFO of Eskom, coal prices had increased by 30% in the 2007/2008 financial year (*Engineering News*, 2007)[10]. This was due to short-term contracts that Eskom had to negotiate to keep up with the country's growing electricity demand. He further indicated that the other critical factor that increased coal prices was that Eskom's long-term coal suppliers were increasingly attracted to the more lucrative export markets when the export coal price was peaking at above $100/tonne, "creating huge security of supply issues" (*Engineering News*, 2008). The high costs were also a consequence of the fact that the existing power station fleet, which had to run harder owing to capacity shortfalls, was burning more coal than that contracted for with the dedicated collieries on a long-term basis. More coal also had to be transported from distant mines by road, which had added considerably to logistics

[9] Accessed from: http://www.engineeringnews.co.za/article/eskom-to-study-how-surging-coal-price-can-be-contained-2007-11-22-1
[10] Accessed from: http://www.engineeringnews.co.za/article/eskom-to-study-how-surging-coal-price-can-be-contained-2007-11-22-1

costs. Eskom has indicated that it will be unable to manage without the expensive short-term contract of coal supply until 2018. It is currently negotiating with short-term coal providers to accept longer 10-year contracts extending to 2018.

For a solar rooftop system the fuel is sunshine, which is free, i.e. there are no fuel costs for a solar rooftop system. In addition, water for washing the PV tiles and thermal collectors (especially flat plates) is also free – rain.

- Operation, maintenance and repair costs

OM&R cost items determined for a coal-fired power plant included variable O&M costs at R1.50/MWh totalling an annual cost of R56 764 800, and fixed O&M costs at R100/kW/year totalling an annual cost of R480 000 000. Life-cycle price escalation used for O&M cost items is 9%, since these items often escalate at rates above general inflation, e.g. CPI data averaged 6.7% in July 2009.[11] As indicated in Chapter 4, thus far there have been no maintenance issues or any sort of complications associated with the solar power rooftop system installed at Lynedoch. A 1.7 kW PV roof tile system has been operating for over a year now (since September 2008) and 3.3 kW PV system has been in operation for over three months now (since May 2009) and no maintenance problems have been identified with either system thus far. A 300 litre SWH system has now been in operation for two months and there have not been any complications so far.

Most advocates of PV systems maintain that no maintenance costs are incurred by a solar PV. This is probably true for PV panels themselves as they are very robust devices, but the PV installations do not only comprise the panels but also other components such as an inverter that uses power and normal electronics that can fail. Even though there have not been operation and maintenance issues with the Lynedoch pilot project thus far, five years of operating experience of the Springerville PV generating plant in Arizona, USA, has shown that the average annual maintenance cost as a percentage of the initial capital investment was 0.12%, of which 60% was attributed to the inverter. The Springerville PV plant is a large-scale PV application, approximately 3.51 MW, but its experience can help improve performance and avoid system failure of small-scale PV applications. The 0.12% of

[11] Accessed from: http://www.statssa.gov.za/publications/statskeyfindings.asp?PPN=p0141&SCH=4462

initial capital costs of the Lynedoch solar power rooftop pilot project amounts to R412.78 per annum, but according to Sieckmann (2009), the maintenance costs that will be incurred by the solar rooftop system amount to R777.50 every six months. This means that a solar PV rooftop system at Lynedoch will incur R1 555 per annum as maintenance costs. This is for unforeseen electrical faults as well as for cleaning of tiles (maybe twice a year). According to Atlantic Solar, the manufacturer and installer of the SWH system at Lynedoch, none of the SWHs (2x150 litre geysers) requires an anode replacement. Depending on water quality, Atlantic Solar points out that it would be wise to schedule a collector flush every two to three years. Therefore, this thesis uses R1 555 as maintenance costs incurred by Lynedoch pilot project (PV and SWH) as maintained by Sieckmann (2008). For a million residential solar power systems, this figure amounts to R1.5 billion in the 2009 base year.

- Replacement costs

The number and timing of capital replacements of a solar power rooftop system depend on the estimated life of the system. Both SWH and PV roof tile systems have an estimated life span of 25 years and provision is made for a replacement after 25 years. It is recommended that the same sources that provide cost estimates for initial investments are used to obtain estimates of replacement costs and expected useful lives (Barringer, 2003; Fuller, 2008). Barringer (2003) and Fuller (2008) maintain that a good starting point for estimating future replacement costs is to use their cost from the base year. The LCCA method will escalate base-year amounts to their future time of occurrence. The cost items measured here included a 5 kW PV roof tile system at a cost of R343 979.99, two inverters at a total cost of R50 265.08, a web-box at a cost of R12 428.96 and a 300 litre SWH system at a cost of R13 286. The LCCA will escalate replacement costs at CPI figures. PV roof tile system costs of R343 979.99 would have escalated to R1 740 378.32 in year 25 when the PV system reached the end of its useful life. This was calculated using CPI data of 6.7% of July 2009 base year. This value was then discounted to the 2009 base year at a 9% discount rate (see Section 5.2(c)) to get R201 827.90, which is the replacement costs incurred today in 2009 real terms. A 300 litre SWH cost of R13 286 escalated to R67 220.96 in year 25 when it reached the end of its useful life and was discounted at a 9% discount rate to get the present replacement cost of R7 795.47. A 1.7 kW inverter cost of R20 824.60 escalated to R105 362.76 in year 25 and was discounted at a 9% discount rate to get the present replacement cost of R12 218.69. A 3.3 kW inverter cost of R29 440.48 escalated to R148 955.10 in year 25 and was also discounted at a 9% discount rate to get the present replacement cost of R17 274.00. A web-box cost of R12 428.96 escalated to R62 884.74 in year 25 and was discounted at a 9% discount rate to get the present replacement cost of R7 292.61. The CPI of 6.7% was used as an escalation rate in all replacement cost calculations. Replacement costs for a coal-fired power plant are part of fixed O&M annual costs.

- Residual values – resale or salvage values or disposal or decommissioning costs

The residual value of a system (or component) is its remaining value at the end of its life/study period, or at the time of its replacement during the study period. Fuller (2008) argues that, as a rule of thumb, the residual value of a system with remaining useful life in place can be calculated by linearly prorating its initial costs. The cost items measured for residual values are replacement cost items, namely SWH and PV roof tile. For example, in this research study, for a SWH with an expected useful life of 25 years, which will be installed 15 years before the end of the study period (which is 40 years) to replace the old system that has reached its end of life, the residual value would be approximately [(25-15)/25] = 2/5 or 40% of its initial cost. The residual cost for the SWH in this research study would be 0.4 x R19 679 = R7 871.60. Similarly, the residual value for the PV roof tile system would be 0.4 x R343 979.99 = R137 592. The likelihood is that the solar rooftop system would not be dismantled and sold after the study period to realise the salvage value but would rather continue providing electrical and thermal energy to the households. Hence, this study would not use residual values at the end of the study period. Eskom’s current coal-based expansion programme does not include decommissioning costs that will be incurred at the end of the project’s useful life. The focus of this thesis is therefore on capital and operational costs during the life of a project.

- Other costs – finance charges (loan interest payments), non-monetary benefits or costs

The other cost items measured for a coal-fired power plant included carbon costs at 2c/kWh[12] generated from a coal-fired power plant. This is a carbon tax on operational carbon emissions from a coal-fired power plant and not emissions from the embodied energy of the materials used to construct a coal-fired power station. There are no carbon emissions resulting from the operation of a residential solar power system, and as a result, there is no carbon tax imposed on it. This thesis focuses on capital and operational costs of the two project alternatives over a 40-year period; hence it uses 2c/kWh for operational carbon emissions. The carbon credits are treated as uncertain input values in this thesis, which may have great impact on the LCC of the Lynedoch pilot project. This is because the carbon markets are subject to a number of major uncertainties at this stage, primarily that of a post-2012 Kyoto compliance period. This thesis will therefore use €10/tonne of $CO_2e$ that is used by the Kuyasa[13] project in Khayelitsha, Cape Town, South Africa (SouthSouthNorth, [s.a.]) in its calculations of the 40-year LCC of the residential solar power system (PV and SWH).

The cost items and cost details of a 4 800 MW coal-fired power plant and solar power rooftop system (comprising a 5 kW PV roof tile system and a 300 litre SWH) discussed above are presented in Table 5.2 and Table 5.3 respectively. The calculations use generic assumptions for the main technical and economic parameters, such economic lifetime of 40 years, average capacity factor of 90% for base-load, and a discount rate of 9% for a coal-fired power plant. For a residential solar power system, the economic lifetime is 25 years, average capacity factor is 23% (using South African average radiation levels of 5.5 kWh/kW/day), and discount rate is 9%.

[12] This is the year SA business will feel the touch of Kyoto, February 04, 2009. http://www.busrep.co.za/index.php?fSectionId=561&fArticleId=4824556
[13] Refer to http://www.kuyasacdm.co.za/ for more information.

**Table 5.2: Cost items and details of a 4 800 MW coal-fired power plant**

| | | |
|---|---|---|
| **COAL-FIRED POWER PLANT** | | |
| **Capacity:** | **4 800 MW** | |
| **Capacity factor:** | **90%** | |
| **Annual generation:** | **37 843 200 000 kWh** | |
| **Initial costs:**[14] | Plant costs | R100 000 000 000 |
| | Transmission costs | R2 000 000 000 |
| | Fixed annual costs (R6/kW) | R28 800 000 |
| | Other direct costs (10% of EPC) | R10 000 000 000 |
| | Total initial costs | R112 028 800 000 |
| **Coal costs:**[15] | Annual coal consumption | 14 600 000 tonnes |
| | Coal costs | R175/tonne |
| | Annual coal costs | R2 555 000 000 |
| **Water costs:**[16] | Water consumption | 1.35 L/kWh |
| | Annual water consumption | 51 088 320 kL |
| | Water costs | R7/kL |
| | Annual water costs | R357 618 240 |
| **Sorbent costs:**[17] | Sorbent consumption | 0.05tonne/tonne of coal |
| | Annual sorbent consumption | 730 000 tonnes |
| | Sorbent costs | R125/tonne |
| | Annual sorbent costs | R91 250 000 |
| **O&M costs:**[18] | Variable O&M costs | R1.50/MWh |
| | Annual variable O&M costs | R56 764 800 |
| | Fixed O&M costs | R100/kW/year |
| | Annual fixed O&M costs | R480 000 000 |
| | Total annual O&M costs | R536 764 800 |
| **Carbon costs:**[19] | Carbon tax | R0.02/kWh |
| | Annual carbon costs | R756 864 000 |
| | Coal carbon emission factor | 1.2 kg $CO_2$/kWh |
| | Annual carbon emissions | 45 411 840 tonnes $CO_2$ |

[14] Accessed from: http://www.engineeringnews.co.za/article/medupi-cost-escalates-to-r120-billion-eskom-2009-07-20
[15] Accessed from: http://www.engineeringnews.co.za/article/eskom-to-study-how-surging-coal-price-can-be-contained-2007-11-22-1
[16] Accessed from: http://www.eskom.co.za/aanreport09/ar (9/9/2009)
[17] Accessed from: http://www.engineeringnews.co.za/article/eskom-to-study-how-surging-coal-price-can-be-contained-2007-11-22-1
[18] Accessed from: http://www.engineeringnews.co.za/article/eskom-to-study-how-surging-coal-price-can-be-contained-2007-11-22-1
[19] Trevor Manuel, former Minister of Finance, in his Budget Vote Speech of February 2009.

**Table 5.3: Cost items and details of a residential solar rooftop system (PV and SWH) including the roof**

| RESIDENTIAL SOLAR ROOFTOP SYSTEM (PV and SWH) | | |
|---|---|---|
| **PV system size:** 5 kW<br>**Capacity factor:** 23%<br>**SWH system size:** 300 litre SWH<br>**Solar radiation (SA annual average):** 5.5 kWh/kW/day<br>**Annual solar PV production:** 10 038 kWh (calculated)<br>**Annual SWH energy savings:** 3 600 kWh (based on 40% monthly electricity savings) | | |
| **Initial costs:** | PV system costs | R343 979.99 |
| | PV system replacement costs (discounted at 9%) | R201 827.91 |
| | Project management | R6 000 |
| | Design | R2 100 |
| | On-site visits | R4 500 |
| | Installation | R1 800 |
| | System commissioning | R600 |
| | Travel | R3 500 |
| | Additional materials | R6 485.75 |
| | 1.7 kW inverter | R20 824.60 |
| | 1.7 kW inverter replacement costs | R12 218.69 |
| | 3.3 kW inverter | R29 440.48 |
| | 3.3 kW inverter replacement costs | R17 274.00 |
| | Web-box | R12 428.96 |
| | Web-box replacement costs | R7 292.61 |
| | Import and storage costs | R16 318.36 |
| | Roof support structure | R46 396.39 |
| | **Total initial PV costs** | **R732 987.74** |
| | | |
| | SWH system costs | R13 286 |
| | SWH replacement costs (discounted) | R7 795.47 |
| | Generic domestic external plumbing kit | R2 500 |
| | Pressure control valve | R495 |
| | Geyser timer | R963 |
| | Installation/labour costs | R2 310 |
| | Fuel allowance costs | R125 |
| | **Total initial SWH costs** | **R 27 474.47** |
| | | |
| | **Combined initial PV and SWH costs** | **R760 462.21** |
| **O&M costs:** | O&M costs | R1 555 |
| **Residual values:** | SWH | R7 871.60 |
| | PV roof tile | R137 592 |

The total installation cost of a residential solar power system is very high, but if a million or more houses were to be installed with these systems these costs will likely come down drastically.

Fuller (2008) argues that only those costs within each category that are relevant to the decision and significant in amount are needed to make a valid investment decision. He further argues that costs are relevant when they are different for one alternative compared with another; costs are significant when they are large enough to make a credible difference in the LCC of a project alternative. All the costs are entered as base-year amounts in today's money; the LCCA method escalates all the amounts to their future year of occurrence and discounts them back to the base year to convert them to present values (Fuller, 2008). Hence this thesis will now look at the parameters for present value analysis.

**(c) The parameters for present value analysis**

- Discount rate

Various authors (Burger & Swilling, 2009; Barringer, 2003; Fuller, 2008; Hunkeler et al., 2009) argue that a critical factor is the selection of a discount rate to convert future money into present value in order to compare costs and benefits spread unevenly over time. In order to do this, the LCC method converts them to present values by discounting them to a common point in time, usually the base year. The interest rate used for discounting is a rate that reflects an investor's opportunity cost of money over time, meaning that an investor wants to achieve a return at least as high as that of his/her next best investment. Hence, the discount rate represents the investor's minimum acceptable rate of return. According to Burger and Swilling (2009), the higher the discount rate, the smaller the weight of future costs in the net present value (NPV). These authors point out that since the majority of costs in a capital investment are incurred early in the life-cycle and the benefits are accrued over the longer term, it is advisable to use a higher discount rate in order to have a pessimistic view on future benefits. They argue that another factor influencing the choice of a discount rate is the economic situation of the particular source (Burger & Swilling, 2009). They illustrate this by referring to Winkler et al. (2002 cited in Burger & Swilling), who used a social discount rate of 8% for tax-funded investment but a consumer discount rate of 30% for investment by poor households in their cost-benefit analysis of energy efficiency in urban low-cost housing (Burger & Swilling, 2009). They maintain that Winkler et al. (2002) argued that poor households do not have money to invest upfront, forcing them to rely on punitive sources of capital, hence the higher discount rate.

In LCCA, benefits or returns are not quantified. The costs incurred over a period of time for two or more alternatives serving the same purpose are discounted to a NPV and the alternative with the lowest NPV therefore represents the most cost effective investment. According to Burger and Swilling (2009), future costs should be weighted more in the NPV, meaning a lower discount rate. They argue that future costs for poor households with their lower than inflation increase in revenue should similarly be weighed conservatively more than present costs by means of a lower than social discount rate. This thesis proposes that a million or more solar power rooftop systems (comprising SWH and PV) should be financed from coal-fired generation capacity that will no longer be needed. In other words, it proposes that the government should finance a million or more solar power rooftop systems as part of a public infrastructure spending or that Eskom should fund the programme as part of its DSM programme and/or as part of its strategy to diversify its primary energy sources (ISEP). To avoid being accused of deliberately favouring solar power rooftop systems with their higher capital costs and lower life-cycle operating cost over coal-fired power plant, this thesis uses the 2007 National Treasury's prescribed 9% social discount rate for both alternatives. In addition to that the 2003 World Nuclear Association Report provides a summary of several studies carried out that compare the relative costs of generating electricity by new plants using different technologies. It is indicated that the discount rate for coal projects was 9.6% in the US in 2003 and 9.5% in 2004; 8% in the EU in 2003 and 5% in 2004; 7.5% in the UK in 2004; and 8% in Canada in 2003.

Financial institutions and organisations often set internal discount rates (which often change) to make economic decisions easy for all stakeholders (engineers, planners, policy makers and others). Various authors (Barringer, 2003; Fuller, 2009) argue that there is a host of considerations and relationships which is reflected in discount rates, including very low risk investment returns such as government bonds and

Treasury-bills (T-bills), factors such as internal rate of return (IRR), inflation/deflation and estimated uncertainties.

Businesses and organisations should summarise LCC results in a net present value (NPV) format considering depreciation, taxes and time value of money. According to Barringer (2003), government organisations and agencies do not require the inclusion of depreciation or taxes for LCC decisions but they should consider the time value of money. The calculations of LCC in this thesis do not take into account taxation or capital allowances and are only intended to provide an indication of the costs of production of electricity from a coal-fired power plant and a residential solar power system (PV and SWH) at the point of plant or system connection to the electricity grid.

A net present value (NPV) approach was chosen in this thesis for evaluating and comparing the cost of electricity generated from a coal-fired power plant to that of a residential solar power rooftop system (PV and SWH) alternative. The present value of a future amount of money (cost in this case) is

$$PV = \frac{FV}{(1+r)\hat{}n}$$

where PV is the present value, FV is the future value, n is the number of years in the future that the future cost will be incurred, and r is the discount rate, which is the same as the interest rate.

The discount rates are used as multipliers or dividers to put financial transactions into the future and present values of money. An example of this is provided in Table 5.4 using a discount rate of 10%.

**Table 5.4: An example of the present value and future value of money**

| **Discount rate = 10%** | | | **Investment = R1.00** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| PV | R1.00 | R0.91 | R0.83 | R0.75 | R0.68 | R0.62 | R0.56 | R0.51 | R0.47 | R0.42 | R0.39 |
| FV | R1.00 | R1.10 | R1.21 | R1.33 | R1.46 | R1.61 | R1.77 | R1.95 | R2.14 | R2.36 | R2.59 |

- Cost period

According to Fuller (2008), cost period can refer to the length of the study period, service period and contract period. Since this thesis focuses more on operational costs, all these cost periods would be considered as the service period over which operational and maintenance costs and benefits are evaluated. This service period will be equivalent to the life span of the project alternatives starting with the base year – the year to which all cash flows are discounted. The cost period for this thesis is 40 years.

- Discounting convention

In this thesis all annually recurring cash flows (e.g. operational costs) are discounted from the end of the year in which they are incurred. All single amounts (e.g. replacement costs) are discounted from the year they occur.

Tables 5.5, 5.6 and 5.7 provide the cost profiles for a coal-fired power plant including carbon costs and cost profiles for a residential solar power system (PV and SWH) in R/kWh. Calculations for both are based on 9% interest on a loan per annum. The first calculation for residential solar power system is based on estimated annual energy yield of 10 038 kWh from a 5 kW PV roof tile system. This is followed by an actual annual average energy yield of 4 906 kWh produced from a 5 KW PV system in the uncertainty assessment.

**Table 5.5: Cost profiles for coal-fired power plant including carbon costs in R/kWh (Figures in red are present values in 2009 base year)**

| Coal (R/kWh) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Capex | Capex PV | Coal | Coal PV | Water | Water PV | Sorbent | Sorbent PV | O&M | O&M PV | Carbon | Carbon PV |
| 0 | R 0.28 | R 0.28 | R 0.00 | R 0.00 | R 0.00 | R 0.00 | R 0.00 | R 0.00 | R 0.00 | R 0.00 | R 0.00 | R 0.00 |
| 1 | R 0.28 | R 0.28 | R 0.07 | R 0.06 | R 0.01 | R 0.01 | R 0.00 | R 0.00 | R 0.01 | R 0.01 | R 0.02 | R 0.02 |
| 2 | R 0.28 | R 0.28 | R 0.08 | R 0.07 | R 0.01 | R 0.01 | R 0.00 | R 0.00 | R 0.01 | R 0.01 | R 0.02 | R 0.02 |
| 3 | R 0.28 | R 0.28 | R 0.09 | R 0.07 | R 0.01 | R 0.01 | R 0.00 | R 0.00 | R 0.02 | R 0.01 | R 0.03 | R 0.02 |
| 4 | R 0.28 | R 0.28 | R 0.11 | R 0.08 | R 0.02 | R 0.01 | R 0.00 | R 0.00 | R 0.02 | R 0.01 | R 0.03 | R 0.02 |
| 5 | R 0.28 | R 0.28 | R 0.12 | R 0.08 | R 0.02 | R 0.01 | R 0.00 | R 0.00 | R 0.02 | R 0.01 | R 0.03 | R 0.02 |
| 6 | R 0.28 | R 0.28 | R 0.14 | R 0.08 | R 0.02 | R 0.01 | R 0.00 | R 0.00 | R 0.02 | R 0.01 | R 0.04 | R 0.02 |
| 7 | R 0.28 | R 0.28 | R 0.16 | R 0.09 | R 0.02 | R 0.01 | R 0.01 | R 0.00 | R 0.02 | R 0.01 | R 0.05 | R 0.03 |
| 8 | R 0.28 | R 0.28 | R 0.19 | R 0.09 | R 0.03 | R 0.01 | R 0.01 | R 0.00 | R 0.03 | R 0.01 | R 0.05 | R 0.03 |
| 9 | R 0.28 | R 0.28 | R 0.21 | R 0.10 | R 0.03 | R 0.01 | R 0.01 | R 0.00 | R 0.03 | R 0.01 | R 0.06 | R 0.03 |
| 10 | R 0.28 | R 0.28 | R 0.25 | R 0.10 | R 0.04 | R 0.01 | R 0.01 | R 0.00 | R 0.03 | R 0.01 | R 0.07 | R 0.03 |
| 11 | R 0.28 | R 0.28 | R 0.28 | R 0.11 | R 0.04 | R 0.02 | R 0.01 | R 0.00 | R 0.03 | R 0.01 | R 0.08 | R 0.03 |
| 12 | R 0.28 | R 0.28 | R 0.33 | R 0.12 | R 0.05 | R 0.02 | R 0.01 | R 0.00 | R 0.04 | R 0.01 | R 0.09 | R 0.03 |
| 13 | R 0.28 | R 0.28 | R 0.37 | R 0.12 | R 0.05 | R 0.02 | R 0.01 | R 0.00 | R 0.04 | R 0.01 | R 0.11 | R 0.03 |
| 14 | R 0.28 | R 0.28 | R 0.43 | R 0.13 | R 0.06 | R 0.02 | R 0.01 | R 0.00 | R 0.04 | R 0.01 | R 0.12 | R 0.04 |
| 15 | R 0.28 | R 0.28 | R 0.50 | R 0.14 | R 0.07 | R 0.02 | R 0.02 | R 0.00 | R 0.05 | R 0.01 | R 0.14 | R 0.04 |
| 16 | R 0.28 | R 0.28 | R 0.57 | R 0.14 | R 0.08 | R 0.02 | R 0.02 | R 0.00 | R 0.05 | R 0.01 | R 0.16 | R 0.04 |
| 17 | R 0.28 | R 0.28 | R 0.66 | R 0.15 | R 0.09 | R 0.02 | R 0.02 | R 0.01 | R 0.05 | R 0.01 | R 0.19 | R 0.04 |
| 18 | R 0.28 | R 0.28 | R 0.75 | R 0.16 | R 0.11 | R 0.02 | R 0.03 | R 0.01 | R 0.06 | R 0.01 | R 0.22 | R 0.05 |
| 19 | R 0.28 | R 0.28 | R 0.87 | R 0.17 | R 0.12 | R 0.02 | R 0.03 | R 0.01 | R 0.06 | R 0.01 | R 0.25 | R 0.05 |
| 20 | R 0.28 | R 0.28 | R 1.00 | R 0.18 | R 0.14 | R 0.03 | R 0.03 | R 0.01 | R 0.07 | R 0.01 | R 0.28 | R 0.05 |
| 21 | R 0.28 | R 0.28 | R 1.15 | R 0.19 | R 0.16 | R 0.03 | R 0.04 | R 0.01 | R 0.08 | R 0.01 | R 0.33 | R 0.05 |
| 22 | R 0.28 | R 0.28 | R 1.32 | R 0.20 | R 0.19 | R 0.03 | R 0.05 | R 0.01 | R 0.08 | R 0.01 | R 0.38 | R 0.06 |
| 23 | R 0.28 | R 0.28 | R 1.52 | R 0.21 | R 0.22 | R 0.03 | R 0.05 | R 0.01 | R 0.09 | R 0.01 | R 0.43 | R 0.06 |
| 24 | R 0.28 | R 0.28 | R 1.74 | R 0.22 | R 0.25 | R 0.03 | R 0.06 | R 0.01 | R 0.10 | R 0.01 | R 0.50 | R 0.06 |
| 25 | R 0.28 | R 0.28 | R 2.00 | R 0.23 | R 0.29 | R 0.03 | R 0.07 | R 0.01 | R 0.11 | R 0.01 | R 0.57 | R 0.07 |
| 26 | R 0.28 | R 0.28 | R 2.30 | R 0.25 | R 0.33 | R 0.04 | R 0.08 | R 0.01 | R 0.12 | R 0.01 | R 0.66 | R 0.07 |
| 27 | R 0.28 | R 0.28 | R 2.65 | R 0.26 | R 0.38 | R 0.04 | R 0.09 | R 0.01 | R 0.13 | R 0.01 | R 0.76 | R 0.07 |
| 28 | R 0.28 | R 0.28 | R 3.05 | R 0.27 | R 0.44 | R 0.04 | R 0.10 | R 0.01 | R 0.14 | R 0.01 | R 0.87 | R 0.08 |
| 29 | R 0.28 | R 0.28 | R 3.50 | R 0.29 | R 0.50 | R 0.04 | R 0.12 | R 0.01 | R 0.15 | R 0.01 | R 1.00 | R 0.08 |
| 30 | R 0.28 | R 0.28 | R 4.03 | R 0.30 | R 0.58 | R 0.04 | R 0.14 | R 0.01 | R 0.17 | R 0.01 | R 1.15 | R 0.09 |
| 31 | R 0.28 | R 0.28 | R 4.63 | R 0.32 | R 0.66 | R 0.05 | R 0.16 | R 0.01 | R 0.18 | R 0.01 | R 1.32 | R 0.09 |
| 32 | R 0.28 | R 0.28 | R 5.33 | R 0.34 | R 0.76 | R 0.05 | R 0.18 | R 0.01 | R 0.20 | R 0.01 | R 1.52 | R 0.10 |
| 33 | R 0.28 | R 0.28 | R 6.13 | R 0.36 | R 0.88 | R 0.05 | R 0.21 | R 0.01 | R 0.22 | R 0.01 | R 1.75 | R 0.10 |
| 34 | R 0.28 | R 0.28 | R 7.05 | R 0.38 | R 1.01 | R 0.05 | R 0.24 | R 0.01 | R 0.24 | R 0.01 | R 2.01 | R 0.11 |
| 35 | R 0.28 | R 0.28 | R 8.11 | R 0.40 | R 1.16 | R 0.06 | R 0.28 | R 0.01 | R 0.26 | R 0.01 | R 2.32 | R 0.11 |
| 36 | R 0.28 | R 0.28 | R 9.32 | R 0.42 | R 1.33 | R 0.06 | R 0.32 | R 0.01 | R 0.28 | R 0.01 | R 2.66 | R 0.12 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 37 | R 0.28 | R 0.28 | R 10.72 | R 0.44 | R 1.53 | R 0.06 | R 0.37 | R 0.02 | R 0.30 | R 0.01 | R 3.06 | R 0.13 |
| 38 | R 0.28 | R 0.28 | R 12.33 | R 0.47 | R 1.76 | R 0.07 | R 0.42 | R 0.02 | R 0.33 | R 0.01 | R 3.52 | R 0.13 |
| 39 | R 0.28 | R 0.28 | R 14.18 | R 0.49 | R 2.03 | R 0.07 | R 0.49 | R 0.02 | R 0.36 | R 0.01 | R 4.05 | R 0.14 |
| 40 | R 0.28 | R 0.28 | R 16.30 | R 0.52 | R 2.33 | R 0.07 | R 0.56 | R 0.02 | R 0.39 | R 0.01 | R 4.66 | R 0.15 |

**Table 5.6: Cost profiles of PV and PV (including roof) in R/kWh (Figures in red are present values in 2009 base year)**

| PV (R/kWh) | | | | | PV (including roof) (R/kWh) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | Capex | Capex PV | O&M costs | O&M PV | Year | Capex | Capex PV | O&M costs | O&M PV |
| 0 | R 6.36 | R 6.36 | R 0.00 | R 0.00 | 0 | R 6.79 | R 6.79 | R 0.00 | R 0.00 |
| 1 | R 6.36 | R 6.36 | R 0.15 | R 0.14 | 1 | R 6.79 | R 6.79 | R 0.15 | R 0.14 |
| 2 | R 6.36 | R 6.36 | R 0.16 | R 0.14 | 2 | R 6.79 | R 6.79 | R 0.16 | R 0.14 |
| 3 | R 6.36 | R 6.36 | R 0.17 | R 0.13 | 3 | R 6.79 | R 6.79 | R 0.17 | R 0.13 |
| 4 | R 6.36 | R 6.36 | R 0.18 | R 0.13 | 4 | R 6.79 | R 6.79 | R 0.18 | R 0.13 |
| 5 | R 6.36 | R 6.36 | R 0.20 | R 0.13 | 5 | R 6.79 | R 6.79 | R 0.20 | R 0.13 |
| 6 | R 6.36 | R 6.36 | R 0.21 | R 0.13 | 6 | R 6.79 | R 6.79 | R 0.21 | R 0.13 |
| 7 | R 6.36 | R 6.36 | R 0.23 | R 0.12 | 7 | R 6.79 | R 6.79 | R 0.23 | R 0.12 |
| 8 | R 6.36 | R 6.36 | R 0.24 | R 0.12 | 8 | R 6.79 | R 6.79 | R 0.24 | R 0.12 |
| 9 | R 6.36 | R 6.36 | R 0.26 | R 0.12 | 9 | R 6.79 | R 6.79 | R 0.26 | R 0.12 |
| 10 | R 6.36 | R 6.36 | R 0.28 | R 0.12 | 10 | R 6.79 | R 6.79 | R 0.28 | R 0.12 |
| 11 | R 6.36 | R 6.36 | R 0.30 | R 0.11 | 11 | R 6.79 | R 6.79 | R 0.30 | R 0.11 |
| 12 | R 6.36 | R 6.36 | R 0.32 | R 0.11 | 12 | R 6.79 | R 6.79 | R 0.32 | R 0.11 |
| 13 | R 6.36 | R 6.36 | R 0.34 | R 0.11 | 13 | R 6.79 | R 6.79 | R 0.34 | R 0.11 |
| 14 | R 6.36 | R 6.36 | R 0.36 | R 0.11 | 14 | R 6.79 | R 6.79 | R 0.36 | R 0.11 |
| 15 | R 6.36 | R 6.36 | R 0.39 | R 0.11 | 15 | R 6.79 | R 6.79 | R 0.39 | R 0.11 |
| 16 | R 6.36 | R 6.36 | R 0.41 | R 0.10 | 16 | R 6.79 | R 6.79 | R 0.41 | R 0.10 |
| 17 | R 6.36 | R 6.36 | R 0.44 | R 0.10 | 17 | R 6.79 | R 6.79 | R 0.44 | R 0.10 |
| 18 | R 6.36 | R 6.36 | R 0.47 | R 0.10 | 18 | R 6.79 | R 6.79 | R 0.47 | R 0.10 |
| 19 | R 6.36 | R 6.36 | R 0.51 | R 0.10 | 19 | R 6.79 | R 6.79 | R 0.51 | R 0.10 |
| 20 | R 6.36 | R 6.36 | R 0.54 | R 0.10 | 20 | R 6.79 | R 6.79 | R 0.54 | R 0.10 |
| 21 | R 6.36 | R 6.36 | R 0.58 | R 0.10 | 21 | R 6.79 | R 6.79 | R 0.58 | R 0.10 |
| 22 | R 6.36 | R 6.36 | R 0.62 | R 0.09 | 22 | R 6.79 | R 6.79 | R 0.62 | R 0.09 |
| 23 | R 6.36 | R 6.36 | R 0.66 | R 0.09 | 23 | R 6.79 | R 6.79 | R 0.66 | R 0.09 |
| 24 | R 6.36 | R 6.36 | R 0.71 | R 0.09 | 24 | R 6.79 | R 6.79 | R 0.71 | R 0.09 |
| 25 | R 6.36 | R 6.36 | R 0.76 | R 0.09 | 25 | R 6.79 | R 6.79 | R 0.76 | R 0.09 |
| 26 | R 6.36 | R 6.36 | R 0.81 | R 0.09 | 26 | R 6.79 | R 6.79 | R 0.81 | R 0.09 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 27 | R 6.36 | R 6.36 | R 0.87 | R 0.09 | 27 | R 6.79 | R 6.79 | R 0.87 | R 0.09 |
| 28 | R 6.36 | R 6.36 | R 0.93 | R 0.08 | 28 | R 6.79 | R 6.79 | R 0.93 | R 0.08 |
| 29 | R 6.36 | R 6.36 | R 1.00 | R 0.08 | 29 | R 6.79 | R 6.79 | R 1.00 | R 0.08 |
| 30 | R 6.36 | R 6.36 | R 1.07 | R 0.08 | 30 | R 6.79 | R 6.79 | R 1.07 | R 0.08 |
| 31 | R 6.36 | R 6.36 | R 1.14 | R 0.08 | 31 | R 6.79 | R 6.79 | R 1.14 | R 0.08 |
| 32 | R 6.36 | R 6.36 | R 1.22 | R 0.08 | 32 | R 6.79 | R 6.79 | R 1.22 | R 0.08 |
| 33 | R 6.36 | R 6.36 | R 1.31 | R 0.08 | 33 | R 6.79 | R 6.79 | R 1.31 | R 0.08 |
| 34 | R 6.36 | R 6.36 | R 1.40 | R 0.07 | 34 | R 6.79 | R 6.79 | R 1.40 | R 0.07 |
| 35 | R 6.36 | R 6.36 | R 1.50 | R 0.07 | 35 | R 6.79 | R 6.79 | R 1.50 | R 0.07 |
| 36 | R 6.36 | R 6.36 | R 1.60 | R 0.07 | 36 | R 6.79 | R 6.79 | R 1.60 | R 0.07 |
| 37 | R 6.36 | R 6.36 | R 1.71 | R 0.07 | 37 | R 6.79 | R 6.79 | R 1.71 | R 0.07 |
| 38 | R 6.36 | R 6.36 | R 1.83 | R 0.07 | 38 | R 6.79 | R 6.79 | R 1.83 | R 0.07 |
| 39 | R 6.36 | R 6.36 | R 1.96 | R 0.07 | 39 | R 6.79 | R 6.79 | R 1.96 | R 0.07 |
| 40 | R 6.36 | R 6.36 | R 2.10 | R 0.07 | 40 | R 6.79 | R 6.79 | R 2.10 | R 0.07 |

**Table 5.7: Cost profiles of PV and SWH (including roof) in R/kWh (Figures in red are present values in 2009 base year)**

| PV and SWH (including roof) (R/kWh) | | | | |
|---|---|---|---|---|
| Year | Capex | Capex PV | O&M costs | O&M PV |
| 0 | R 6.85 | R 6.85 | R 0.00 | R 0.00 |
| 1 | R 6.85 | R 6.85 | R 0.15 | R 0.14 |
| 2 | R 6.85 | R 6.85 | R 0.16 | R 0.14 |
| 3 | R 6.85 | R 6.85 | R 0.17 | R 0.13 |
| 4 | R 6.85 | R 6.85 | R 0.18 | R 0.13 |
| 5 | R 6.85 | R 6.85 | R 0.20 | R 0.13 |
| 6 | R 6.85 | R 6.85 | R 0.21 | R 0.13 |
| 7 | R 6.85 | R 6.85 | R 0.23 | R 0.12 |
| 8 | R 6.85 | R 6.85 | R 0.24 | R 0.12 |
| 9 | R 6.85 | R 6.85 | R 0.26 | R 0.12 |
| 10 | R 6.85 | R 6.85 | R 0.28 | R 0.12 |
| 11 | R 6.85 | R 6.85 | R 0.30 | R 0.11 |
| 12 | R 6.85 | R 6.85 | R 0.32 | R 0.11 |
| 13 | R 6.85 | R 6.85 | R 0.34 | R 0.11 |
| 14 | R 6.85 | R 6.85 | R 0.36 | R 0.11 |
| 15 | R 6.85 | R 6.85 | R 0.39 | R 0.11 |

| | | | | |
|---|---|---|---|---|
| 16 | R 6.85 | R 6.85 | R 0.41 | R 0.10 |
| 17 | R 6.85 | R 6.85 | R 0.44 | R 0.10 |
| 18 | R 6.85 | R 6.85 | R 0.47 | R 0.10 |
| 19 | R 6.85 | R 6.85 | R 0.51 | R 0.10 |
| 20 | R 6.85 | R 6.85 | R 0.54 | R 0.10 |
| 21 | R 6.85 | R 6.85 | R 0.58 | R 0.10 |
| 22 | R 6.85 | R 6.85 | R 0.62 | R 0.09 |
| 23 | R 6.85 | R 6.85 | R 0.66 | R 0.09 |
| 24 | R 6.85 | R 6.85 | R 0.71 | R 0.09 |
| 25 | R 6.85 | R 6.85 | R 0.76 | R 0.09 |
| 26 | R 6.85 | R 6.85 | R 0.81 | R 0.09 |
| 27 | R 6.85 | R 6.85 | R 0.87 | R 0.09 |
| 28 | R 6.85 | R 6.85 | R 0.93 | R 0.08 |
| 29 | R 6.85 | R 6.85 | R 1.00 | R 0.08 |
| 30 | R 6.85 | R 6.85 | R 1.07 | R 0.08 |
| 31 | R 6.85 | R 6.85 | R 1.14 | R 0.08 |
| 32 | R 6.85 | R 6.85 | R 1.22 | R 0.08 |
| 33 | R 6.85 | R 6.85 | R 1.31 | R 0.08 |
| 34 | R 6.85 | R 6.85 | R 1.40 | R 0.07 |
| 35 | R 6.85 | R 6.85 | R 1.50 | R 0.07 |
| 36 | R 6.85 | R 6.85 | R 1.60 | R 0.07 |
| 37 | R 6.85 | R 6.85 | R 1.71 | R 0.07 |
| 38 | R 6.85 | R 6.85 | R 1.83 | R 0.07 |
| 39 | R 6.85 | R 6.85 | R 1.96 | R 0.07 |
| 40 | R 6.85 | R 6.85 | R 2.10 | R 0.07 |

### (d) Life-cycle cost calculation

After identifying all costs by year and amount and discounting them to present values, they are added to arrive at the total life-cycle costs for each alternative. Fuller (2008) gives the following formula for total LCC:

LCC = I + R + E + W + OM&R + O – r

- LCC = Total LCC in present value (PV) money of a given alternative

- I = PV of investment costs – initial costs (if incurred at base year, they need not be discounted)
- R = PV of capital replacement costs
- E = PV of energy costs
- W = PV of water costs
- OM&R = PV of non-fuel operation, maintenance and repair costs
- O = PV of other costs
- r = PV of residual value (resale or salvage value) less disposal costs

The project alternative with the lowest LCC shows cost effectiveness compared to other project alternatives.

The objective of this research study is to choose the most cost effective project alternative in its useful life with the least NPV per kWh. Tables 5.8 and 5.9 show the cost effectiveness of coal project compared to PV, PV and roof, and PV, roof and SWH systems.

**Table 5.8: Comparing cost effectiveness of coal-based electricity with PV and SWH including the cost of the roof in R/kWh (Figures in red are total LCC in 2009 present value (PV) money of coal-based electricity)**

| Coal-fired power plant | | | | | | | |
|---|---|---|---|---|---|---|---|
| Year | NPV Capex | NPV coal | NPV water | NPV sorbent | NPV O&M | NPV carbon | Total NPV |
| **0** | R 0.28 | R 0.00 | R 0.00 | R 0.00 | R 0.00 | R 0.00 | **R 0.28** |
| **0-5** | R 0.28 | R 0.36 | R 0.05 | R 0.01 | R 0.06 | R 0.10 | **R 0.87** |
| **0-10** | R 0.28 | R 0.83 | R 0.12 | R 0.03 | R 0.13 | R 0.24 | **R 1.62** |
| **0-15** | R 0.28 | R 1.44 | R 0.21 | R 0.05 | R 0.19 | R 0.41 | **R 2.57** |
| **0-20** | R 0.28 | R 2.24 | R 0.32 | R 0.08 | R 0.25 | R 0.64 | **R 3.81** |
| **0-25** | R 0.28 | R 3.29 | R 0.47 | R 0.11 | R 0.31 | R 0.94 | **R 5.40** |
| **0-30** | R 0.28 | R 4.66 | R 0.67 | R 0.16 | R 0.38 | R 1.33 | **R 7.47** |
| **0-35** | R 0.28 | R 6.44 | R 0.92 | R 0.22 | R 0.44 | R 1.84 | **R 10.15** |
| **0-40** | R 0.28 | R 8.78 | R 1.25 | R 0.30 | R 0.50 | R 2.51 | **R 13.63** |

**Table 5.9: Comparing cost effectiveness of PV, PV including roof costs, and a combination of PV and SWH including roof costs in R/kWh (Figures in red are total LCC in present value (PV) money of a residential solar power system)**

| PV (R/kWh) | | | | PV (including roof) (R/kWh) | | | | PV and SWH (including roof) (R/kWh) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | NPV Capex | NPV O&M | Total NPV | Year | NPV Capex | NPV O&M | Total NPV | Year | NPV Capex | NPV O&M | Total NPV |
| **0** | R 6.36 | R 0.00 | **R 6.36** | 0 | R 6.79 | R 0.00 | **R 6.79** | 0 | R 6.85 | R 0.00 | **R 6.85** |
| **0-5** | R 6.36 | R 0.66 | **R 7.02** | 0-5 | R 6.79 | R 0.66 | **R 7.45** | 0-5 | R 6.85 | R 0.66 | **R 7.51** |
| **0-10** | R 6.36 | R 1.27 | **R 7.63** | 0-10 | R 6.79 | R 1.27 | **R 8.06** | 0-10 | R 6.85 | R 1.27 | **R 8.12** |
| **0-15** | R 6.36 | R 1.82 | **R 8.18** | 0-15 | R 6.79 | R 1.82 | **R 8.61** | 0-15 | R 6.85 | R 1.82 | **R 8.67** |
| **0-20** | R 6.36 | R 2.32 | **R 8.68** | 0-20 | R 6.79 | R 2.32 | **R 9.11** | 0-20 | R 6.85 | R 2.32 | **R 9.17** |
| **0-25** | R 6.36 | R 2.78 | **R 9.14** | 0-25 | R 6.79 | R 2.78 | **R 9.57** | 0-25 | R 6.85 | R 2.78 | **R 9.63** |
| **0-30** | R 6.36 | R 3.20 | **R 9.56** | 0-30 | R 6.79 | R 3.20 | **R 9.99** | 0-30 | R 6.85 | R 3.20 | **R 10.05** |
| **0-35** | R 6.36 | R 3.58 | **R 9.94** | 0-35 | R 6.79 | R 3.58 | **R 10.37** | 0-35 | R 6.85 | R 3.58 | **R 10.43** |
| **0-40** | R 6.36 | R 3.92 | **R 10.28** | 0-40 | R 6.79 | R 3.92 | **R 10.71** | 0-40 | R 6.85 | R 3.92 | **R 10.77** |

Tables 5.8 and 5.9 show that the PV roof tile system (without SWH) is the most cost effective with a LCC of R10.28/kWh, followed by the PV roof tile system including the cost of the reinforced roof with a LCC of R10.71/kWh, and a LCC of R10.77/kWh for the PV roof tile and SWH including the cost of the reinforced roof, compared to coal-based electricity with a LCC of R13.63/kWh over a 40-year period. Overall, a residential solar power system (PV and SWH) including the cost of the reinforced roof has the lowest LCC of R10.77/kWh over a period of 40 years. This means that it is the most cost effective compared to a 4 800MW coal-fired power plant over the same period. The LCC of coal-based electricity at R13.63/kWh is 27% higher than that of a residential solar power system at R10.77/kWh. This is due to fuel and O&M costs of operating a coal-fired power plant over 40 years.

- Break-even analysis

Fuller (2008) maintains that sometimes decision makers want to know the maximum cost of an input that will allow the project to still break even, or conversely, what minimum benefit a project can produce and still cover the costs of the investment. To do this a break-even analysis is performed.

According to Barringer (2003), the break-even charts are useful tools for showing effects of fixed (capital) costs and variable (O&M) costs in the LCC process. For this thesis the cost effectiveness for the two alternatives are compared in Tables 5.8 and 5.9 and Figures 5.3 and 5.4. In Figures 5.3 and 5.4, the net present values (NPVs) are indicated on the Y-axis to combine monetary cost with time, indicated on the X-axis, and show how the effects of expenditures and cost reductions play together. The objective of this study is to choose the most cost effective project alternative in its useful life with the least NPV per kWh. In this case this is shown to be the residential solar power system (PV and SWH) including the cost of the reinforced roof at R10.77/kWh, compared to a coal-fired power plant which has the highest NPV value of R13.63/kWh at the end of its 40 year life-cycle. This is best shown by the break-even charts (see Figures 5.3 and 5.4). A residential solar power system (PV and SWH including the cost of the roof) breaks even just after year 35 at R10.77/kWh, and a PV roof tile system (without SWH and the roof) breaks even just before year 35 at R9.94/kWh.

**Figure 5.3: Total cost effectiveness comparison of coal-based electricity and solar power system (PV and SWH including roof costs) electricity over a 40-year period in R/kWh**

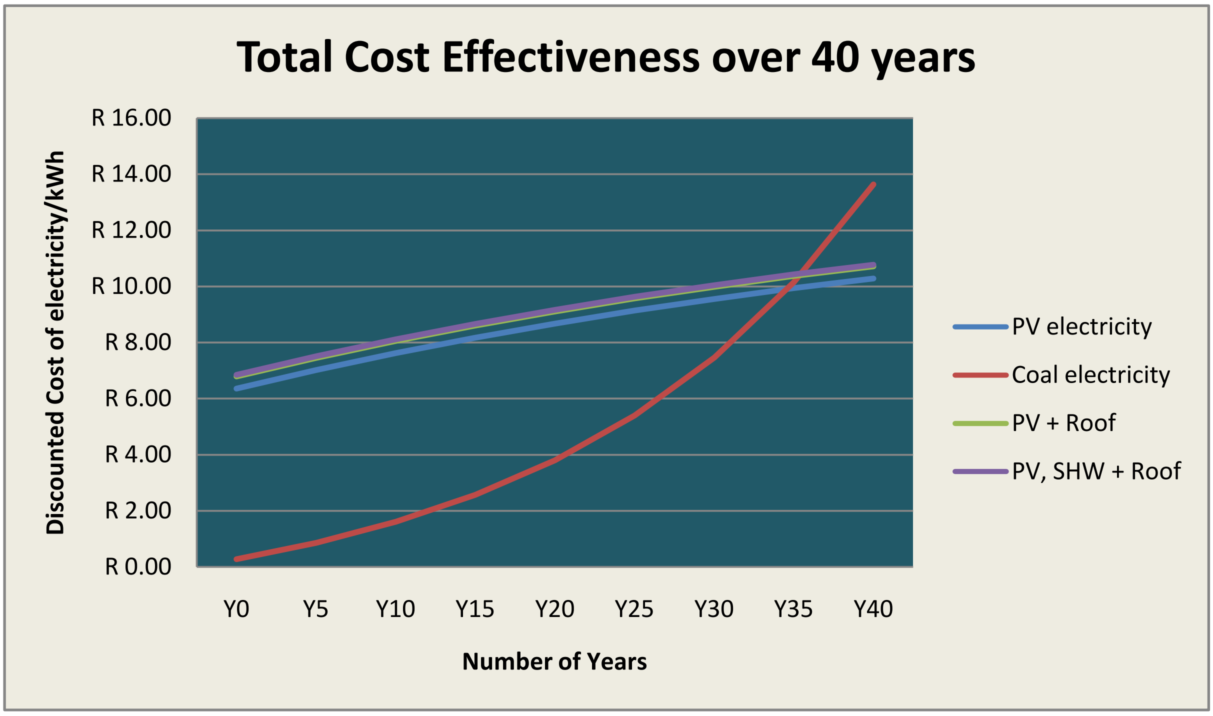
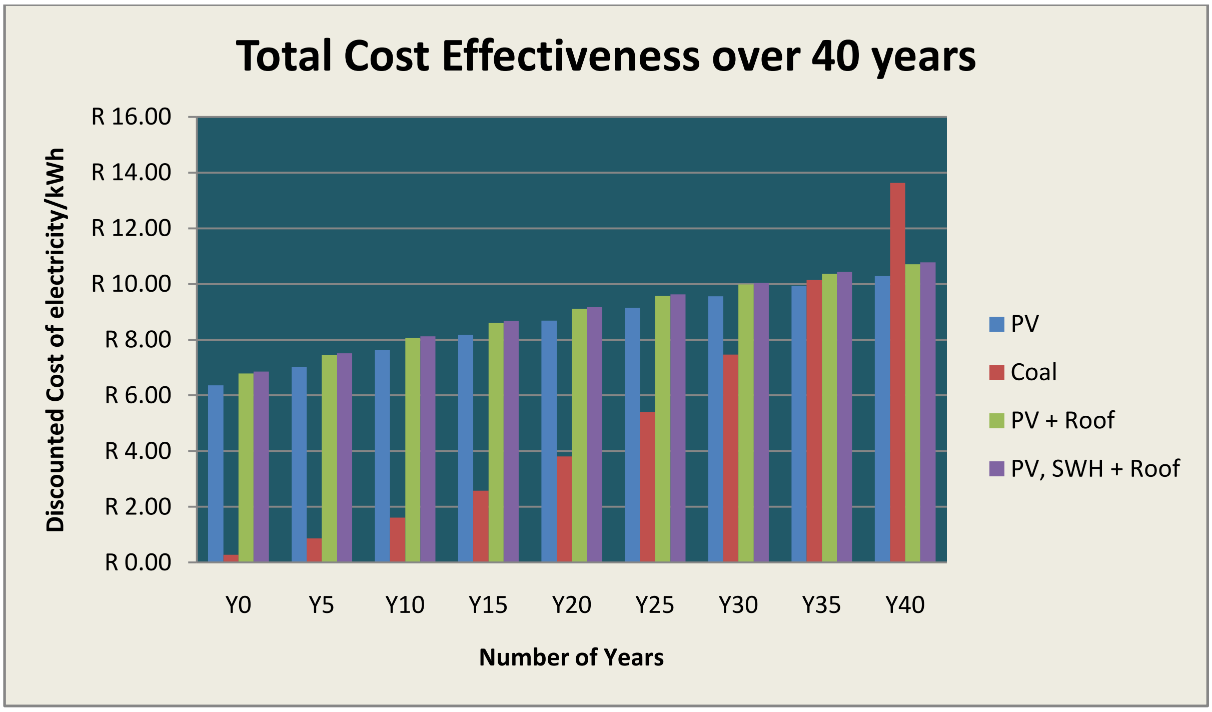


**Figure 5.4: Total cost effectiveness comparison of coal-based electricity and solar power system (PV and SWH including roof costs) electricity over a 40-year period in R/kWh**




**e) Uncertainty assessment in life-cycle cost analysis**

Various authors (Barringer, 2003; Fuller, 2008; Hunkeler et al., 2009) argue that the decision about project-related investments (e.g. power projects) typically involve a great deal of uncertainty about their costs and potential savings. LCCA greatly increases the likelihood of choosing a project that saves money in the long term. Yet, there may be some uncertainty associated with the LCC results. These authors argue that LCCAs are usually performed in the design process when only estimates of costs and savings are available, rather than real money amounts. They further maintain that uncertainty in input values means that actual outcomes may differ from estimated outcomes. Different techniques can be used to assess uncertainty of input variables; two of these, namely sensitivity analysis and break-even analysis (see Section 5.2(d)), often form part of the LCCA.

- Sensitivity analysis

Sensitivity analysis is the technique recommended for energy and water conservation projects. It is useful for the following:

- To identify which of the uncertain input values has the greatest impact on a specific measure of economic evaluation (e.g. LCCA)
- To determine how variability in the input value affects the range of a measure of economic evaluation
- To test different scenarios to answer 'what if' questions

To identify critical parameters, arrive at estimates of upper and lower bounds, or answer 'what if' questions, simply change the value of each input up or down, holding all others constant, and recalculate the economic measure (e.g. LCCA) to be tested. In this study volatile coal prices that are dependent on global markets have been identified as uncertain input values that may have the greatest impact on LCCA. The fact that coal prices had increased by 30% in the 2007/2008 financial year, according to the former chief financial officer of Eskom (*Engineering News*, 2008), makes coal price a critical parameter in LCCA. The short-term contracts that Eskom has to negotiate to keep up with the country's growing electricity demand and the fact that Eskom's long-term coal suppliers are increasingly attracted to the more lucrative export markets make coal price a very uncertain input value. The export coal price for first-grade coal peaked at above $100/tonne[20] in 2008. So, the upper bound of coal price for poor-quality coal used by Eskom in the next 40 years should be at least $50/tonne (R369.50/tonne at an exchange rate of R7.39/$ on 16 September 2009). The lower bound should be R90/ton of coal that Eskom pays its tied collieries based on their long-term contract of coal supply agreement should be R90/tonne of coal. For a residential solar power system, the uncertain input value that may have the greatest impact on LCCA is the actual energy yield (output) that so far has been just less than half of the estimated energy yield of 10 038 kWh. Therefore, the lower bound is the actual energy yield of 4 906 kWh per annum and the upper bound is an estimated value of 10 038 kWh per annum. The upper bound has already been used in the LCCA calculations (see Sections 5.2(c) and (d). The discount rate usually forms part of the uncertainty analysis, but since the National Treasury (2006) prescribed a 9% social discount rate for social projects, the discount rate did not form part of the uncertainty assessment in this thesis.

[20] Refer to: http://www.engineeringnews.co.za/article/eskom-to-study-how-surging-coal-price-can-be-contained-2007-11-22-1

Carbon markets are subject to a number of major uncertainties at this stage, primarily that of the post-2012 Kyoto compliance period. Developed countries (Annex 1 countries) which have signed the Kyoto Protocol and some of the developing countries (Annex 3 countries) which are not obliged to sign Kyoto Protocol are preparing for a new global pact on climate change that will be negotiated in Copenhagen, Denmark in December 2009. There is a high level of risk surrounding certified emissions reductions (CERs) since it is not known at this stage what is going to happen to global carbon markets after 2012. This means that no buyer is willing to pay for a future stream of CERs upfront, and very few are willing to buy credits after 2012. There is also a cost implication associated with the Clean Development Mechanism registration process which needs to be assessed against project activity cash flow requirements. For this reasons carbon credits are treated as uncertain input values which may have significant impact on a LCC of the Lynedoch pilot project. This thesis will therefore use €10/tonne of $CO_2$e that was used by the Kuyasa project in Khayelitsha, Cape Town, South Africa. Therefore coal price, carbon credits and the actual annual energy yield of the 5 kW PV system are a combination of high cost and vital few items of concern that need to be carefully considered in this thesis. The rand-euro exchange rate of R10.80/€ of September 16 2009 is used in this thesis. Therefore the price of R108/tonne $CO_2$e is used for carbon credit uncertainty assessment.

Figure 5.5 shows how the upper bound of the coal price (R369.50/tonne) affects the LCC of coal-based electricity over 40 years. The contribution of coal to overall costs of electricity is 32% or R0.14/kWh out of a total cost of R0.44/kWh. The residential solar power system breaks even just after year 25 compared to breaking even after year 35 in the case where the price of coal is R175/tonne. Overall, the residential solar power system (PV and SWH including roof) has the lowest LCC of R10.77/kWh compared to a LCC of R22.41/kWh of coal-based electricity over a period of 40 years.

**Figure 5.5: The effect of R369.50/tonne of coal on a 40-year LCC of coal-based electricity compared with solar power system (PV and SWH) electricity in R/kWh**

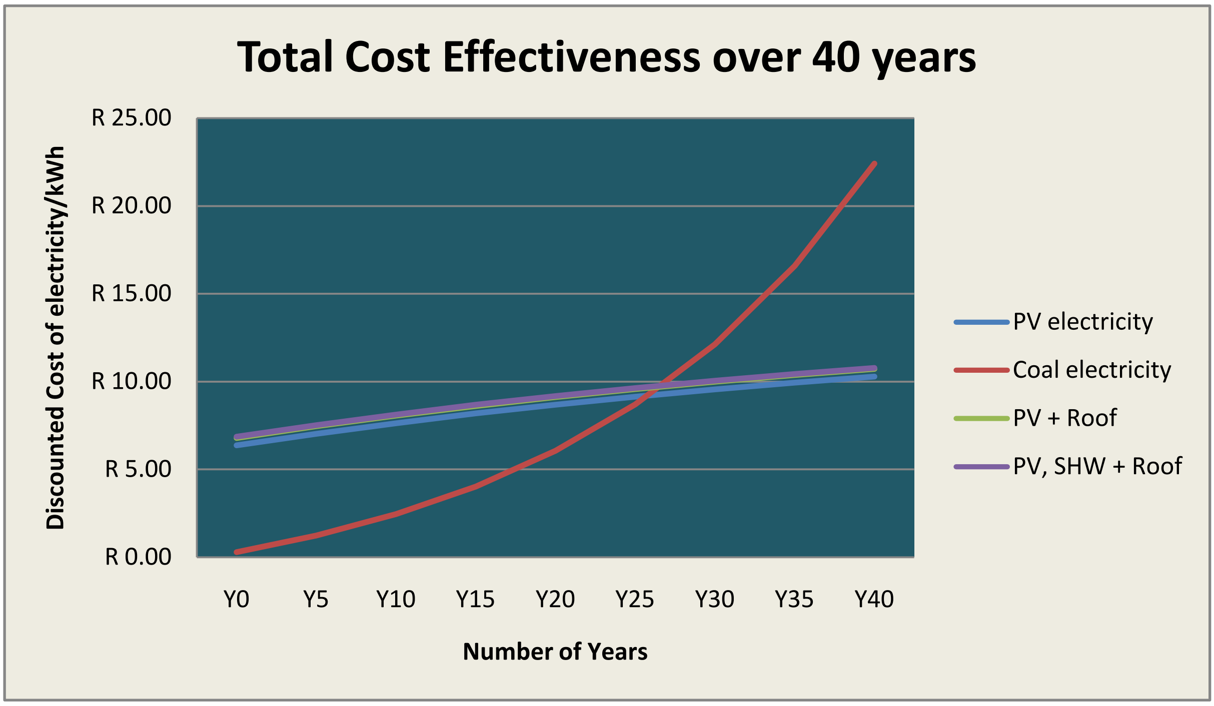
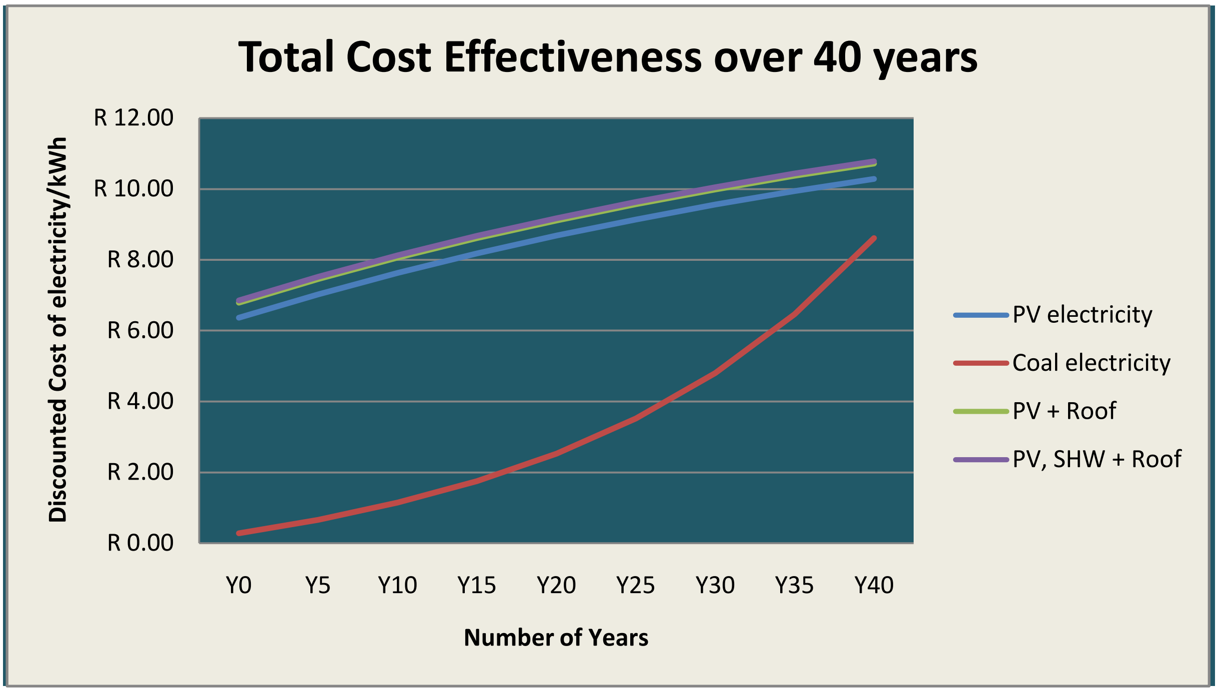


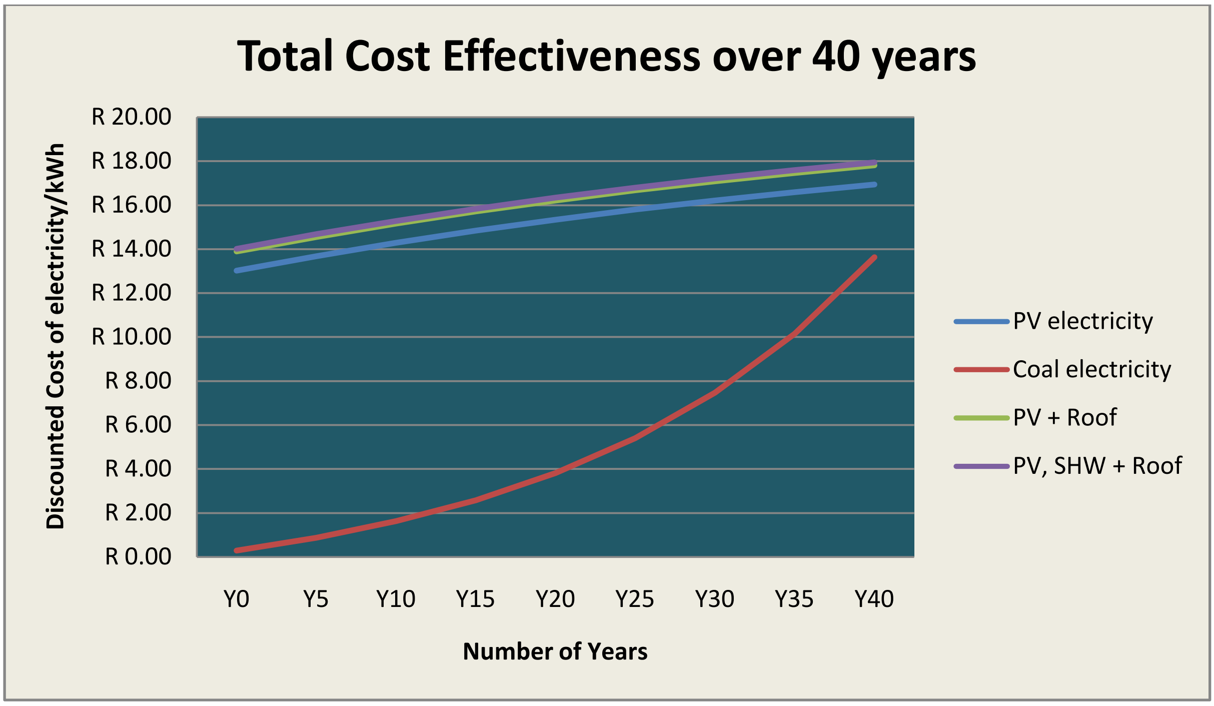

Figure 5.6 shows the lower bound of the coal price at R90/tonne and what impact it has on the LCC of coal-based electricity over 40 years. The contribution of coal to overall costs of electricity is 9% or R0.03/kWh out of a total cost of R0.34/kWh. The coal option is cost effective for the entire life-cycle of the two project alternatives. Overall, the residential solar power system (PV and SWH including roof) has a LCC of R10.77/kWh compared to a LCC of R8.61/kWh of coal-based electricity over a period of 40 years. Here it is shown how the variability in the coal price affects the range of LCC of coal-based electricity when all other items are kept constant.

**Figure 5.6: The effect of R90/tonne of coal on a 40-year LCC of coal-based electricity compared with solar power system (PV and SWH) electricity in R/kWh**



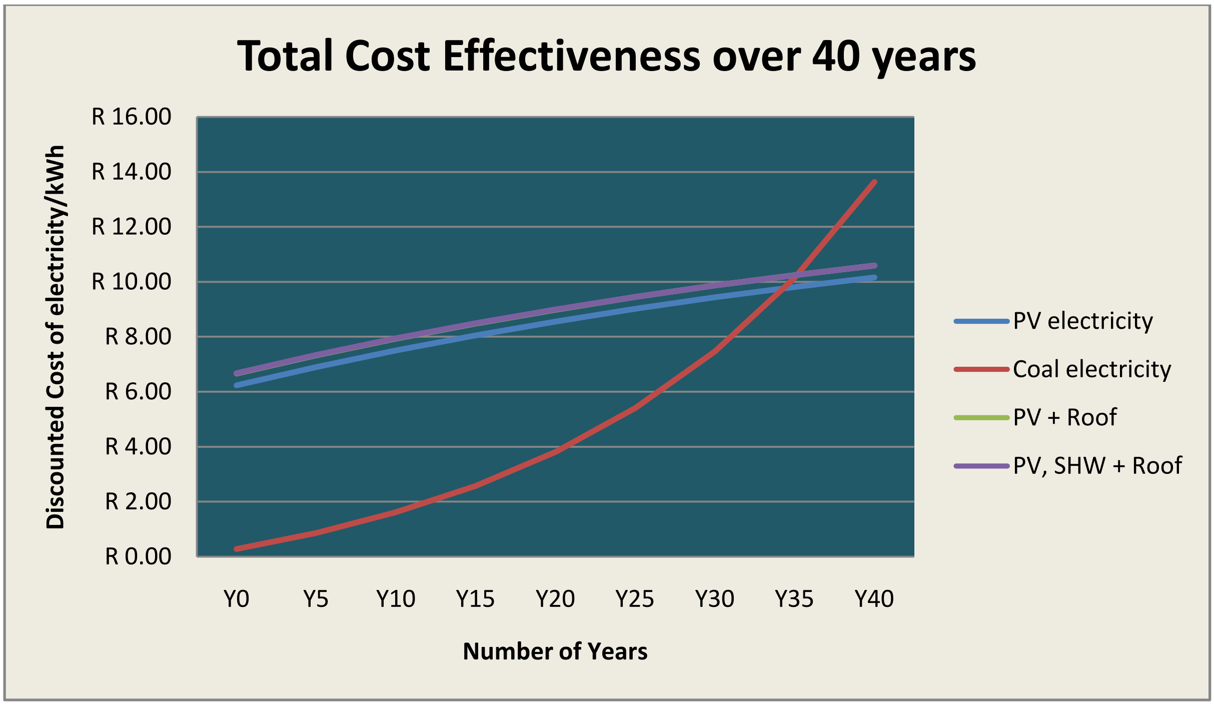

As mentioned earlier the decisions about project-related investments (e.g. power projects) typically involve a great deal of uncertainty about their costs, potential savings and performance. LCCAs are usually performed in the design process when only estimates of costs, savings and performance are available, rather than real money amounts or/and actual yield in terms of energy production. For this reason actual performance of the 5 kW PV system was considered a critical factor in the LCCA in this study. The uncertainty in input values means that actual outcomes may differ from estimated outcomes, as is the case with estimated energy yield and actual energy yield from the 5 kW PV roof tile system. The estimated annual energy yield of 10 038 kWh was used in the calculations of LCC (see Section 5.2(d)). The actual annual average energy yield of 4 906 kWh forms part of this uncertainty assessment. However, it should be remembered that 4 906 kWh per annum is calculated on the basis of the fact that a 1.7 kW PV roof tile system was commissioned in September 2008, while a 3.3 kW PV roof tile system was only commissioned in May 2009. So, the calculation of electricity produced by the 5 kW PV roof tile system is based on the actual monthly average of 152 kWh generated by the 1.7 kW PV roof tile system from 12-month data, and an actual monthly average of 257 kWh generated by the 3.3 kW PV roof tile system calculated from three-month data, which may not fully reflect the true situation.

**Figure 5.7: The effect of uncertainty in energy yield from the 5 kW PV roof tile system resulting in actual outcome of 4 906 kWh differing from estimated outcome of 10 038 kWh on a 40-year LCC in kWh**




All other items were kept constant while changing energy yield from 10 038 kWh (calculated) to 4 906 kWh (actual energy yield) to see the effect on the LCC of the project alternatives. The residential solar power system (PV and SWH including the roof) has a LCC of R17.93/kWh compared to the LCC of R13.63/kWh of coal-based electricity. The PV roof tile system (without SWH and roof) has a LCC of R16.93/kWh. Coal-based electricity is again the most cost effective of the two alternatives over the life-cycle. Figure 5.8 shows the effect that the revenue from carbon credits has on the 40-year LCC of a residential solar power system (PV and SWH including roof) compared to that of coal-based electricity.

**Figure 5.8: The effect of carbon credits on a 40-year LCC of solar power system (PV and SWH including roof costs) electricity compared with coal-based electricity in R/kWh**




The effect of carbon credits (CERs) at a price of €10/tonne $CO_2$e on the LCC of a residential solar power system (PV and SWH including roof) is minimal. The PV roof tile option has a LCC of R10.15/kWh compared to the LCC of R13.63/kWh of coal-based electricity. A residential solar power system (PV and SWH including roof) has a LCC of R10.59/kWh. The residential solar power system breaks even in year 35 – this is almost similar to the case without carbon credits (where the LCC is R10.77/kWh). In this case, the high CDM registration costs would be more expensive than the value of the carbon credits. But the cumulative effect of a million or more houses with solar power (PV and SWH) systems will result in more than 16 million tonnes of estimated annual carbon savings based on Eskom's emission factor of 1.2 kg $CO_2$/kWh for coal-based electricity. This is 37% of South Africa's annual carbon emissions.

## 5.3 Variations of the solar power system

The Lynedoch pilot project has an expensive roof because of the weight of the PV roof tiles – the PV roof tiles are heavier than normal roof tiles – and as a result the roof had to be reinforced to withstand the extra weight. The reinforced roof costs more than double the price of a normal roof (see Chapter 4), with laminated beams contributing to this high cost. This means that a much lighter PV roof tile must be designed and manufactured locally that can easily go onto a normal roof structure and would not be as expensive. New players in the South African PV market have been innovative in the design and manufacture of PV systems. Lomold, in particular, have made advancements in their technology that they claim will bring the cost of a normal PV module down from $7.60/W to $4.50/W. Lomold is planning to manufacture a PV roof tile from recycled plastic that could potentially revolutionise the cost of producing solar PV electricity. At the moment a usual solar PV power costs $7.60/W fully installed. The Lynedoch PV roof tile (PV cell and the material it is mounted on) costs $9.30/W. The Lynedoch PV roof tile system costs more than double the cost of a normal PV module at $18.60/W fully installed (including roof and replacement costs). The subsidies around the world range between $2.00 and $4.00/W to bring the end-user price to between $3.00 and $5.00/W. In China the subsidy is $2.95/W while in some US states subsidies go up to $4.00/W.

To put this in context, it costs between $1.5 and $2.00/W to build a coal-fired power plant. However, it is currently costing Eskom over $3.00/W to build the Medupi coal-fired power plant. Until solar PV as it is presently constituted decreases to below $4.00/W from the current $7.60/W, solar PV energy will remain the ‘holy grail’ of renewable energy.

Pieter du Toit, chief executive at Lomold, has created a breakdown of the actual costs using some new global cost survey[21] documentation. He then tested the breakdown against the experience of Peter Sieckmann, who installed the 5 kW PV roof tile system at Lynedoch. The global survey corresponded with Peter Sieckmann’s actual hands-on practice in the market and the experience gained by the Lynedoch team led by Prof. Mark Swilling, academic director of the Sustainability Institute, in building these solar systems at Lynedoch. So, the reality check supports Du Toit’s conclusions of the PV costing.

The breakdown is as follows:

[21] Wiser et al., 2009. *Tracking the sun: The installed cost of photovoltaics in the US from 1998-2007*. Environmental Energy Technologies Division. Lawrence Berkeley National Laboratory.

- $3.80/W for the PV panel (including the photovoltaic cell and the material it is mounted on). The photovoltaic cell is made from silicone and has an average efficiency of 17% to 20%. This represents 52% of the total cost of the PV system.
- $0.40/W for the inverter – 5% of the total cost
- $0.70/W for the actual installation – 10% of the total cost
- $0.70/W for the brackets that hold the panel on the roof – 10% of the total cost
- $1.70/W for the margins – running at between 12 and 23% depending on geographical regions in the world.

This is how the $7.00 plus per watt is made up and the proportions seem constant around the world. For comparison purposes, the following is the cost breakdown of the Lynedoch PV roof tile system:

- $14.80/W ($9.30/W for the solar PV roof tile plus $5.50/W for the solar PV roof tile replacement cost). This includes the PV cell, a glass cover, and the slate it is mounted on and constitutes 79% of the total cost.
- $2.20/W for two inverters (including their replacement cost) – 12% of the total cost
- $1.10/W for additional materials (including web-box, roof, import and storage) – 6% of the total cost
- $0.50/W for labour (including project management, design, on-site visits, installation, system commissioning and travel) – 3% of the total cost

Altogether the Lynedoch PV roof tile system costs $18.60/W fully installed, 144% more than a normal PV system at $7.60/W and 313% more than the Lomold anticipated PV roof tile at $4.50/W.

However, Du Toit's argument is that it could take years to bring down the cost of the PV cell itself because this is a complex technological challenge. Nor is it possible to change the costs of the inverter (unless there is a breakthrough with regard to mini-inverters attached to the PV module) or the margins. What can change is the cost of the brackets ($0.70/W), the cost of installation and the cost of the material on which the PV cell is mounted, which is built into the $3.80/W cost for the panel. The market leaders at the moment are solar roof tiles with PV cells (Q Cells made in

Switzerland) stuck onto fibre cement tiles (made in many places). As mentioned earlier, these are very heavy items, which is why it costs so much to make the wooden support structure to hold up the roof.

Du Toit reckons that it will be possible to cut costs by manufacturing a tile that is made from plastic in accordance with a 3D design. This means that it will have a flat surface like the current tile, but unlike all the current tiles it will have a ribbed structure underneath that will support the entire tile by resting on only a few strong wooden trusses. At the same time, the plastic tile will be moulded together with the PV cell. The PV cell will be bought from a supplier in 10 cm x 10 cm modules. (Du Toit prefers a Taiwanese product made by a company that has perfected the art of making PV cells in different colours, which is crucial to the aesthetic factor.) These modules will be placed automatically in a mould, the mould will then close, and the molten plastic will be moved into the mould. Because Lomold is the only technology that can mould using long glass fibre for parts with a 3D design, this will be technically possible. What then comes out of the mould is a complete tile with a PV cell attached – no separate process is needed to glue the PV cell onto the tile.

Du Toit argues that this tile will be much cheaper to make because of the mass production single-stop process; it will reduce installation costs because it will be possible to clip tiles together using an ingenious design, thus speeding up installation. There will also be a massive reduction in the cost of the sub-structure to hold the roof because the ribbed structure of the tile will ‘hold itself’. The cost of brackets, which will not be needed, will also be avoided.

Du Toit further argues that Lomold can produce a solar PV roof tile that will cost $4.50/W, i.e. $3.10/W less than the current industry standard and $14.10/W less than the Lynedoch roof tile system. His argument is that if subsidies are making solar roof tiles work at $4.00/W then his tile will make it possible to massively expand the market without dependence on subsidies. However, if governments want to replace coal-based electricity (which they cannot do now), then a tile that comes in at $4.50/W with an efficiency of 17 to 20% can be subsidised by only $2.00, thus making new coal-fired power redundant. In addition, Du Toit reckons that the solar roof tile could be made from recycled polyethylene terephthalate (PET), the material that plastic bottles are made of. As there is no major market for recycled PET to give a real value to waste PET – which is the only thing that will ensure that plastic bottles are not thrown away – creating a mega-market for PET will effectively help clean up the planet. This might attract additional funding for a solar roof tile.

Looking at these claims made by Pieter du Toit, the total cost of the Lomold 5 kW PV roof tile system (including the PV cell, a glass cover and the slate it is mounted on) will be R140 410 (calculated by using $3.80/W that is converted to R28.08/W at the dollar/rand exchange rate of R7.39 of 15 September 2009) compared to R343 979.99 investment cost for Lynedoch's 5 kW PV roof tiles. This cost can even come down given the possibility of the solar roof tile being made from recycled PET, reducing the cost of the material on which the PV cell is mounted, which is built into the $3.80/W cost for the panel. In addition, the Lomold PV roof tile system eliminates the cost of brackets ($0.70/W), the cost of installation ($0.70/W), the cost of import and storage (PV cells will be made locally) and the cost of the reinforced roof. The Lomold PV roof tile system has only one inverter, which brings the cost down from R50 000 plus for two Lynedoch inverters to less than R20 824.60 for one inverter. The 'mini-inverter' that transforms DC to AC for each tile is still in the research phase; hence it is not used in this thesis. With all the changes, the breakdown of the costs of the Lomold PV roof tile is as follows:

**Table 5.10: Cost items and details of the Lomold residential solar power system (Lomold PV and SWH)**

| LOMOLD RESIDENTIAL SOLAR ROOFTOP SYSTEM (PV and SWH) | | |
|---|---|---|
| **PV system size:** 5 kW<br>**SWH system size:** 300 litre SWH<br>**Capacity factor** 23%<br>**Solar radiation (SA annual average):** 5.5 kWh/kW/day<br>**Annual solar PV production:** 10 038 kWh (calculated)<br>**Annual SWH energy savings:** 3 600 kWh (based on 40% monthly electricity savings) | | |
| **Initial costs:** | PV system costs | R140 410 |
| | PV system replacement costs (discounted at 9%) | R82 384.61 |
| | Project management | R6 000 |
| | Design | R2 100 |
| | On-site visits | R4 500 |
| | System commissioning | R600 |
| | Travel | R3 500 |
| | 5 kW inverter | R20 824.60 |
| | 5 kW inverter replacement costs | R12 218.69 |
| | Web-box | R12 428.96 |
| | Web-box replacement costs | R7 292.61 |
| | | |
| | **Total initial PV costs** | **R292 259.47** |
| | | |
| | SWH system costs | R13 286 |
| | SWH replacement costs (discounted) | R7 795.47 |
| | Generic domestic external plumbing kit | R2 500 |
| | Pressure control valve | R495 |
| | Geyser timer | R963 |
| | Installation/labour costs | R2 310 |
| | Fuel allowance costs | R125 |
| | **Total initial SWH costs** | **R 27 474.47** |
| | | |
| | **Combined initial PV and SWH costs** | **R319 733.94** |
| | | |
| **O&M costs:** | | R1 555 |
| **Residual values:** | SWH | R7 871.60 |
| | Lomold PV roof tile system | R56 164 |

The cost of the expensive inverter, replacement cost of the inverter, cost of the web-box and replacement cost of the web-box are included in the final cost of the Lomold PV roof tile system, which is \$7.90/W and not the estimated \$4.50/W. However, both \$7.90/W and \$4.50/W are used in the analysis for comparing cost effectiveness with coal-based electricity. The SWH costs are exactly the same as in the case of Lynedoch pilot project. Since the revenue from carbon credits has such little impact on the total LCC of the residential solar power system, they are not included in the analysis of Lomold residential solar power system (PV roof tile system and SWH). Tables 5.11, 5.12 and 5.13 show the life-cycle cost calculations of the Lynedoch solar power system, the Lomold solar power system (comprising a Lomold PV roof tile system and SWH) and a coal-fired power plant.

**Table 5.11: Comparing cost effectiveness of coal-based electricity with solar power system (PV and SWH) (Figures in red are total LCC in present value (PV) money of coal-based electricity in R/kWh)**

| Coal (R/kWh) | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Year** | **NPV Capex** | **NPV coal** | **NPV water** | **NPV sorbent** | **NPV O&M** | **NPV carbon** | **Total NPV** |
| **0** | R 0.28 | R 0.00 | R 0.00 | R 0.00 | R 0.00 | R 0.00 | **R 0.28** |
| **0-5** | R 0.28 | R 0.36 | R 0.05 | R 0.01 | R 0.06 | R 0.10 | **R 0.87** |
| **0-10** | R 0.28 | R 0.83 | R 0.12 | R 0.03 | R 0.13 | R 0.24 | **R 1.62** |
| **0-15** | R 0.28 | R 1.44 | R 0.21 | R 0.05 | R 0.19 | R 0.41 | **R 2.57** |
| **0-20** | R 0.28 | R 2.24 | R 0.32 | R 0.08 | R 0.25 | R 0.64 | **R 3.81** |
| **0-25** | R 0.28 | R 3.29 | R 0.47 | R 0.11 | R 0.31 | R 0.94 | **R 5.40** |
| **0-30** | R 0.28 | R 4.66 | R 0.67 | R 0.16 | R 0.38 | R 1.33 | **R 7.47** |
| **0-35** | R 0.28 | R 6.44 | R 0.92 | R 0.22 | R 0.44 | R 1.84 | **R 10.15** |
| **0-40** | R 0.28 | R 8.78 | R 1.25 | R 0.30 | R 0.50 | R 2.51 | **R 13.63** |

**Table 5.12: Comparing cost effectiveness of PV, PV (including roof costs), PV and SWH (including roof costs) (Figures in red are total LCC in 2009 present value (PV) money of solar power system in R/kWh)**

| PV (R/kWh) | | | | PV (including roof) (R/kWh) | | | | PV and SWH (including roof) (R/kWh) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | NPV Capex | NPV O&M | **Total NPV** | Year | NPV Capex | NPV O&M | **Total NPV** | Year | NPV Capex | NPV O&M | **Total NPV** |
| **0** | R 6.36 | R 0.00 | **R 6.36** | 0 | R 6.79 | R 0.00 | **R 6.79** | 0 | R 6.85 | R 0.00 | **R 6.85** |
| **0-5** | R 6.36 | R 0.66 | **R 7.02** | 0-5 | R 6.79 | R 0.66 | **R 7.45** | 0-5 | R 6.85 | R 0.66 | **R 7.51** |
| **0-10** | R 6.36 | R 1.27 | **R 7.63** | 0-10 | R 6.79 | R 1.27 | **R 8.06** | 0-10 | R 6.85 | R 1.27 | **R 8.12** |
| **0-15** | R 6.36 | R 1.82 | **R 8.18** | 0-15 | R 6.79 | R 1.82 | **R 8.61** | 0-15 | R 6.85 | R 1.82 | **R 8.67** |
| **0-20** | R 6.36 | R 2.32 | **R 8.68** | 0-20 | R 6.79 | R 2.32 | **R 9.11** | 0-20 | R 6.85 | R 2.32 | **R 9.17** |
| **0-25** | R 6.36 | R 2.78 | **R 9.14** | 0-25 | R 6.79 | R 2.78 | **R 9.57** | 0-25 | R 6.85 | R 2.78 | **R 9.63** |
| **0-30** | R 6.36 | R 3.20 | **R 9.56** | 0-30 | R 6.79 | R 3.20 | **R 9.99** | 0-30 | R 6.85 | R 3.20 | **R 10.05** |
| **0-35** | R 6.36 | R 3.58 | **R 9.94** | 0-35 | R 6.79 | R 3.58 | **R 10.37** | 0-35 | R 6.85 | R 3.58 | **R 10.43** |
| **0-40** | R 6.36 | R 3.92 | **R 10.28** | 0-40 | R 6.79 | R 3.92 | **R 10.71** | 0-40 | R 6.85 | R 3.92 | **R 10.77** |

**Table 5.13: Comparing cost effectiveness of Lomold PV (with and without CERs) at \$7.90/W fully installed with Lomold PV at \$4.50/W fully installed (Figures in red are total LCC in 2009 present value (PV) money of solar power system in R/kWh)**

| Lomold PV (without CERs) (R/kWh) | | | | Lomold PV (with CERs) (R/kWh) | | | | Lomold PV at \$4.50/W (R/kWh) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | NPV Capex | NPV O&M | **Total NPV** | Year | NPV Capex | NPV O&M | **Total NPV** | Year | NPV Capex | NPV O&M | **Total NPV** |
| **0** | R 2.71 | R 0.00 | **R 2.71** | 0 | R 2.58 | R 0.00 | **R 2.58** | 0 | R 1.54 | R 0.00 | **R 1.54** |
| **0-5** | R 2.71 | R 0.66 | **R 3.37** | 0-5 | R 2.58 | R 0.66 | **R 3.24** | 0-5 | R 1.54 | R 0.66 | **R 2.20** |
| **0-10** | R 2.71 | R 1.27 | **R 3.98** | 0-10 | R 2.58 | R 1.27 | **R 3.85** | 0-10 | R 1.54 | R 1.27 | **R 2.81** |
| **0-15** | R 2.71 | R 1.82 | **R 4.53** | 0-15 | R 2.58 | R 1.82 | **R 4.40** | 0-15 | R 1.54 | R 1.82 | **R 3.36** |
| **0-20** | R 2.71 | R 2.32 | **R 5.03** | 0-20 | R 2.58 | R 2.32 | **R 4.90** | 0-20 | R 1.54 | R 2.32 | **R 3.86** |
| **0-25** | R 2.71 | R 2.78 | **R 5.49** | 0-25 | R 2.58 | R 2.78 | **R 5.36** | 0-25 | R 1.54 | R 2.78 | **R 4.32** |
| **0-30** | R 2.71 | R 3.20 | **R 5.91** | 0-30 | R 2.58 | R 3.20 | **R 5.78** | 0-30 | R 1.54 | R 3.20 | **R 4.74** |
| **0-35** | R 2.71 | R 3.58 | **R 6.29** | 0-35 | R 2.58 | R 3.58 | **R 6.16** | 0-35 | R 1.54 | R 3.58 | **R 5.12** |
| **0-40** | R 2.71 | R 3.92 | **R 6.63** | 0-40 | R 2.58 | R 3.92 | **R 6.50** | 0-40 | R 1.54 | R 3.92 | **R 5.46** |

**Table 5.14: Comparing cost effectiveness of Lomold solar power system (Lomold PV and SWH) with other alternatives (Figures in red are total LCC in 2009 present value (PV) money of Lomold solar power system in R/kWh)**

| Lomold PV at $7.9/W and SWH | | | |
|---|---|---|---|
| **Year** | NPV Capex | NPV O&M | **Total NPV** |
| **0** | R 2.73 | R 0.00 | **R 2.73** |
| **0-5** | R 2.73 | R 0.66 | **R 3.39** |
| **0-10** | R 2.73 | R 1.27 | **R 4.00** |
| **0-15** | R 2.73 | R 1.82 | **R 4.55** |
| **0-20** | R 2.73 | R 2.32 | **R 5.05** |
| **0-25** | R 2.73 | R 2.78 | **R 5.51** |
| **0-30** | R 2.73 | R 3.20 | **R 5.93** |
| **0-35** | R 2.73 | R 3.58 | **R 6.31** |
| **0-40** | R 2.73 | R 3.92 | **R 6.65** |

Tables 5.11, 5.12 and 5.13 clearly show that the Lomold PV system is the most cost effective with a LCC of R5.46/kWh, compared to the Lynedoch PV system (without SWH and the roof) at R10.28/kWh, the Lynedoch residential solar power system (PV and SWH including roof) at LCC of R10.77/kWh, and a coal-fired power plant with a LCC of R13.63/kWh over a 40-year period. The Lomold residential solar power system (comprising Lomold PV and SWH) has a LCC of R6.65/kWh, the Lomold PV roof tile system without CERs has a LCC of R6.63/kWh, and the Lomold PV roof tile system with CERs has a LCC of R6.50/kWh over a period of 40 years. The comparison of cost effectiveness is best shown by the following break-even chart (see Figure 5.9). The Lomold residential solar power system (PV and SWH) breaks even just before year 25. The LCC of coal-based electricity at R13.63/kWh is 105% higher than that of the Lomold residential solar power system at R6.65/kWh. The Lynedoch residential power system at R10.77/kWh is 62% higher than the Lomold residential power system.

**Figure 5.9: Total cost effectiveness comparison of coal-based electricity, Lynedoch solar power system (PV and SWH including roof costs), Lomold PV, and Lomold PV and SWH over 40-year period in R/kWh**

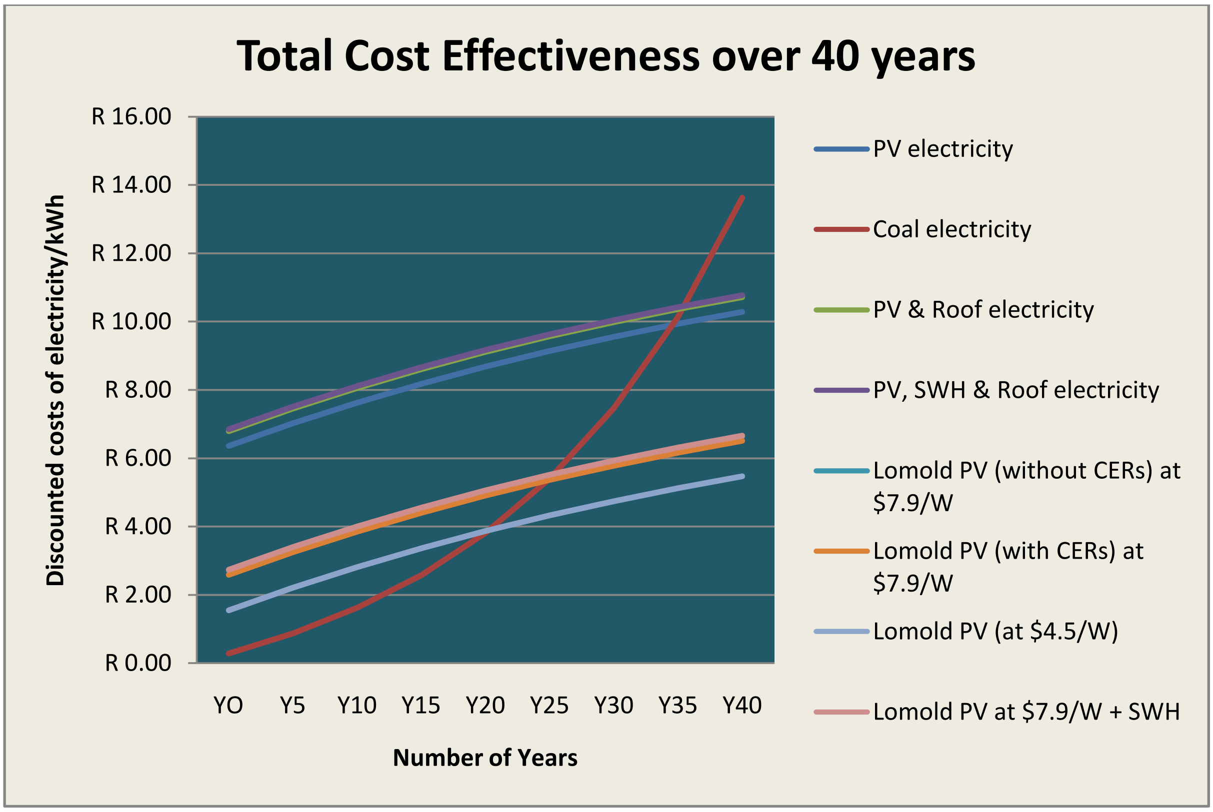
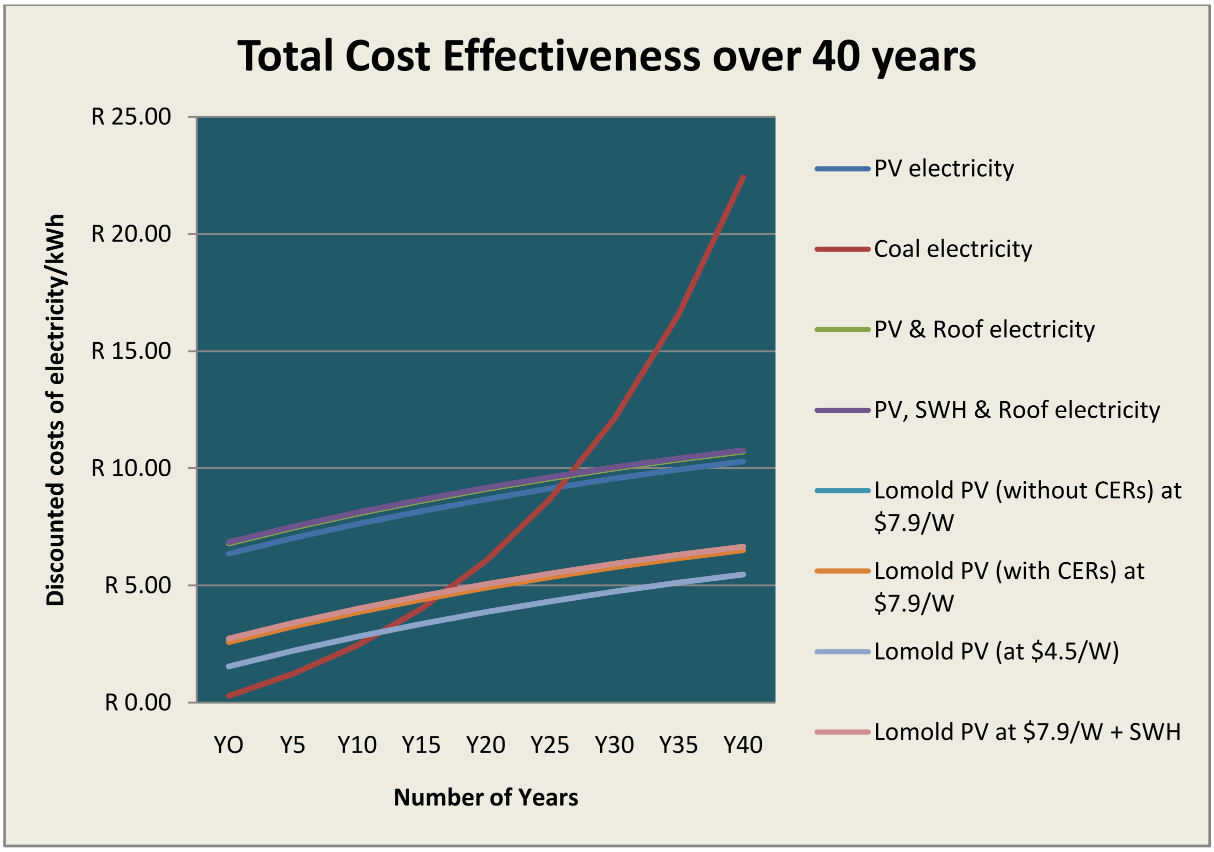



Figure 5.10 shows how the upper bound of the coal price (R369.50/tonne) used in this thesis effects the LCC of coal-based over 40 years when compared to the total LCC of Lomold PV electricity as well as Lomold PV and SWH. The Lomold PV roof tile system at $4.50/W breaks even with coal-base electricity just after year 10, when LCC is R2.81/kWh. Lomold residential solar power system (comprising Lomold PV roof tile and SWH) breaks even with coal-based electricity just after year 15, when LCC is R4.55/kWh, compared to breaking even after year 25, when the price of coal is R175/tonne. Overall, the Lomold residential solar power system (PV and SWH) has a LCC of R6.65/kWh compared to a LCC of R22.41/kWh of coal-based electricity over a period of 40 years. Thus the LCC of coal-based electricity is 237% higher than that of the Lomold residential solar power system (Lomold PV and SWH).

**Figure 5.10: The effect of R369.50/tonne of coal on a 40-year LCC of coal-based electricity compared with Lynedoch solar power system (PV and SWH including roof) and Lomold power system (PV and SWH) electricity in R/kWh**




## 5.4 Closing remarks

Various authors (Barringer, 2003; Fuller, 2008; Hunkeler et al., 2009) argue that LCCA can be applied to any capital investment decision in which relatively higher initial costs are traded for reduced future cost obligations. LCCA provides a significantly better assessment of the long-term cost effectiveness of a project than an alternative economic method that focuses only on first costs or on operation-related costs in the short term. In order words, the balance between all cost items of the project alternative is achieved through LCCA.

LCCA considers the inflation adjusted costs incurred annually plus the lumped costs incurred upfront and/or at the end of the project as shown. The costs are for each cost item for different alternatives and are represented in terms of cost per kWh (i.e. how much each cost item contributes to the final cost of electricity). Each cost has been discounted using 9% discount rate as prescribed by the National Treasury

(2006) over the useful life of each alternative power provision system and these are presented as present values (PVs). In the case of a coal-fired power plant, all fuel cost items have been escalated at 15% annually and O&M cost items were escalated at 9% per annum. For the residential solar power system options (PV, PV including roof, PV and SWH including roof, Lomold PV, and Lomold PV and SWH), the annual escalation rate used for operation and maintenance was general inflation using the CPI at 7%.

# Chapter 6 : Analysis of results

## 6.1 The key findings of the life-cycle cost analysis

The objective of this research study was to compare the life-cycle cost of a residential solar power system (comprising a PV roof tile system and a SWH) with a 4 800 MW coal-fired generation capacity by, as far as possible, using costing of recent, ongoing and planned power projects in South Africa. The aim was to determine if the common belief that sustainable and renewable energy alternatives are too expensive compared to the current supply approach of mega-power is valid. Initial capital costs are often used as the primary (and sometimes only) criterion for making decisions about power projects such as a coal-fired power plant. Due to life-cycle stages, often the real costs of the coal projects or any other power project are not reflected by the upfront investment capital (Hunkeler et al., 2008; Barringer, 2003; Fuller, 2008; Burger & Swilling, 2009). LCCA was therefore used in this thesis to choose an investment alternative to a coal-fired power plant in terms of the lowest long-term cost during the useful life of the project. LCCA indicated that operational savings are sufficient to justify the upfront investment costs of residential solar power systems (comprising a 5 kW PV roof tile system and 300 litre SWH), which are often greater than the upfront investment costs of coal projects in terms of the project's functional unit (e.g. cost/kWh).

Tables 5.8 and 5.9 and Figures 5.3 and 5.4 (see Section 5.2(d)) reveal that the common belief that sustainable and renewable energy alternatives are too expensive is a false perception created by looking no further than initial capital costs. The Lynedoch residential solar power system (PV and SWH including roof) used in this analysis requires R6.85 of upfront capital to be invested in order to produce a kilowatt-hour (kWh) compared to only R0.28 of upfront capital required by a 4 800 MW coal-fired power plant to produce a kilowatt-hour. However, a residential solar power system becomes a superior energy provision solution that promotes ecological, social and economic sustainability through less resource consumption, improved access to energy services and lowest life-cycle operating costs. The Lynedoch solar power alternative (PV and SWH including roof) has, measured in NPV at a 9% discount rate, a lower life-cycle cost of R10.77/kWh compared to a coal-fired power plant's life-cycle cost of R13.63/kWh over the 40-year technical design working life, with the potential to have an even higher LCC of R22.41/kWh when the coal price comes under upward pressure due to uncertainty in global markets. The Lomold solar power alternative (Lomold PV and SWH) requires R2.73 of upfront capital to be invested in order to produce a kilowatt-hour and has, measured in NPV at 9% discount rate, a life-cycle cost of R6.65/kWh. The Lomold PV roof tile system (fully installed at $4.50/W and without SWH) requires R1.54 of upfront capital to be invested in order to produce a kilowatt-hour and has, measured in NPV at a 9% discount rate, the lowest life-cycle cost at R5.46/kWh. Table 6.1 shows the comparison of the net present value (NPV) life-cycle cost of a residential solar power system and a coal-fired power plant.

**Table 6.1: Comparison of NPV LCC of solar power system and coal-based electricity in R/kWh**

| Comparison of NPV life-cycle cost of solar power system (PV and SWH) and coal-based electricity | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Year** | **PV** | **PV (including roof costs)** | **PV (including roof costs) and SWH** | **Lomold PV (without CERs) at $7.9/W** | **Lomold PV (with CERs) at $7.9/W** | **Lomold PV (at $4.5/W** | **Lomold PV (at $7.9/W) and SWH** | **Coal** |
| **NPV LCC (R/kWh)** | 0 | R6.36 | R6.79 | R6.85 | R2.71 | R2.58 | R1.54 | R2.73 | R0.28 |
| | 0-5 | R7.02 | R7.45 | R7.51 | R3.37 | R3.24 | R2.20 | R3.39 | R0.87 |
| | 0-10 | R7.63 | R8.06 | R8.12 | R3.98 | R3.85 | R2.81 | R4.00 | R1.62 |
| | 0-15 | R8.18 | R8.61 | R8.67 | R4.53 | R4.40 | R3.36 | R4.55 | R2.57 |
| | 0-20 | R8.68 | R9.11 | R9.17 | R5.03 | R4.90 | R3.86 | R5.05 | R3.81 |
| | 0-25 | R9.14 | R9.57 | R9.63 | R5.49 | R5.36 | R4.32 | R5.51 | R5.40 |
| | 0-30 | R9.56 | R9.99 | R10.05 | R5.91 | R5.78 | R4.74 | R5.93 | R7.47 |
| | 0-35 | R9.94 | R10.37 | R10.43 | R6.29 | R6.16 | R5.12 | R6.31 | R10.15 |
| | 0-40 | R10.28 | R10.71 | R10.77 | R6.63 | R6.50 | R5.46 | R6.65 | R13.63 |

The LCC of coal-based electricity at R13.63/kWh is 105% more than that of the Lomold residential solar power system, fully installed, i.e. including installation and replacement costs, at R6.65/kWh, and 27% more than the Lynedoch residential power system, fully installed, i.e. including installation, replacement, import and storage and roof costs, at R10.77/kWh (last row of Table 6.1). The LCC of the Lynedoch residential power system, fully installed, is 62% more than that of the Lomold residential power system, fully installed. This is due to a lower initial investment capital needed for Lomold solar power system as it will be much cheaper to make because of an ingenious design and a mass production single-stop process.

Apart from life-cycle cost effectiveness, the rapidly increasing scarcity of water and other raw materials, such as coal and sorbent (limestone), for coal-based electricity is making sustainable and renewable energy initiatives inevitable. In addition, the constraint in electricity supply in South Africa will continue to exist until such time as the first base load plant is commissioned. The commissioning may only take place in five to six years due to the looming crisis of the building programme funding shortfall currently experienced by Eskom. The consequence of delays or shortfalls in the building programme will be a reserve margin of less than 10% up to 2014/2015, which means that load curtailment and emergency shedding will be a feature of South African electricity supply for the next five years or longer. Future South African electricity initiatives are coal based, which means that South Africa’s carbon footprint is not only getting larger, but is also getting deeper. In its effort to become a key global player in decision-making processes, South Africa must at least start to show some commitment to a sustainable energy future. The residential solar power system (PV and SWH) is the alternative demand-side solution that can eliminate the need to build a new coal-fired power plant.

Besides the fact that the alternative solar power system is cost effective in its lifetime, it has benefits that are not quantified in this thesis because they are either not quantifiable or fall outside the scope of this thesis. These benefits include improved access to energy services, improved quality of life, skills development and capacity building, and creation of assets for the poor. According to Burger and Swilling (2009), the establishment of quality neighbourhoods are indispensable for realising the intended economic value of residential property. The integration of PV systems and SWHs into residential properties improves the economic value of those properties. The investment value of PV and SWH may further be magnified by the ecological design of residential properties, enhancing their economic value even further.

In addition to non-quantifiable benefits, there are a range of cost advantages that a residential solar power system has over a large coal-fired power station. These cost advantages are not included quantitavely in the costing model but it is important to highlight them in order to help emphasise the fact that coal-based electricity, is, after all, not as cheap as it is often made out to be. These include (but not limited to) to the following:

- Cost of constructing new transmission network to accommodate an increased electricity supply capacity...this is usually equal to (but often more than) the cost of the coal plant itself.
- Cost of power losses along the transmission network wich are about 8%-10% (Eskom, 2009). This means that the effective capacity of the coal-fired power plant is 10% less than the rated capacity. This means that 4 800 MW used in this thesis effectively drops to 4 320MW.
- Recurrent costs of transmission network maintenance.
- Higher cost of borrowing finance for a coal-fired power plant due to relatively long lead times when compared to just a few months for a residential solar power system.
- Higher financial risks for a coal-fired power plant due to uncertainties related to extended periods with unpredictable international capital and money markets and interest rates.
- Residential solar power systems help mobilise communities to claim a stake in the power supply business and provide them an opportunity to intellectually contribute to the solutions of the country’s electricity problems while earning an income. This is what empowerment and/or development of people is all about.

## 6.2 Application of PV and SWH in a million South African households

Solar PV and SWH application is rapidly becoming cost effective, especially for community-level systems. An average South African household of four people uses a monthly average of 750 kWh. This is about 9 000 kWh annually. A 4 800 MW coal-fired power plant with a capacity factor of 90% and an annual electricity production of 37.8 TWh can power 4 204 800 homes in a year. A 5 kW PV roof tile system with a capacity factor of 23% and an estimated annual energy yield of 10 038 kWh is more than enough to provide for all the annual household electricity needs. In terms of electricity production, i.e. taking the capacity factor into account, this means that 3.8 million 5 kW PV roof tile systems would be needed to replace a 4 800 MW coal-fired power plant. The large number of PV systems required to replace a coal-fired power plant was expected since the playing field is not levelled in terms of capacity factor. However, if a 5 kW PV roof tile system had a capacity factor of 90% (similar to that of a 4 800 MW coal-fired power plant) only 960 000 of them would be needed to replace a 4 800 MW coal-fired power plant.

One of the objectives of this thesis was to investigate what the total output would be if a million micro-solar systems (PV and SWH) were installed on residential units, and what the equivalent in coal-fired power generation capacity would be? It was found that the annual output from a million 5 kW PV roof tile systems is only a quarter (10.038 TWh) of the annual output from a 4 800 MW coal-fired power plant, which is 37.8 TWh. Again the capacity factor played a significant role in the production of electricity from both project alternatives. Looking at it in a different way, a million 5 kW PV roof tile systems would replace 1 273 MW of coal-fired generation capacity taking into account a capacity factor of 90% for a coal-fired power plant.

Eskom has previously calculated that its (thus far) unsuccessful programme to roll out 925 000 solar water heaters (SWHs) in higher-income households would reduce peak power demand by 578 MW. That was calculated using a diversity factor of 20.8%. If 3.8 million households are equipped with SWHs, extending them to low-income households, then, assuming a roughly comparable savings rate, Eskom would save power equivalent to 2 371 MW. This is almost half the capacity of a 4 800 MW coal-fired power plant. This means that 3.8 million residential solar power systems (comprising PV and SWH) can replace 7 171 MW (4 800 MW + 2 371 MW) of coal-fired generation capacity. If a million households are equipped with SWHs, Eskom would save 624 MW.

This means that a million residential solar power systems (comprising a 5 kW PV roof tile system and a 300 litre SWH) such as the one installed at Lynedoch Eco-village will replace 1 897 MW (1 273 MW + 624 MW) of coal-fired generation capacity. That is 44% of 4 800 MW coal generation capacity taking into account a capacity factor of 90%, i.e. 1 897 MW is 44% of 4 320 MW (90% of 4 800 MW). This means that another 1.3 million residential solar power systems (PV and SWH) would be needed to provide the remaining 56% of 4 320 MW coal-fired generation capacity. A total of 2.3 million residential solar power systems (comprising a 5 kW PV roof tile system and 300 litre SWH) would be needed to replace the entire 4 800 MW of coal-fired generation capacity.

Another objective was to investigate the comparative upfront costs of the two project alternatives. The total installation cost for the Lynedoch pilot project (a 5 kW PV roof tile system and a 300 litre SWH, including roof and replacement costs) was R760 462.21. Total installation of a million residential solar power systems would therefore cost R760 billion of upfront capital compared to R112 billion capital investment for a 4 800 MW coal-fired generation capacity. A million Lynedoch residential solar power systems would cost almost seven times more than the 4 800 MW coal-fired generation option. For the 2.3 million residential solar power systems needed to replace an entire 4 800 MW coal-fired generation capacity the investment cost will be over R1.7 trillion (fifteen times more than the cost of the 4 800 MW coal-fired generation option). The total installation cost for a Lomold residential solar power system (5 kW Lomold PV roof tile system and 300 litre SWH, including replacement costs) is R319 733.47. Total installation of a million Lomold residential solar power systems would therefore cost over R319 billion of upfront capital; this is almost three times more than a 4 800 MW coal-fired generation option. The total upfront cost for 2.3 million Lomold residential solar power systems would be R735 billion (six and half times more than the cost of a 4 800 MW coal-fired generation option). The total cost of a 5 kW Lomold PV roof tile system at $4.50/W, fully installed (without SWH), is R166 275. A million of these PV roof tile systems would cost R166 billion of upfront capital. The total installation cost of 2.3 million 5 kW Lomold PV roof tile systems would be R382 billion.

The Lynedoch solar power system has a very high cost, especially a PV roof tile system at R68.80/W without installation and other costs; R146.60/W including installation, import and storage costs, replacement costs of the PV roof tile system itself, two expensive inverters and a web-box. The Lynedoch pilot project has an expensive roof because of the weight of the PV roof tiles – the PV roof tiles are heavier than normal roof tiles and as a result the roof had to be reinforced to withstand the extra weight. Further contributing to the high cost is the investment cost of a 300 litre SWH plus the replacement cost. The low capacity factor (at 23%) and efficiency (at 11%) contributed to a high cost per kWh produced by the system.

The high cost of a million or more residential solar power systems may be offset by potentially low annual O&M costs. The annual O&M cost of a million residential solar power systems (PV and SWH) is R1.5 billion. Therefore, the annual O&M cost of 2.3 million systems would be R3.4 billion compared to R4.3 billion[22] for a 4 800 MW coal-fired power plant. It is a saving of almost R1 billion a year – and given the fact that fuel (coal, water, sorbent and others) is a scarce resource, its price is subjected to severe upward pressure, escalating at a rate of at least 15% per annum going forward to 2050. The operational savings makes a residential solar power system cost effective over a 40-year life-cycle in terms of the project's functional unit (R/kWh).

However, the cost of PV roof tile systems is still very high and has to be reduced drastically to stimulate the PV market in the country. The Lomold residential solar power system (a 5 kW Lomold PV roof tile system and a 300 litre SWH), fully installed, i.e. including installation and replacement costs, is two and half times cheaper than the Lynedoch residential solar power system, fully installed, i.e. including installation, replacement, import and storage and roof costs. With the Lomold PV roof tile potentially coming down to $4.50/W (R33.25/W using a R7.39/$ exchange rate), fully installed, the Lomold residential power system becomes even cheaper compared to the Lynedoch residential solar power system. However, since 2.3 million Lomold residential solar power systems (the cheaper solar option) are still six and half times more costly than the 4 800 MW coal-fired generation capacity they need to replace, support through policy and other interventions will be needed to roll

[22] This includes mainly fuel and O&M costs.

out this massive solar rooftop programme. The prices of SWHs in South Africa have remained constant for the last three years, and are projected to remain at current levels for the next three to four years, unless there is a sudden high demand that would essentially push prices down.[23]

### 6.3 Potential for job creation

Large-scale deployment of micro PVs (3 to 5 kW) and SWHs would not only rein in power price increases in the future, but also promote the urgent establishment of local manufacturing capacity and a well coordinated plan to take such solar systems to every corner of the country.

Government's integrated manufacturing strategy[24] (through the Department of Trade and Industry [the dti]) and the advanced manufacturing technology strategy[25] (through the Department of Science and Technology [the DST]) both emphasise the importance of building globally competitive capabilities in knowledge-intensive industries, such as the aerospace and automotive industries. Solar PV and thermal energy technology is also a prime example of such an industry, if South Africa is to grow its economic and industrial development away from resource-based industries.

Labour-intensive renewable energy technologies, such as wind, solar PV and thermal, will further advance government's development priorities in terms of equity and growth: black economic empowerment (BEE), small business development, employment, poverty reduction and geographical spread. Solar PV and SWH systems complemented by a smart-grid revolution could lead to a boom in job creation. Table 6.2[26] shows the estimated number of jobs created from a $1 billion capital expenditure in energy and energy efficiency. A R1 billion investment in solar PV creates 1 481 jobs on average – nearly twice the 868 jobs created with similar investment in coal power projects. A R1 billion investment in solar thermal creates

[23] This is based on personal communication and interviews with SWH industry actors, especially Atlantic Solar.
[24] Department of Trade and Industry. The Integrated Manufacturing Strategy, September 2002.
[25] Department of Science and Technology. The Advanced Manufacturing Technology Strategy, March 2003.
[26] Accessed from: http://www.earthpolicy.org/index.php?/plan_b_updates/2008/update80 (23/09/2009)

2 274 jobs on average – more than two and half times the 868 jobs created with similar investment in coal power projects.

**Table 6.2: Estimated jobs created from a $1 billion capital expenditure in energy and efficiency**

| | **Manufacturing, construction & installation** | **Operation, maintenance & fuel processing** | **Total (estimated range)** | **Total (averaged)** |
|---|---|---|---|---|
| Retrofitting buildings | 6 750 | n/a | 6 750 | 6 750 |
| Wind | 965-5 631 | 48 | 1 013-5 680 | 3 347 |
| Solar thermal (CSP) | 458-3 558 | 53-481 | 510-4 038 | 2 274 |
| Solar photovoltaics | 1 344-1 449 | 34-134 | 1 378-1 583 | 1 481 |
| Nuclear | 674-1 067 | 113-179 | 787-1 245 | 1 016 |
| Geothermal | 417 | 467 | 883 | 883 |
| Coal | 498-864 | 137-237 | 635-1 101 | 868 |
| Note: In allocating the $1 billion expenditure the analysis considers only the initial capital cost. It does not consider the cost of fuel used over the life of a power plant. Therefore the estimated number of jobs created for coal and nuclear is likely to be overstated. Manufacturing, construction and installation jobs are temporary jobs that are maintained over the time required to build the power facility or retrofit a building. Operation, maintenance and fuel processing jobs are permanent jobs that are maintained over the lifetime of the power facility. | | | | |

Source: Earth Policy Institute (2008)

Based on the study of the Earth Policy Institute (2008), it can be calculated that if Lynedoch residential solar power systems (a 5 kW PV roof tile system and a 300 litre SWH, including replacement, installation, import and storage and roof costs) were to be installed on the rooftops of a million South African households at a cost of R760 billion, 152 308 jobs would be created in the entire supply chain, from designers to installers/maintainers. If the 2.3 million Lynedoch residential solar power systems needed to replace an entire 4 800 MW of coal-fired generation capacity at the cost R1.7 trillion would be installed, 340 690 jobs would be created in the entire supply chain. The total installation cost of a million Lomold residential solar power systems (a 5 kW Lomold PV roof tile system and a 300 litre SWH, including replacement costs) is R319 billion, which means that 63 929 jobs would be created in the supply chain. The total cost for 2.3 million Lomold residential solar power systems is R735 billion, which equates to 147 298 jobs being created.

The higher levels of sustainable and local job creation will help achieve social sustainability, especially in a country such as South Africa, faced with serious developmental challenges. Economic sustainability is ascribed to the lower life-cycle costs of residential solar power systems (PV and SWH) and their ability to provide cheaper peak demand energy than through the installation of new peaking power capacity. The environmental sustainability of residential solar systems lies in their potential to reduce environmental impact, especially in reducing greenhouse gas emissions (GHGs).

A million residential solar power systems (a 5 kW PV system and a 300 litre SWH) could potentially offset more than 16 million tonnes of carbon emissions per annum, based on Eskom's emission factor of 1.2 kg of $CO_2$ for coal-based electricity. The 2.3 million residential solar systems needed to replace a 4 800 MW coal-fired generation capacity could potentially save over 37 million tonnes of carbon emissions annually. This is approximately 8% of South Africa's annual emissions.

## 6.4 Closing remarks

It was found that a Lynedoch residential solar power system (PV and SWH, including roof cost), fully installed, was a cost effective alternative compared to coal-fired generation capacity as it achieved the lower LCC per kWh due to freely available fuel (sunshine) and very low O&M costs. However, a Lomold residential power system, fully installed, was the most cost effective alternative compared to both the Lynedoch solar power system and a coal-fired generation capacity, achieving the lowest LCC per kWh.

It was also found that the potential exists for application of micro PVs and SWHs on a million South African residential rooftops with a potential for maximising job creation. This will require political will and a massive initial capital investment, however.

## Chapter 7 : Conclusion and recommendations

The overall research question of the thesis was whether a residential solar power system (comprising a solar photovoltaic [PV] system and a solar water heater [SWH]), a demand-side option, has a lower life-cycle cost than a coal-fired power plant, a supply-side option, or vice versa. The thesis also investigated whether a million residential solar power systems could potentially replace a 4 800 MW coal-fired power plant in South Africa.

The first step in answering the research question was to start with a review of both global and South African energy contexts in order to set the context for the study. A literature review provided a working definition of the concept of sustainable development. The aim was to align the study with the global, national and local imperatives of incorporating considerations for the environment, societies and economies in decision-making processes, with renewable energy at the centre of reliable and sustainable energy solutions for the 21$^{st}$ century.

The common belief is that solar PV technology is unviable for electricity production because it is too expensive compared to coal-based electricity. Statements such as these are made because the initial capital costs (procurement costs) are often used as the primary (and sometimes only) criterion for project, equipment or system selection based on a simple payback period. Due to life-cycle stages, often the real costs of the project or equipment are not reflected by the upfront capital costs. In this thesis, a methodology was developed to investigate the life-cycle cost effectiveness of a residential solar power system (comprising a 5 kW PV roof tile system and a 300 litre SWH) and a 4 800 MW coal-fired plant in order to choose the most cost effective alternative in terms of the project's functional unit (kWh).

The research findings indicated that a residential solar power system (comprising solar PV and SWH), a demand side option, was a cost effective alternative compared to coal-fired generation capacity, a supply side option, as it achieved the lower LCC per kWh. The LCC of coal-based electricity at R13.63/kWh is 105% more than that of the Lomold residential solar power system, fully installed, i.e. including installation and replacement costs, at R6.65/kWh, and 27% more than the Lynedoch residential power system, fully installed, i.e. including installation, replacement, import and storage and roof costs, at R10.77/kWh. It was also found that the potential exists for application of micro PVs and SWHs on a million South African residential rooftops with a potential for maximising job creation and greenhouse gas emission reductions.

The Lynedoch case study analysis revealed significant findings: first the new crèche at Lynedoch was installed with solar roof tiles which are not the usual PV modules that are stuck on top of the roof. The reason for this was that the installer and the owner of the PV roof tile system had hoped that the cost of the PV array will be cross-subsidised by the cost of the roof. In other words the combined cost of a roof-integrated PV array (e.g. PV roof tiles) and the roof would be less than the cost of a normal roof plus a normal PV array. This was not the case as it was revealed that the PV roof tiles are heavier than normal roof tiles and as a result the roof had to be reinforced to withstand the extra weight. The cost of the reinforced roof was more than double the price of a normal roof, with laminated beams contributing to this high cost.

Due to the high roof cost it means that a much lighter PV roof tile should be designed and manufactured that can easily go onto a normal roof structure that is not as expensive. However, the argument is that it could take years to bring down the cost of the PV cell itself because this is a complex technological challenge. Nor is it possible to change the costs of the inverter (unless there is a breakthrough with regard to mini-inverters attached to the PV module) or the margins. What can change is the cost of the brackets, the cost of installation and the cost of the material on which the PV cell is mounted, which is built into the cost for the panel. These areas present a challenge as well as an opportunity for the PV industry to drive innovation.

Since coal is more affordable and available to consumers than any other fossil fuel new power plants are being built to perform at ‘supercritical’ and ‘ultra-supercritical’ conditions of temperature and pressure, increasing electricity generation efficiency from an average 30% to 50% or higher. These new coal technologies will encourage the continued use of coal for electricity generation and other purposes, making it difficult for renewable energies to become a significant component of the energy mix.

But the burning of fossil fuels have been proven for a long time to have local side-effects, such as heavy smoke, dust and other pollution, with associate respiratory problems. Additionally, at the end of the previous century attention was drawn to the fact that the emission of greenhouse gases (GHGs) by burning fossil fuels contributes to a change in the earth's atmospheric structure which ultimately will result in a change in climatic conditions (Haw & Hughes, 2007; IPCC, 2007).

While both the population and economic growth rates in South Africa will further increase the electricity demand going forward, South Africa needs to rid itself of its obsession with coal and find new ways of supplying in and managing increased electricity demand. South Africa provides some of the best opportunities to develop renewable energy (RE) capacity to meet the country's growing energy needs. It has extremely high solar insolation levels, adequate wind energy resource, its coastline provide good opportunity to harness wave and tidal energy resource, and with the well established farming industry biomass exploration offers great potential.

In this thesis it was found that a residential solar power system is the most cost effective alternative for electricity supply when compared to a coal-fired power plant in terms of cost per kilowatt-hour during the life-cycle. However, the initial investment cost for a residential solar (PV and SWH) power system needed to produce a kWh is still very high – for example, Lynedoch residential solar power system (PV and SWH including roof) used in this analysis requires R6.85 of upfront capital to be invested in order to produce a kilowatt-hour (kWh) compared to only R0.28 of upfront capital required by a 4 800. Put differently a usual PV module requires $7.60 of upfront investment to install a watt (W) of power capacity. The Lynedoch PV roof tile (PV cell and the material it is mounted on) costs $9.30/W. The Lynedoch PV roof tile system costs more than double the cost of a normal PV module at $18.60/W fully installed (including roof, replacement and other costs).

To put this in context, it costs between $1.5 and $2.00/W to build a coal-fired power plant. However, it is currently costing Eskom over $3.00/W to build the Medupi coal-fired power plant. Until solar PV as it is presently constituted decreases to below $4.00/W from the current $7.60/W, solar PV energy will remain the 'holy grail' of renewable energy. This gives rise to a need to introduce strategic policy support mechanisms that will bring down the upfront costs of installing the micro solar power capacity to around $4.00/W. The subsidies around the world range between $2.00 and $4.00/W to bring the end-user price to between $3.00 and $5.00/W. In China the subsidy is $2.95/W while in some US states subsidies go up to $4.00/W.

Strategic options outlined in the LTMS process (Hughes et al., 2007) (See Appendix A2 for a description of the LTMS process and outcomes) simply translate into a need for a consolidated approach by South Africa to achieving a low-carbon economy. This can be attained by means of the following:

- Shifting incentives from attracting energy-intensive investments to promoting lower-carbon industries
- Promoting higher value-added and ambitious energy efficiency targets while energy-intensive industries are in transition
- Defining new areas of advantage and innovation in a climate-friendly technology and becoming a market leader, e.g. solar technologies

According to Sebitosi and Pillay (2008), transition to a low-carbon economy is often achieved through the application of policy support mechanisms that promote the dissemination of RE technologies. These support mechanisms are generally categorised as investment cost reduction and/or public investment and market facilitation. These are complemented by additional instruments that include accounting for externalities such as the adverse effects of fossil fuel usage on human health (such as lung cancer from the resultant smoke, dust and local air pollution) through emission taxes and/or tax relief to RE investors (Sebitosi & Pillay, 2008). The success of these policies has varied over the years in different countries. Policy consistency and continuity has been identified as critical to success of policies as new investment suffered in countries with short term RE incentive regimes while their renewal remained bogged down in the approval bureaucracy process (Sebitosi & Pillay, 2008).

If the South African government is intent on creating a genuinely conducive environment for investment it should promptly draft a RE strategy (Sebitosi & Pillay, 2008). As set out in the policy document itself: “Underpinning the Renewable Energy Strategy is a Macro-economic analysis to guide cost efficient Government financial assistance based on a least-cost and employment maximising supply model in reaching the target" (DME, 2003). In particular, the strategy should promote those practices and models that have worked successfully in the economy and avoid the problematic ones. For example, the country's domestic aviation industry provides one model that is worth emulating (Sebitosi & Pillay, 2008). The industry was transformed from virtually one dominant state-owned operator to a successful mix of private and public operators (Sebitosi & Pillay, 2008). The model has seen phenomenal growth in the industry with a substantial drop in fares, even as fuel prices have been rising consistently. Sebitosi and Pillay (2008) argue that the major difference between the operation of the South African electricity and aviation sectors is that the latter enjoys a level playing field anchored by the Domestic Air Travel Deregulation Act. Thus a deregulated mixed public/private business model would offer the necessary checks and balances for sustainable RE industry in South Africa.

New renewable energy technologies that were previously excluded in the REFIT (NERSA, 2009), such as solar PV systems (large ground and/or roof-mounted) and concentrating PV, now form part of the REFIT. However, phase two of the REFIT included solar PV, but not solar-micro PV. Wave, tidal and geothermal technologies were excluded, as NERSA pointed out that these technologies were not yet commercially available. But what about a large residential development with solar PV on rooftops? This could qualify as a mini-solar PV plant, and it is commercially available.

Developing nations in particular do not have access to modern energy services and renewable energy is an obvious option to mitigate energy poverty. South Africa, with its obsession with mega-power (> 100 MW) supply capacity, focuses on building not only large coal-fired power plants but also large renewable energy facilities. While large RE facilities would certainly contribute to the RE industry in the country, small-scale applications of renewable energy can stimulate the RE industry because of their ability to spread over geographical areas with weak renewable energy sources.

On a domestic scale, solar system (PV and SWH) application, in combination with relatively simple and cost effective changes to the design of the existing or new housing developments (Birkeland, 2002), such as passive solar heating, cooling and lighting, can reduce the operating energy demands of housing development by up to 90%. This is simply because the mechanical systems and operational energy requirements of buildings – which are costly in terms of money, energy and resources to manufacture, distribute and operate – can be reduced drastically or eliminated altogether. Birkeland (2002) argues that households can save half of their annual electricity bill by simply retrofitting their existing housing with basic off-the-shelf design measures, such as insulation and smart windows.

There have been developments in the South African renewable energy sphere, such as REFIT, carbon tax, LTMS and others. These developments have certainly meant definite improvement, although we have yet to see whether these developments will indeed push renewable energy forward. Overall, progress is being made in South Africa and it shall be seen what happens after the Copenhagen Climate Change Conference in December 2009. The industry is already investigating RE options in light of the possibilities after the Copenhagen Conference. However, as Sebitosi and Pillay (2008) argue, a carefully considered plan is needed at national level to complement policy and articulate programmes for intervention.

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# Appendices

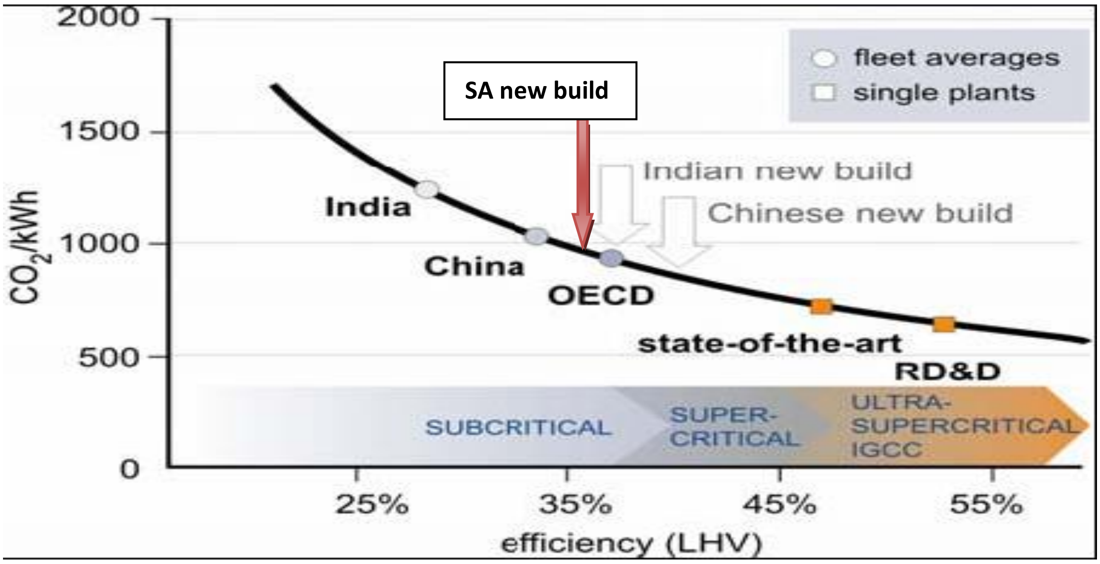
## Appendix A: Detailed discussion of some important issues relevant to this thesis

### Appendix A1: A discussion on some 'clean' coal technologies that have been, and continue to be, developed to address carbon emission concerns regarding coal utilisation

In order to contribute to a substantial reduction in greenhouse gas emissions, retrofit programmes continue to improve plant performance. However, greater deployment of these technologies should be encouraged to address sulphur, nitrogen oxides, carbon dioxide and many other emissions. Since coal is more affordable and available to consumers than any other fossil fuel new power plants are being built to perform at 'supercritical' and 'ultra-supercritical' conditions of temperature and pressure, increasing electricity generation efficiency from an average of 30 to 50% and higher (see Figure 6.1). Increasing efficiency decreases concentration levels of carbon emissions in the atmosphere. China brought on line the first 1 000 MW supercritical plant in November 2006, in line with the Chinese government's aim of phasing out small, inefficient plants (WEC, 2007: 4).

Technology demand promoted innovative thinking as part of the solution to contribute towards global imperatives in mitigating carbon emissions while adapting to climate change., Integrated gasification combined cycle, commonly known as IGCC, is another technology that can be used in coal utilisation in an effort to mitigate greenhouse gases. In this case coal is not burnt to raise steam (WEC, 2007: 4), as with conventional power plants, but instead reacted to form a synthesis gas of hydrogen and carbon monoxide which is then used to operate a gas turbine to generate electricity, with waste heat being used to raise steam for a secondary steam turbine. IGCC not only raises generation efficiencies but reduces $CO_2$ emissions and pollutant emissions with 33% less $NO_x$ gases, 75% less $SO_x$ gases and almost no particulate emissions compared to more advanced conventional technologies. IGCC uses 30 to 40% less water than conventional plants and can capture up to 90% of mercury emissions at one-tenth of the costs for conventional plants (WEC, 2007: 4). Figure 7.1 shows the power plant performance comparing $CO_2$ emission per kWh with the level of efficiency.

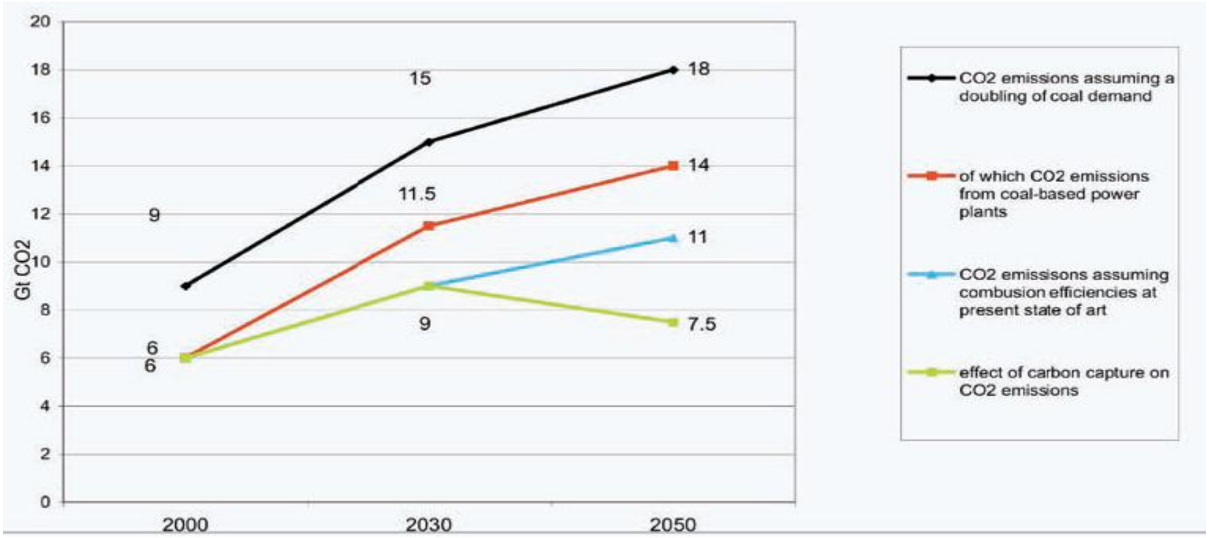
**Figure 7.1: Power plant performance**




Source: IEA (2006)

According to the WEC (2007: 5), emissions will have to be addressed in a carbon-constrained future but without impacting economic growth (economic growth is still seen as a prerequisite for human development) and energy security. One of the most vital tools in mitigating greenhouse gases is carbon capture storage (CCS), in which carbon dioxide is removed from emissions by power generation and industrial activity and injected underground, for example, into deep saline aquifers or used for enhanced oil recovery. According to the Intergovernmental Panel on Climate Change (IPCC, 2001), there is a global storage capacity of at least 2 000 billion tonnes of $CO_2$, which is expected to account for up to 55% of the cumulative mitigation effort going forward to 2100. The IPCC (2001) further states that the costs of mitigation may be reduced by 30% or more when CCS is included in a climate stabilisation strategy. Figure 7.2 indicates the global $CO_2$ emissions from coal-based power plants assuming higher efficiencies and carbon capture going forward to 2050 and beyond.

**Figure 7.2: Global $CO_2$ emissions from coal assuming efficiencies and carbon capture**



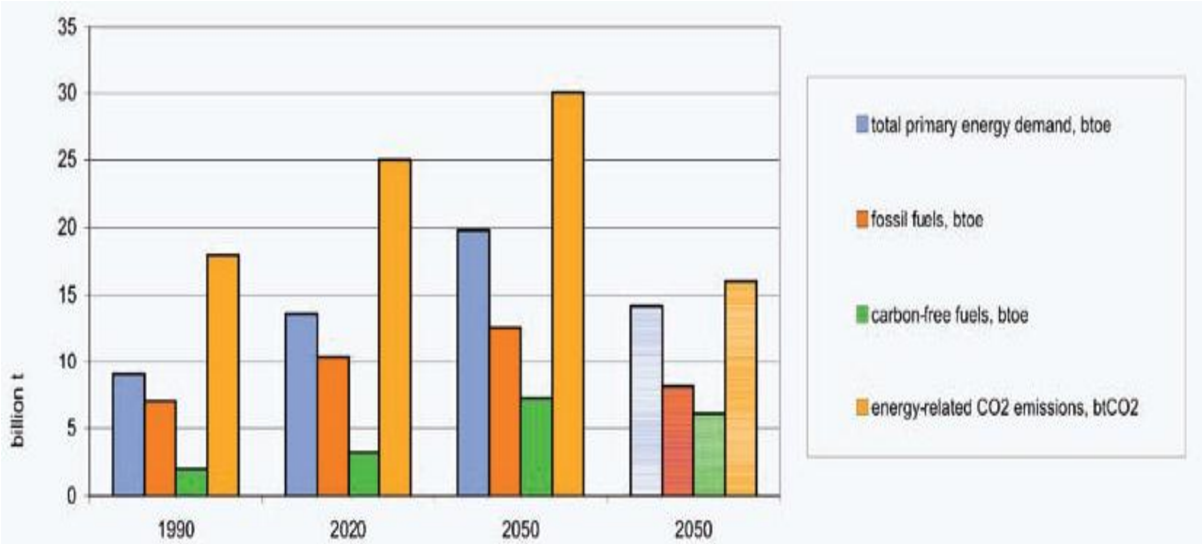

Source: WEC (2007)

The WEC (2007: 7) maintains that coal mine methane (CMM) is another greenhouse gas that can be recovered and utilised for heating and power generation. If this methane from coal mining activities is captured and used as mentioned above, it will substantially contribute to the reduction of greenhouse gases. Underground coal gasification (UCG*)* is another burgeoning area of interest, according to Christine Copley of the World Coal Institute (WCI), (as cited in WEC 2007: 7). UCG allows a reaction of coal to form a syngas as in the IGCC process. Carbon dioxide from UCG can be safely returned to the gasified coal seams, resulting in zero emissions. However, this is just a proposal on a theoretical level.

While laws to implement strict carbon abatement measures are urgently needed, IGCC, CCS, CMM, UCG and other measures that encourage the continued use of coal for power generation are still at a research and development stage and it will take decades for them to even reach demonstration stage. Action to mitigate GHG emissions is needed now – not in 2030.

Fossil fuels are the largest energy resources to be used in the history of mankind and they are the driving forces behind many developing and developed economies. Figure 7.3 indicates that, under current policies, fossil fuel demand will increase by 80% between 1990 and 2050 (first column, 2050). However, under alternative policies, increased efficiencies and substitution of fossil fuels by renewable energy resources could constrain fossil fuel demand and related carbon dioxide emissions. In such a scenario, fossil fuel demand could be reduced drastically and $CO_2$ emissions reduced by almost 50% by 2050 (last column, 2050).

**Figure 7.3: World primary energy demand and related $CO_2$ emissions**




Source: WEC (2007)

This figure shows clearly the situation that the world will be facing in 2050 under current policies with little room for alternative energy sources – carbon dioxide emissions will be 30 billion tonnes (first column, 2050) whereas under alternative policies this figure can be reduced by almost a half (last column, 2050). With efforts to reduce fossil fuels consumption we should also understand that fossil fuels still have a future in development strategies and that new, 'cleaner' fossil fuel technologies and applications mentioned earlier will be developed and utilised to mitigate greenhouse gases. But as indicated earlier that it would be years before these 'clean' coal technologies have any effect on development policies. Therefore, the options available to drastically reduce the use of fossil fuels in electricity generation are the large-scale introduction of renewable energy (RE) technologies and energy efficiency (EE) as a technological aid.

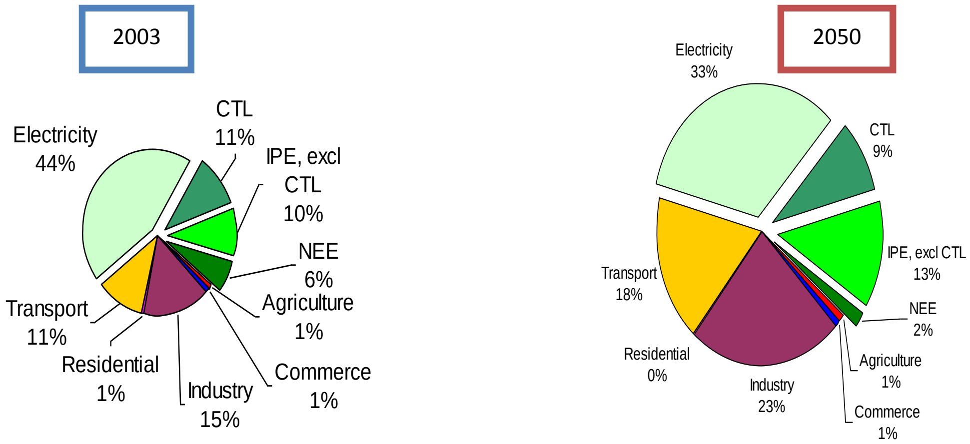
**Appendix A2: The LTMS process and outcomes**

The LTMS process was carried out by a scenario building team (SBT) comprising strategic thinkers from government and think tanks from academia, business and civil society. Starting from 2003 as base year and continuing to 2050, the SBT explored two possible scenarios, assessing them against the full range of possible international climate change contexts (DEAT, 2008). The two scenarios, namely growing without constraints (GWC) and required by science (RBS) are discussed below. Under the RBS scenario, which is the more robust of the two, the SBT further explored four strategic options for mitigating the emission of GHGs. In order to keep this thesis within the scope of its research, the LTMS has been limited to energy emissions inputs only.

A group of experts, namely Alison Hughes, Mary Haw, Harold Winkler, Andrew Marquard and Bruno Merven from the Energy Research Centre (ERC) at the University of Cape Town, prepared the *Long-term mitigation scenarios (LTMS) input report 1: Energy emissions* on behalf of the Department of Environmental Affairs and Tourism (DEAT) in October 2007. The LTMS identified energy emissions mitigation actions in the energy supply (electricity generation and liquid fuels), as well as energy use in major economic sectors – industry, transport, residential, commercial and agricultural sectors (Hughes et al., 2007). The main mitigation actions identified in the LTMS are energy efficiency (EE) in the industry, transport, residential, commercial and agricultural sectors; renewable electricity; nuclear power; and tax on $CO_2$ (Hughes et al., 2007).

South Africa, which accounts for more than 50% of total African emissions (DEAT, 2008), faces the challenge of creating a post-carbon economy based on new technologies, innovation and competitiveness. As is illustrated in Figure 7.4, Eskom’s coal-based electricity accounted for 44% of all South Africa’s emissions and Sasol’s coal-to-liquid (CTL) processes accounted for 11% of all South Africa’s emissions in 2003. The corresponding figures in 2050 will be 33% of all emissions for Eskom’s coal-based emissions and 9% for Sasol’s CTL emissions (DEAT, 2008).

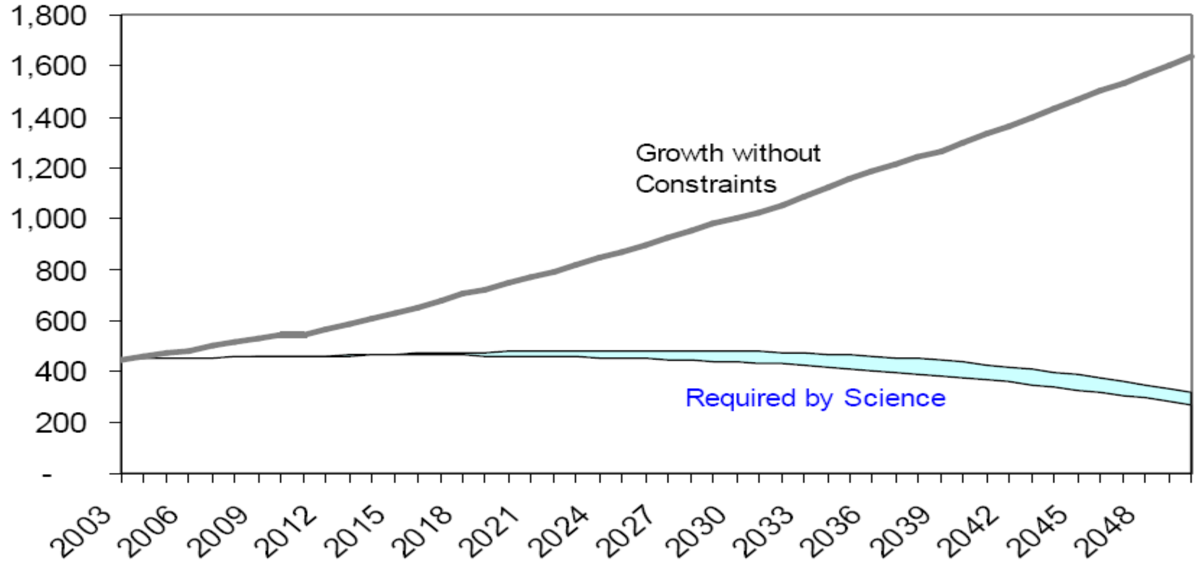
**Figure 7.4: SA emissions by sector in 2003 and 2050**




Source: DEAT (2008)

The LTMS provides for two scenarios (see Figure 7.5): Growth without constraints (GWC) is the 'no-mitigation' scenario, in which there is growth that involve no change from current trends, not even implementing existing policies, while the required by science (RBS) scenario assumes that South Africa implements mitigation to the extent required by science for global emission reductions, as indicated in the IPCC's Fourth Assessment Report (AR4) of 2007 (Hughes et al., 2007). Under the GWC scenario, energy demand grows mainly in the industry and transport sectors as South Africa successfully implements ASGISA to achieve growth objectives, resulting in total emissions growing almost four-fold. This is shown by the gap – the difference between where emissions might go and where they need to go (GWC less RBS emissions in 2050) (see Figure 7.5). The gap is about 1 300 Mt of $CO_2$e in 2050 – more than three times the annual emissions in 2003.

**Figure 7.5: Growth without constraints (GWC) scenario vs required by science (RBS) scenario for long-term mitigation scenarios (LTMS) for South Africa**




Source: Hughes et al. (2007)

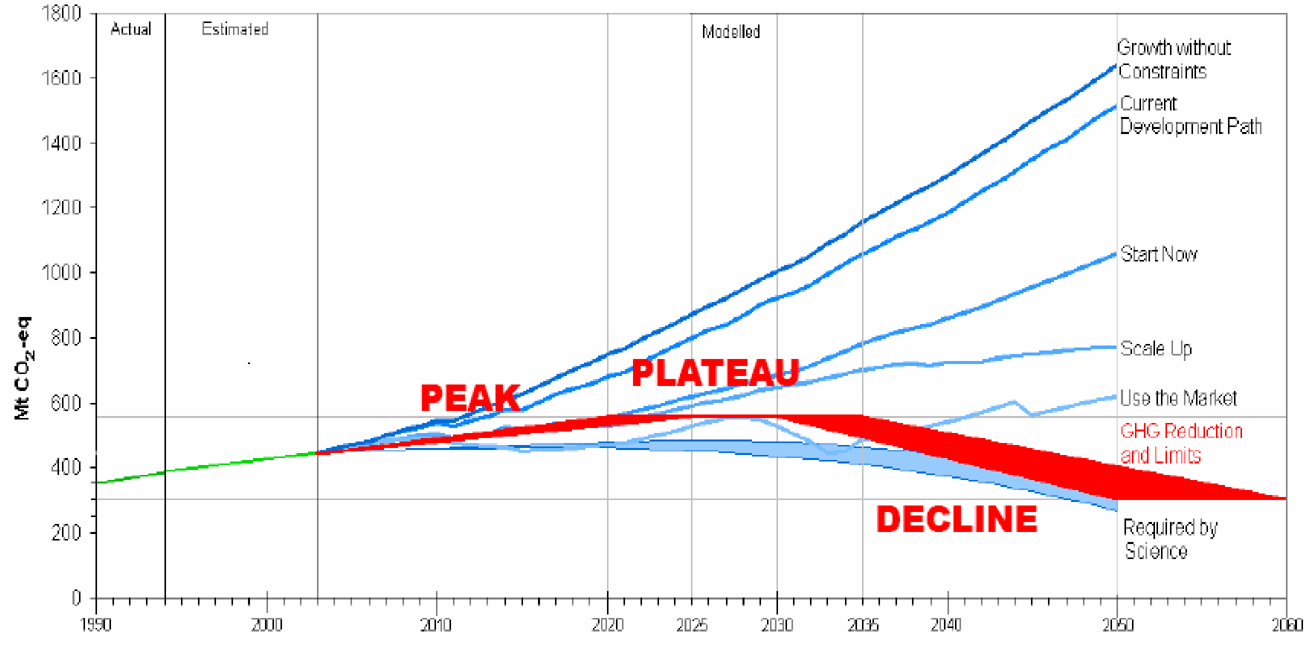
In the GWC scenario, total fuel consumption across all sectors increases more than five-fold, from 2 365 PJ in 2003 to 11 915 PJ in 2050 (Hughes et al., 2007). For example, coal will still dominate electricity production whilst renewable energy (RE) would contribute less than a percent of installed capacity, declining from 2.18% of installed capacity in 2003 to 0.74% in 2050, comprising only existing hydro and biomass (mainly bagasse) capacity, and a small amount of added landfill gas capacity (Hughes et al., 2007). On the other hand, in the RBS scenario of actions considered in the LTMS emissions must be reduced by 30 to 40% of the base year levels (2003) by 2050. In other words, emissions will peak by 2015 at 550 Mt of $CO_2$e before declining to the target of 30% emission reductions of 2003 level (about 315 Mt of $CO_2$e) by 2050 (Hughes et al., 2007).

Using the best estimates, the IPCC's AR4 maintains that the most stringent scenarios (i.e. stabilising emissions at 435-490 ppm of $CO_2$e by volume) could limit global mean temperature increases to 2 to 2.4 °C above pre-industrial levels, requiring emissions to peak within the next 15 years and to be around 50% of current levels by 2050 (IPCC, 2007: Chapter 3). This is done through energy efficiency (EE) in all sectors, a modal shift to public transport, electric vehicles, hybrid vehicles, biofuels, renewable electricity up to 27% of installed capacity, nuclear power up to

27%, 'cleaner' coal (IGCC), $CO_2$ tax and solar water heaters. For a detailed discussion on this refer to Hughes et al. (2007).

The LTMS considers four strategic options for achieving the RBS scenario in South Africa: start now; scale up; use the market; and reach for the goal (DEAT, 2008).

**Figure 7.6: Four LTMS strategic options for South Africa**



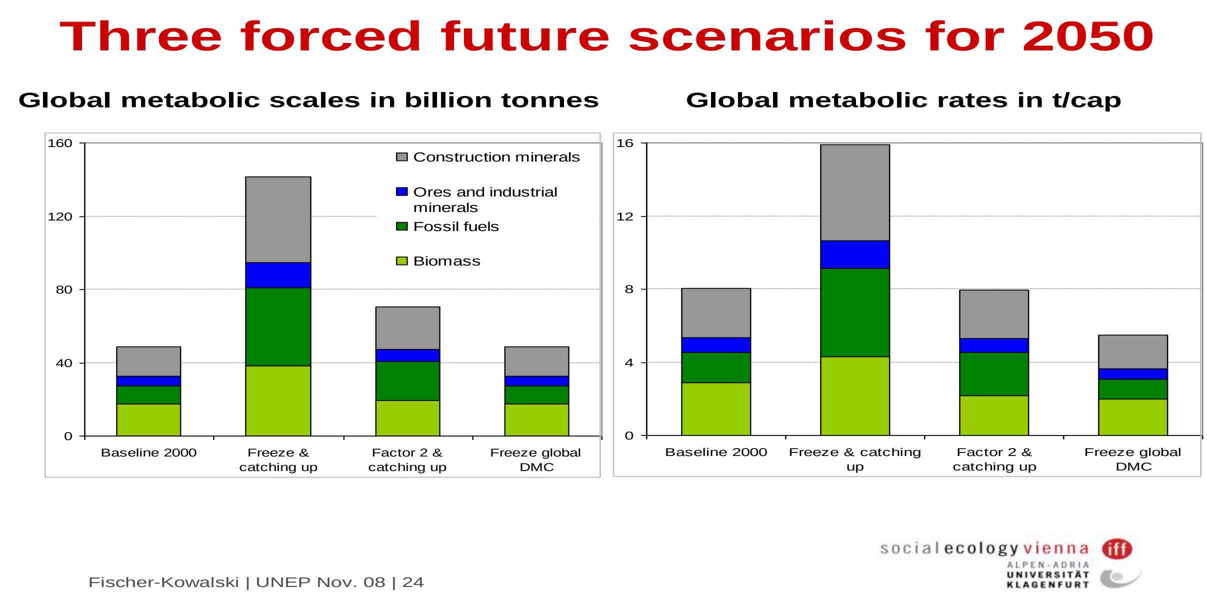

Source: Spencer (2009); DEAT (2008); Hughes et al. (2007)

- Start now
  - GDP impact is negative over the period – less than a tenth of a percent
  - Pattern of socio-economic impacts is confirmed – decrease in jobs for less-skilled households
  - However, most households are better off due to lower energy prices
- Scale up
  - High growth effect due to higher levels of investment
  - GDP impact is positive (from 1 to 1.3%) in contrast with the static model
  - Wage income increases for all skilled groups (between 17 and 29%)
  - Welfare improves for low-income groups, with a decline in welfare among richer households who derive most income from capital, not wages
- Use the market

- GDP impact is mildly positive (0.73%) instead of the previous minus 2%
    - Price increases are overshadowed by higher investments
    - Income from employment increases for all household groups
    - Difference in welfare effects are marginal
- Reach for the goal
    - New technology
    - Identify (sustainable) resources
    - People-oriented measures (and solutions)
    - Transition to low-carbon economy

The GWC scenario is similar to what Swilling (2009) in his “Three forced future scenarios for 2050”, using material flow analysis (MFA), refers to as the “freeze and catching up” scenario, essentially meaning that the developed countries flatten their consumption rates of the extracted materials while developing countries tremendously increase their consumption rates of the extracted materials in order to catch up to the living standards of the developed world. On the other hand, the RBS scenario is similar to Swilling’s “freeze global DMC” scenario, basically referring to ‘decoupling’ and ‘dematerialisation’ of the global economic growth. Whether decoupling and/or dematerialisation of the global economic growth are possible, Germany, Japan and other countries may have something to prove (see Figure 7.7).

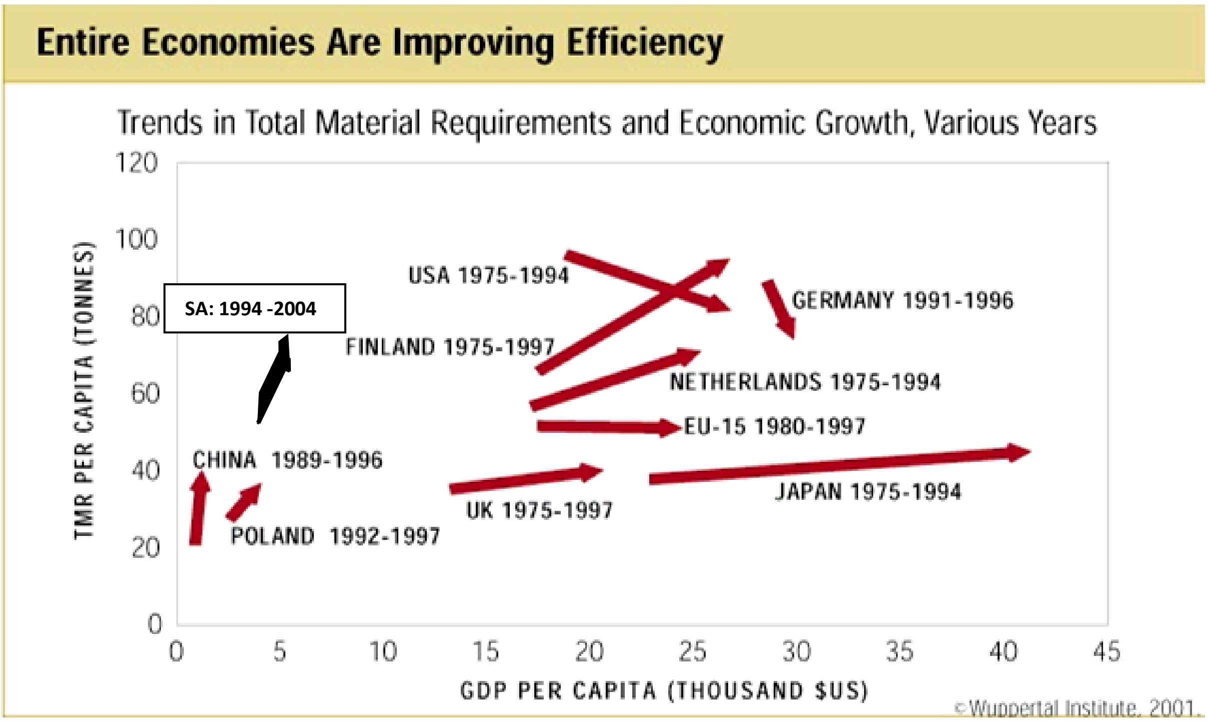
**Figure 7.7: Three forced future scenarios for 2050**




Source: Swilling (2009)

Figure 7.8 shows the trends in total material requirements (TMR) with global economies improving efficiencies and GDP per capita. South Africa clearly lags far behind with an inefficient economy and significantly small GDP per capita growth from the period 1994 to 2004.

**Figure 7.8: Dematerialisation: TMR vs economic growth**




Source: Swilling (2009)

**Appendix A3: Discussion of some RE initiatives and associated challenges in South Africa**

In South Africa, the focus has been on the dissemination of certain types of demand-side technologies, such as SWHs and compact fluorescent lights (CFLs), in an attempt to address the shortfall in generating capacity. This has not been successful. As reported by the media, Cabinet pledged to deploy photovoltaics (PVs) at the country's traffic junctions (Sebitosi & Pillay, 2008). Again this has proven to be only lip service to environmental protection. According to Sebitosi and Pillay (2008), the current model of exclusive engagement by government and Eskom in almost every sector of electric power generation and supply is unsustainable. It is certainly not the most optimum way of utilising the country's human resources to address the country's power supply problems. It is clear that Eskom lacks the will to contribute to and promote the area of alternative power generation, particularly RE.

If the South African government is intent on creating a genuinely conducive environment for investment it should promptly draft a RE strategy (Sebitosi & Pillay, 2008). As set out in the policy document itself: "Underpinning the Renewable Energy Strategy is a Macro-economic analysis to guide cost efficient Government financial assistance based on a least-cost and employment maximising supply model in reaching the target" (DME, 2003). In particular, the strategy should promote those practices and models that have worked successfully in the economy and avoid the problematic ones. For example, the country's domestic aviation industry provides one model that is worth emulating (Sebitosi & Pillay, 2008). The industry was transformed from virtually one dominant state-owned operator to a successful mix of private and public operators (Sebitosi & Pillay, 2008). The model has seen phenomenal growth in the industry with a substantial drop in fares, even as fuel prices have been rising consistently. Sebitosi and Pillay (2008) argue that the major difference between the operation of the South African electricity and aviation sectors is that the latter enjoys a level playing field anchored by the Domestic Air Travel Deregulation Act. Thus a deregulated mixed public/private business model would offer the necessary checks and balances for sustainable RE industry in South Africa.

However, in the transition to the low-carbon industry government support for newcomers is needed. We have seen the National Energy Regulator of South Africa (NERSA) publish guidelines on renewable energy feed-in tariff (REFIT) in March 2009, the purpose of which is to set the regulatory framework for initiating tariffs and licensing conditions for a self-sustaining market for grid-connected renewable energy in South Africa (NERSA, 2009). In July 2009, NERSA released a consultation paper for phase two of the REFIT that included a draft of the power purchase agreement (PPA), which renewable energy project developers and investors had been waiting for so that they could start with their projects. It was understood that the PPAs, with Eskom's Renewable Energy Purchasing Agency (REPA) as the single buyer of power generated from RE projects, would be a 20-year contract (NERSA, 2009). New renewable energy technologies that were previously excluded in the REFIT, such as solar PV systems (large ground and/or roof-mounted), concentrating PV and others were now part of the REFIT. However, although phase two of the REFIT included solar PV it did not include solar-micro PV. In its consultation paper, NERSA outlined the levelised cost of electricity for concentrating solar power (CSP) without storage as R3.132/kWh. For PV greater than 1 MW the levelised cost of electricity is R4.488/kWh; solid biomass is R1.181/kWh; biogas is R0.962/kWh; concentrating PV without storage is R5.481/kWh; and CSP tower with storage is R2.308/kWh (NERSA, 2009). Wave, tidal and geothermal technologies were excluded, as NERSA pointed out that these technologies were not yet commercially available. But what about a large residential development with solar PV on its roofs? This could qualify as a mini-solar PV plant – and it is commercially available. We have also witnessed the former Minister of Finance, Trevor Manuel, imposing 2c/kWh carbon tax on non-renewable power generation in his 2008 Budget Speech.

Given these developments, there have been concerns from independent power producers (IPPs) that regulation does not force Eskom to put power from licensed operators onto the grid (*Business Report*, 2009d). Some of the IPPs, such as Mainstream Renewable Power, that are ready to put renewable electricity onto the grid by mid-2010 argue that Eskom has declared that it would be able to connect their renewable electricity from their wind farm in Jeffreys Bay, Western Cape only in three years' time (*Business Report*, 2009d). With regards to the 2c/kWh carbon tax on non-renewable power generation, Sebitosi and Pillay (2008) argue that it is too mild by international standards and there is clearly much room for improvement. It is also not clear what the tax intends to achieve in the short term, since the estimated R2 billion that will be realised would not be used to fund research and/or investment in RE (Sebitosi & Pillay, 2008). And given that there is only one operator, the utility would not feel the pinch as the cost will be easily passed on to the customer.

In the *Business Report* of 21 July 2009, it was reported that thirty-four American scientists signed a letter urging President Barack Obama to speed up efforts to create a clean energy technology fund of about $150 billion (R1.1 trillion at R7.39/$). The proceeds of the fund will go into R&D of clean energy technologies as they argue that without rapid scientific and technical progress, the goal of reducing global GHGs at affordable cost will be compromised (*Business Report*, 2009b). China, on the other hand, may be a developing country but it is not waiting for 'scraps' to come its way from the developed world via technology transfer agreements that are due to be concluded in Copenhagen Climate Change Conference in December 2009 (*Business Report*, 2009b). According to the Breakthrough Institute (*Business Report*, 2009b), a US think tank pushing for clean energy, China, reportedly one of the biggest owners of solar and fuel cell technology, will spend $660 billion over ten years on renewable energy technologies. South Korea, another developing country, is planning to invest $85 billion over the next five years in its renewable energy industry (*Business Report*, 2009b).

South Africa, of course, is nowhere to be found in this landscape. Nevertheless, the Department of Science and Technology (DST) Innovation Fund is starting to target R&D of renewable energy technologies that are near commercialisation, such as semiconductor material for solar PV and rechargeable battery technology (*Business Report*, 2009b). The Innovation Fund as a whole was allocated R152 million for 2009 and 2010. However, it is an insignificant amount when compared with the Australian clean energy budget of $3.5 billion (of which the bulk is dedicated to industrial-scale carbon capture and storage (CCS) projects), let alone the budgets of the US and China (*Business Report*, 2009b). This means that South Africa will be more dependent on the technology transfer aspect of the global pact on climate change than those countries with a healthier intellectual property portfolio in clean energy technologies.

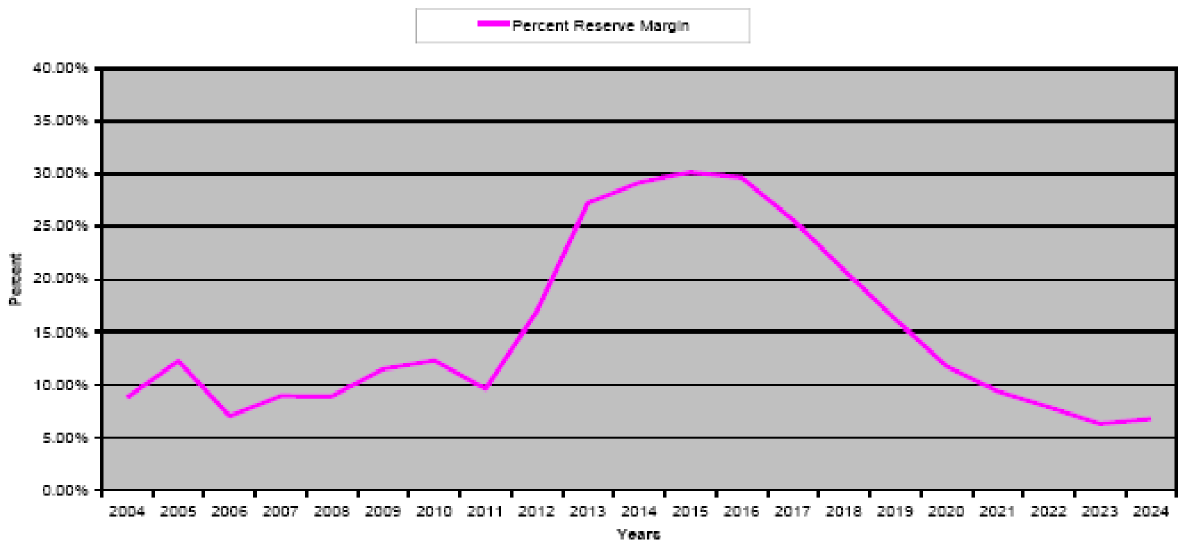
On the other hand, there are several opportunities that can help kick-start the RE industry in South Africa. The 2010 Soccer World Cup that will be hosted in South Africa highlighted the need for new infrastructure development, which includes stadiums and airport terminal buildings among others. Additionally, there is a huge backlog of (affordable) residential housing that is under construction (Sebitosi & Pillay, 2008). These are just the few that present the greatest opportunity for South Africa to initiate a large-scale grid-connected RE industry, particularly in building integrated PVs. The Cape Town municipal district has considered a bylaw to make it mandatory to include solar water heaters (SWHs) in new residential housing. According to Sebitosi and Pillay (2008), this is yet another initiative at municipal level that is likely to be undermined by the lack of a well strategised plan at national level. The Nelson Mandel Bay Metropolitan also plan to roll out 100 000 SWHs over the next five years. The roll-out was set to replace conventional electrical geysers in more than two-thirds of the Metro's 140 000 households (*Business Report*, 2009d).

In addition to REFIT and carbon tax, these developments have contributed to definite improvement, although we have yet to see whether these developments will indeed push RE forward. Overall, progress is being made in South Africa. We will have to wait and see what happens after the Copenhagen Climate Change Conference in December 2009. The industry is already investigating RE options in light of the possibilities after the Copenhagen Conference. However, as Sebitosi and Pillay (2008) argue, a carefully considered plan is needed at national level to complement policy and articulate programmes for intervention.

**Appendix A4: The national reserve margin and some interesting developments with regard to Eskom's expansion programme**

A target reserve margin of between 15 and 20% for steam-based power systems such as South Africa's is assumed as international practice. Eskom acknowledges this and is planning for an average 15% reserve margin by 2012 (EIUG, 2007). Figure 7.9 illustrates the national reserve margin over winter peak for 4% annual growth in electricity demand.

**Figure 7.9: National reserve margin of South African power system over winter peak for national expansion plan vs 4% annual growth in electricity demand**




Source: EIUG (2007)

It is clear from Figure 7.9 that a supply constraint will exist in electricity supply in South Africa until 2012, when the first base load plant is planned to be commissioned. For the period 2013 to 2019 the reserve margin exceeds 15% (EIUG, 2007) – a warning of pending over-investment and an indication of a need to possibly reschedule some new generation commissioning dates. After 2019 the reserve margin falls below 15%.

The EIUG believes that the National Expansion Plan is not without risk and the greatest uncertainties are: (i) the timing and the commissioning of the CCGT plant at Coega, (ii) achieving the DSM targets, (iii) keeping the return to service of Komati and others on track, and (iv) commissioning the Medupi and Kusile first sets on schedule. The consequence of delays or shortfalls in these projects will be a reserve margin of less than 10% up to 2013, which would mean that load curtailment and emergency shedding will be a feature of electricity supply for the next five years.

During the writing if this thesis there have been many developments with regard to Eskom's expansion programme. It was reported in *Business Report* that Eskom had delayed three projects worth R23.8 billion because of funding shortfall (*Business Report*, 2009a). "This had cut the utility expansion programme to March 2013 by 6%," said Braam Conradie, the acting general manager of Eskom's enterprise division. The three projects are the R19 billion Tubetse pumped storage project in Mpumalanga, which was expected to add 1 500 MW of peak capacity, the R3 billion 100 MW wind farm in the Northern Cape and the R1.8 billion Majuba rail project, which entailed building a 68 km railway line between Ermelo and Volksrust in Mpumalanga to transport coal to Eskom's Majuba power station (*Business Report*, 2009a). CIC Energy's R24 billion Mmamabula power project in Botswana and the 100 MW concentrated solar power plant in the Northern Cape at a cost of between R2 billion and R6 billion can be added to the list of delayed Eskom projects (*Business Report*, 2009c). The Coega CCGT plant has also been put on hold until the third quarter of 2013 due to the delayed aluminium smelter (*Business Report*, 2009a).

During this time Eskom was confident that it would be able to fund its three largest expansion projects (costing R235 billion in total), namely the Medupi and Kusile coal-fired power stations in Limpopo and Mpumalanga and the Ingula pumped storage scheme in the Drakensberg (*Business Report*, 2009c). Medupi is now expected to be fully commissioned by January 2016 and Kusile by March 2017, increasing Eskom’s base load by 25% or 9 564 MW, while Ingula is expected to run at full steam by October 2013, increasing Eskom’s peak power by 30% or 1 332 MW. The return to service of three coal-fired power stations (Camden, Grootvlei and Komati) is on track, with the last unit expected to be running by the end of 2011.

With all the delays in Eskom’s expansion plan, Andrew Etzinger, Eskom’s spokesperson, was first to admit that less electricity demand from the effects of the economic recession was helping Eskom to “keep stock levels up” (*Business Report*, 2009c). “Eskom’s spare capacity has risen from less than 5% to an average of 10%, compared with an optimum of between 15% and 20%” (Andrew Etzinger in *Business Report*, 2009c).

**Appendix A5: A brief history of the notion of sustainable development**

Up until about a hundred thousand years ago people lived as nomadic hunter-gatherers. Because of the increasing number of people living on earth these people started experiencing the problem of diminishing wild resources that they depended on (Mebratu, 1998: 494). To adapt to this problem, fifteen thousand years ago they started to plant crops and own animals, and the agricultural revolution began (Mebratu, 1998: 495). However, as agriculture advanced and became a way of life, labour divisions within human society were created and some found ways to exploit others (Mebratu, 1998: 495). The human population continued to increase over the years, and as a result, new scarcities were created, especially in land and energy (Mebratu, 1998: 495). This necessitated another new step, namely the industrial revolution. The success of the industrial revolution resulted in the environmental crisis faced by mankind today, not only in terms of natural resource supply, but also of the absorptive capacity of the natural sinks (Mebratu, 1998: 495). It is this environmental crisis that gave birth to a number of notions, of which sustainable development is one to deal with complex ecological (and social) issues (Mebratu, 1998: 493).

Sustainable development emerged strongly in the 1970s and started featuring prominently in global policy and decision making in the 1980s (Kelly, 2009: 46).

According to Sachs (1999: 76, cited in Kelly, 2009: 46), two prominent sides, namely "the crisis of justice" and "the crisis of nature" were competing for dominance within the realm of development. The former reacted to the failure of many years of development to enable the poor to catch up to the rich (Kelly, 2009: 46-47), while the gap between the two groups had widened even further instead, whereas the latter showed concern about the over-consumption and exploitation of natural resources for the sake of development (Sachs, 1999: 73, in Kelly, 2009: 47) and advocated stricter environmental laws. The two sides were extremely polarised (Kelly, 2009: 47): any action to alleviate poverty and improve the quality of life of poorer nations of the world could be seen to aggravate the crisis of nature, and vice versa.

Sustainable development was found to be the solution as it is development that improves the standard of living of poor people without endangering the environment (Kelly, 2009: 47). Sustainable development, thus, took centre stage in a series of highly significant events. In 1972, the Club of Rome and a group of scientists from MIT published a report called *Limits to growth*, which analysed the relationship between humans and the earth's capacity to provide resources that support life (Smit, 2009: 28). In the same year, the Stockholm Conference on the Human Environment took place as the first of series of United Nations conferences about the environment and development (Smit, 2009: 28). The Brundtland Report, *Our common future*, was published in 1987, followed by the World Conference on Environment and Development (WCED) in 1992. The United Nations Conference on Environment and Development (UNCED), commonly known as the Earth Summit, took place in 1992 as well (Smit, 2009: 28), and the subsequent Rio Cluster of UN Proceedings.

**Appendix A6: Countries with community-scale PV systems**

According to the Photovoltaic Power Systems (PVPS) programme of the IEA, nearly 90% (5.1 GW) of the 5.7 GW PV cumulative installations in 2006 are grid-connected systems (IEA, 2008a). The rapid growth had been in the community-scale PV market segment as planners, developers, builders and communities realise the related benefits and business opportunities in many IEA member countries (IEA, 2008a). In the emerging distributed generation (DG) market, communities are central in mainstreaming PV on an urban scale as they are able to standardise PV technology in the housing or community design. The IEA (2008a) maintains that truly integrated PV communities can maximise the benefits through careful planning and multilateral involvement of all stakeholders. The distributed urban-scale PV market is not the bilateral (utility/customer) relationship of traditional central electricity generation (IEA, 2008a).

According to the Photovoltaic Power Systems (PVPS) programme of the IEA (2008a), involvement of all stakeholders may strengthen both the economic and technical success of the PV communities considering the following:

- Building sector: Developers/builders, engineers and architects need to consider aesthetics, orientation, energy efficiency, end-use and many more to maximise on-site energy use with building design.
- Government: Local governments are particularly important in codifying and verifying building energy performance. They can issue licenses and certifications for installers of PV systems to assure quality and performance, and customer confidence.
- End-users: Owners or occupants of residential and commercial buildings should consider the electric service design to loads, economic benefits (less operational expenses) and opportunities such as feed-in tariff or renewable energy credits (REC) sales and green image.
- PV industry: System manufacturers can develop standardised systems as the PV community market becomes mainstream. The PV system supply chain and retail sector can standardise installations in developments and increase and diversify labour skills.
- Electricity sector: Instead of utilities considering counter measures in the emerging distributed PV community market, they should be aware of business opportunities such as reduced grid service infrastructure requirements, reduce operational costs on smart-portfolio diversified grid and even a smart grid.
- Education sector: As the PV market grows even further there will be greater opportunities for educators to develop the necessary curriculum and on-the-job experience through PV communities.
- Finance and insurance sector: Banks will benefit from the operational savings in overall debt allowances. Both banks and insurance companies should

realise the value in reduced financial risk of volatile energy prices as well as reduced costs in case of property loss from more disaster-resistant building material.

The residential housing sector is a major energy/electricity user (after the industrial and transport sectors) and market opportunity for distributed PV systems. The retrofit market is huge but new housing developments provide opportunities for standardisation of design and installation of the PV systems (IEA, 2008a).

In providing an overview of how other countries have been successful in developing community housing PV development, Japan, California (US), United Kingdom and South Korea are considered. The IEA (2008a) surveyed a total of 38 PV communities in different countries (see Table 6.1). One PV community in Sweden is categorised as ‘public’ and consists of 15 buildings such as museums, schools and others (IEA, 2008a), and the other 37 communities are in ‘residential-urban’ areas. Of these, 21 are ‘single-house’ communities, seven are ‘multi-storey apartment building’ communities, eight are ‘attached houses’ communities, and one is a mixture of all three types (IEA, 2008a). The five communities in the United Kingdom are social housing projects. In Japan and the United States, nearly all the PV communities are newly developed except one in Japan, which is a retrofit. The European PV communities were mainly ‘retrofit’ or ‘added’. In residential-urban PV communities, the largest project is Stad van de Zon (City of the Sun) in the Netherlands, which consisted of more than 3 500 dwellings and approximately 5 MW total capacity. The second largest for total PV power is Pal Town Josai-no-mori (Japan, 553 houses, 2 160 kW), and the second largest for number of houses is Olympic Village, Sydney (Australia, 935 houses, 857 kW).

In terms of PV system types and the PV application type, two French projects are ‘grid-connected – supply side’, with one ‘facade – mounted’ and other ‘inclined roof – PV roof tile’ (IEA, 2008a). Most other communities’ PV system type and application is ‘grid-connected – demand side’ and PV modules are basically placed on the roof, e.g. inclined roof or flat roof.

All PV cells used in the communities are silicon based. In Japan amorphous silicon PV modules are used in some communities and those PV modules are used as PV roof tiles.

As for ownership, PV systems for single houses and attached houses are owned by the inhabitant, while in the case of a Swiss project and two projects in the Netherlands, PV systems are owned by utilities (IEA, 2008a). The PV systems of multi-storey apartment buildings, UK social housing and public buildings are owned by other organisations. According to the IEA (2008a), the PV energy user is classified as inhabitant, other organisation (building owner) or utility, and this basically depends upon scheme for PV electricity, e.g. net-metering or feed-in tariff, and PV owner.

**Table 7.1: The existing urban PV communities in the world**

| Country | Community | Total PV power | PV power per unit |
|---|---|---|---|
| **Austria:** | **Thüringerberg** | **Total PV power:** 146 kW | **PV power per unit:** Approx. 8,5 kW |
| **Canada:** | **Waterloo** | **Total PV power:** 12.8 kW | **PV power per unit:** 3.2 kW/house |
| **Denmark:** | **Solbyen** | **Total PV power:** 60 kW | **PV power per unit:** 1 - 3 kW/house |
| **Denmark:** | **Sol 300** | **Total PV power:** 750 kW | **PV power per unit:** 0.9 - 6 kW/house |
| **France:** | **La Darnaise** | **Total PV power:** 92 kW | **PV power per unit:** 4.8 or 12 kW/building |
| **France:** | **Les Hauts de Feuilly** | **Total PV power:** 25 kW | **PV power per unit:** 1 or 2 kW/house |
| **Japan:** | **Villa Garten Shin-Matsudo** | **Total PV power:** 123 kW | **PV power per unit:** 2.86 - 3.1 kW/house |
| | **Tiara Court Kasukabe** | **Total PV power:** 101 kW | **PV power per unit:** 2.88 kW/house |
| | **Cosmo-Town Kiyomino Saizu** | **Total PV power:** 239 kW | **PV power per unit:** 3 kW/house |
| | **Jo-Town Kanokodai** | **Total PV power:** 285 kW | **PV power per unit:** 3 kW/house |
| | **Cosmo-Town Yumemino Saizu Licht paadje** | **Total PV power:** 180 kW | **PV power per unit:** 2 kW/house |

**Hills-Garden Kiyota**

**Total PV power:** 336 kW **PV power per unit:** 2.4 kW/house

**Pal Town Josai-no-Mori**

**Total PV power:** 2 160 kW **PV power per unit:** 2.6 - 5.0 kW/house

**Sekisui Harmonate-town Shin-Kamagaya**

**Total PV power:** 90 kW **PV power per unit:** 2.0 - 5.6 kW/house

**Panahome-city Seishin-Minami**

**Total PV power:** 299 kW **PV power per unit:** 3 kW/house

**Sengendai Sai-no-michi**

**Total PV power:** 50 kW **PV power per unit:** 2 kW/house

**Sekisui Harmonate-town Tsuru-no-ura**

**Total PV power:** 98 kW **PV power per unit:** 3,5 - 4,0 kW/house

**Jo-Town Rinku Hawaiian Village**

**Total PV power:** 476 kW **PV power per unit:** 2 kW/house

**Hazama-so**

**Total PV power:** 203 kW **PV power per unit:** 11 - 34 kW/building

**Korea: Asan Green Village**

**Total PV power:** 208 kW **PV power per unit:** 2 kW/home

**Korea National Housing Corporation-Apartment**

**Total PV power:** 250 kW

**Switzerland: ABZ Residential Area "Moos"**

**Total PV power:** 100 kW **PV power per unit:** 8,5 kW/building

**UK: Corncroft, Nottingham**

**Total PV power:** 34 kW **PV power per unit:** 1,5 or 1,7 kW/house

**Pinehurst**

**Total PV power:** 14 kW **PV power per unit:** 1,4 or 1,7 kW/house

**Belfast Field Trials – Sunderland road**

**Total PV power:** 51 kW **PV power per unit:** 1,7 kW/flat

**Newbiggin Hall Estate**

**Total PV power:** 38,25 kW **PV power per unit:** 1 - 3 kW/flat

**Campkin Court, Cambridge**

**Total PV power:** 22,1 kW **PV power per unit:** 0,96 kW/flat

**USA: Clarum Homes – Vista Montana**

**Total PV power:** >300 kW **PV power per unit:** 1,2 - 2,4 kW

**Premier Homes – Premier Gardens**

**Total PV power:** 209 kW **PV power per unit:** 2,2 kW

**Centex – Avignon**

| | | |
|---|---|---|
| | **Total PV power:** 105 kW | **PV power per unit:** 3,5 kW |
| | **Grupe – Carsten Crossings** | |
| | **Total PV power:** 345 kW | **PV power per unit:** 2,4 kW |
| | **Treasure Homes – Fallen Leaf** | |
| | **Total PV power:** 64 kW | **PV power per unit:** 2 kW |
| | **Shea Homes – San Angelo** | |
| | **Total PV power:** 120 kW | **PV power per unit:** 1,2 kW |
| **Sweden:** | **City of Malmö** | |
| | **Total PV power:** 500 kW | **PV power per unit:** 11 - 166 kW |

Source: IEA (2008)

### Appendix A7: The main technical issues for grid-connected PV systems

PV systems generate electricity as direct current (DC) which is incompatible with grid electricity, alternating current (AC). An inverter is used by all grid-connected PV systems to convert DC into AC.

According to Curren and Makhele (2009: 21), the main technical issues for distributed PV connection relate to reliability and quality of supply, safety and protection, metering, islanding and reactive power management. Key quality of supply issues are voltage regulation, voltage flicker, harmonic voltages and DC injection (Curren & Makhele, 2009: 21).

### Maintaining power quality and acceptable voltage with PV

The PV roof tile system at Lynedoch generates electricity at the point of use (providing for the end-user). The generated electricity can often be forecasted and only changes slightly and very slowly with cloud cover. Generally this electricity from PV systems improve power quality. When there are a large number of small PV installations, one system breaking down will not significantly affect power quality and voltage unlike when a large centralised power plant in operation fails (Curren & Makhele, 2009: 21). Thus, an increasing amount of distributed PV generation can improve the power network by becoming part of the overall network facility (Curren & Makhele, 2009: 21).

**Limiting harmonics distortion caused by PV systems**

Curren and Makhele (2009: 22) point out that harmonics are disturbances on the ideal sine wave, whose frequencies are multiples of the fundamental frequency. TV sets, DVD players and other domestic appliances as well as PVs cause these harmonics on the grid electricity. Some degree of harmonics generated by, for example, a single 5 kW PV roof tile system such as the one at Lynedoch is generally not a problem. However, in the case of multiple PV systems, the result is the cumulative distortions which reflect the existing levels of disturbances on the grid plus inputs from the PVs (Curren & Makhele, 2009: 22). High harmonics levels on the grid result in losses in the power system, overheating of components within the network, and possible harm to the equipment connected to it. The regulations are set to allowable harmonic current distortion when the equipment is operating at rated power. PV inverters often operate at below rated power and the harmonic output could exceed the allowable percentage at low power, hence harmonic limits should be specified at power levels below rated power (Curren & Makhele, 2009: 22). But again setting allowable harmonic limits at power levels below full power might not be necessary according to Curren and Makhele (2009), because recent research has indicated that harmonic distortions from multiple PV systems often cancel each other out rather than being cumulative, thereby reducing the impact on the grid as more PV systems are installed.

**Net metering**

Installing a PV system has a high investment cost, and therefore PV homeowners should realise the full value of electricity produced by their PV systems. This is made possible by what is known as net metering (Curren & Makhele, 2009: 23). A PV system produces electricity that is first used to meet household electricity requirements (lights, appliances and others). If there is excess electricity produced by the PV system it is exported into the grid. Countries with incentives in place, such as Germany, have made net metering an attractive option for homeowners.

**Islanding**

Islanding is one of the main safety issues for grid-connected PV systems. According to Curren and Makhele (2009: 23), islanding is the continued operation of a PV inverter even when the grid is off. The dangers associated with this is that a technician/engineer looking to fix a grid problem may be under the impression that the grid is off and could get an electric shock from the operating PV inverter (Curren & Makhele, 2009: 23). A control unit which monitors grid voltage and grid frequency could stop the PV system from generating electricity through sensing circuits in the inverter electronics (Curren & Makhele, 2009: 23). This approach has been successfully implemented in Germany, Austria, the Netherlands and Switzerland. The PV roof tile system installed at Lynedoch included effective and reliable anti-islanding methods in the inverter electronics which made the installation of the PV system simpler. Some countries have demanded very costly anti-islanding methods, but technically inverters can include reliable anti-islanding methods which could bring the cost of anti-islanding down (Curren & Makhele, 2009: 23).

Preventing islanding means that the PV system is switched off during the power outage to ensure safety, but this could be seen as a barrier to installing PV systems as PV power must ensure energy security and available power even when the grid goes down. This problem could be resolved by setting up a mini-grid which could operate during periods of power outages only. In this case, a PV system could be switched into off-grid mode and feed the loads directly (Curren & Makhele, 2009: 20). However, the battery would be required to manage the loads. Mini-grids could range from an individual household to a larger system connecting a number of users.

## Appendix B: Spreadsheets for calculating cost of electricity from a coal-fired power plant and a residential solar power system (PV and SWH) based on initial capital costs

### Table 7.2: Initial cost of electricity of a coal-fired power plant in R/kWh

| Coal (R/kWh) | | | | |
|---|---|---|---|---|
| Initial costs | Plant costs | R100 000 000 000.00 | | |
| | Transmission line | R2 000 000 000.00 | | |
| | Fixed annual capital costs | R28 800 000.00 | R6.00 | for every kW |
| | Other direct costs (10% of EPC) | R10 000 000 000.00 | 10% | of EPC |
| | Total initial costs | R112 028 800 000.00 | | |
| | | | | |
| | | | | |
| | Size | 4 800 | MW | |
| | Capacity factor | 90% | | |
| | Annual generation | 37843200 | MWh | |
| | | 37843200000 | kWh | |
| | Plant life | 40 | years | |
| | Interest on loan | 9% | pa | |
| | | | | |
| | Annual payback at 9% interest over 40 years | R10 414 153 469.51 | | |
| | **Initial cost share of electricity costs** | **R 0.28** | **/kWh** | |
| | | | | |
| | | | | |
| Coal costs | Coal consumption | 14 600 000 | tonne/year | |
| | Coal costs | R175 | /tonne | |
| | Annual coal costs | R2 555 000 000.00 | | |
| | **Coal cost share of electricity costs** | **R0.07** | **/kWh** | |
| | | | | |
| Water costs | Water consumption | 1.35 | L/kWh | |
| | Annual water consumption | 51 088 320 000 | L/year | |
| | | 51 088 320 | kL/year | |

| | | | | |
|---|---|---|---|---|
| | Water costs | R7.00 | /kL | |
| | Annual water costs | R357 618 240.00 | | |
| | **Water cost share of electricity costs** | **R0.01** | **/kWh** | |
| | | | | |
| Sorbent costs | Sorbent consumption | 0.05 | tonne/tonne of coal | |
| | Annual sorbent consumption | 730 000 | tonne/year | |
| | Sorbent costs | R125.00 | /tonne | |
| | Annual sorbent costs | R91 250 000.00 | | |
| | **Sorbent cost share of electricity costs** | **R0.00** | **/kWh** | |
| | | | | |
| O&M costs | Variable O&M costs | R1.50 | /MWh | |
| | Annual variable O&M costs | R56 764 800.00 | | |
| | Fixed O&M costs | R100.00 | /kW/year | |
| | Annual fixed O&M costs | R480 000 000.00 | | |
| | Total annual O&M costs | R536 764 800.00 | | |
| | **O&M cost share of electricity costs** | **R0.01** | **/kWh** | |
| | | | | |
| | **Final electricity costs** | **R0.37** | **/kWh** | |
| | | | | |
| Carbon costs | Carbon tax | R0.02 | per kWh | |
| | Coal carbon emission factor | 1.2 | kg of $CO_2$/kWh | |
| | Annual carbon emissions | 45 411 840 000 | kg of $CO_2$ | |
| | | 45 411 840 | tonne of $CO_2$ | |
| | Annual carbon emission costs | R756 864 000.00 | | |
| | **Carbon cost share of electricity costs** | **R0.02** | **/kWh** | |
| | | | | |
| | **Final electricity costs with carbon tax** | **R0.39** | **/kWh** | |

**Table 7.3: Initial cost of electricity of a Lynedoch PV roof tile system in R/kWh**

| PV roof tile system (R/kWh) | | |
|---|---|---|
| System life | 25 | + 15 years |
| System size | 5 | kW |
| Solar radiation (SA annual average) | 5.5 | kWh/kW/day |
| Capacity factor | 23% | |
| Annual electricity generation | 10 038 | kWh |
| | | |
| Financed over | 40 | years |
| Interest | 9% | |
| | | |
| **Initial costs** | | |
| Capex (just PV) | R68.80 | W |
| Capex (with total installation costs) | R137.32 | W |
| Total PV system costs | R343 979.99 | |
| System replacement cost at year 25 | R201 827.91 | |
| Project management | R6 000.00 | |
| Design | R2 100.00 | |
| On-site visits | R4 500.00 | |
| Installation | R1 800.00 | |
| System commissioning | R600.00 | |
| Travel | R3 500.00 | |
| Additional materials | R6 485.75 | |
| 1.7 kW inverter | R20 824.60 | |
| 1.7 kW inverter replacement costs at year 25 | R12 218.69 | |
| 3.3 kW inverter | R29 440.48 | |
| 3.3 kW inverter replacement costs at year 25 | R17 274.00 | |
| Web-box | R12 428.96 | |
| Web-box replacement costs | R7 292.61 | |
| Import and storage costs | R16 318.36 | |
| | | |
| **Total PV installation costs** | **R686 591.35** | |
| | | |
| Annual costs (loan repayments) | R63 825.27 | |
| **Initial cost share of electricity costs** | **R6.36** | **kWh** |
| | | |

| **O&M costs** | | |
|---|---|---|
| | | |
| Annual O&M costs | R1 555.00 | |
| **O&M cost share of electricity costs** | **R0.15** | **kWh** |
| | | |
| **Final PV electricity costs** | **R6.51** | **kWh** |
| | | |
| Carbon credits | | |
| Emission factor | 1.2 | kg $CO_2$/kWh |
| Annual PV carbon savings | 12 045.6 | kg $CO_2$ |
| | 12.05 | tonne $CO_2$ |
| CER price | 10 | €/tonne $CO_2e$ |
| CER price at R10.80/€ (16 Sep 2009) | R108.00 | tonne $CO_2e$ |
| Total annual PV carbon savings in cash | R1 300.92 | |
| | | |
| Annual costs (loan repayments) less CERs | R62 524.34 | |
| **Initial cost share of electricity costs with CERs** | **R6.23** | **kWh** |
| | | |
| **Final PV electricity costs including CERs** | **R6.38** | **kWh** |

**Table 7.4: Initial cost of electricity of a Lynedoch PV roof tile system including roof costs in R/kWh**

| **PV system with the roof structure (R/kWh)** | | |
|---|---|---|
| System life | 25 | +15 years |
| System size | 5 | kW |
| Solar radiation (SA annual average) | 5.5 | kWh/kW/day |
| Capacity factor | 23% | |
| Annual electricity generation | 10 038 | kWh |
| | | |
| Financed over | 40 | years |
| Interest | 9% | |
| | | |
| Initial costs | | |
| Capex (just PV) | R68.80 | W |
| Capex (with total installation costs) | R146.60 | W |

| | | |
|---|---|---|
| Total PV system costs | R343 979.99 | |
| PV system replacement cost at year 25 | R201 827.91 | |
| Project management | R6 000.00 | |
| Design | R2 100.00 | |
| On-site visits | R4 500.00 | |
| Installation | R1 800.00 | |
| System commissioning | R600.00 | |
| Travel | R3 500.00 | |
| Additional materials | R6 485.75 | |
| 1.7 kW inverter | R20 824.60 | |
| 1.7 kW inverter replacement costs at year 25 | R12 218.69 | |
| 3.3 kW inverter | R29 440.48 | |
| 3.3 kW inverter replacement costs at year 25 | R17 274.00 | |
| Web-box | R12 428.96 | |
| Web-box replacement costs | R7 292.61 | |
| Import and storage costs | R16 318.36 | |
| Reinforced roof structure costs | R46 396.39 | |
| | | |
| **Total PV and roof installation costs** | **R732 987.74** | |
| | | |
| Annual costs (loan repayments) | R68 138.26 | |
| **Initial cost share of electricity costs** | **R6.79** | **kWh** |
| | | |
| O&M costs | | |
| | | |
| Annual O&M costs | R1 555.00 | |
| **O&M cost share of electricity costs** | **R0.15** | **kWh** |
| | | |
| **Final PV electricity costs** | **R6.94** | **kWh** |
| | | |
| Carbon credits | | |
| Emission factor | 1.2 | kg $CO_2$/kWh |
| Annual PV and roof carbon savings | 12 045.6 | kg $CO_2$ |
| | 12.05 | tonne $CO_2$ |
| CER price | 10 | €/tonne $CO_2$e |
| CER price at R10.80/€ (16 Sep 2009) | R108.00 | tonne $CO_2$e |

| | | |
|---|---|---|
| Total annual PV and roof carbon savings | R1 300.92 | |
| | | |
| Annual costs (loan repayments) less CERs | R66 837.33 | |
| **Initial cost share of electricity costs with CERs** | **R6.66** | **kWh** |
| | | |
| **Final PV electricity costs including CERs** | **R6.81** | **kWh** |

**Table 7.5: Initial cost of electricity of a residential solar power system (Lynedoch PV roof tile system and SWH including roof costs) in R/kWh**

| **PV, SWH and roof (R/kWh)** | | |
|---|---|---|
| System life | 25 | +15 years |
| System size | 5 | kW |
| Solar radiation (SA annual average) | 5.5 | kWh/kW/day |
| Capacity factor | 23% | |
| Annual electricity generation | 10 038 | kWh |
| | | |
| Financed over | 40 | years |
| Interest | 9% | |
| | | |
| SWH savings | | |
| Monthly SWH electricity savings | 300 | kWh |
| Municipal electricity cost | R0.55 | kWh |
| Monthly cash savings | R165.00 | |
| Annual cash savings | R1 980.00 | |
| | | |
| Initial costs | | |
| Capex (just PV) | R68.80 | W |
| Total PV system costs | R343 979.99 | |
| PV system replacement cost at year 25 | R201 827.91 | |
| Project management | R6 000.00 | |
| Design | R2 100.00 | |
| On-site visits | R4 500.00 | |
| Installation | R1 800.00 | |
| System commissioning | R600.00 | |
| Travel | R3 500.00 | |
| Additional materials | R6 485.75 | |

| | | |
|---|---|---|
| 1.7 kW inverter | R20 824.60 | |
| 1.7 kW inverter replacement costs at year 25 | R12 218.69 | |
| 3.3 kW inverter | R29 440.48 | |
| 3.3 kW inverter replacement costs at year 25 | R17 274.00 | |
| Web-box | R12 428.96 | |
| Web-box replacement costs | R7 292.61 | |
| Import and storage costs | R16 318.36 | |
| Reinforced roof structure costs | R46 396.39 | |
| | | |
| **Total PV and roof installation costs** | **R732 987.74** | |
| | | |
| SWH costs | R13 286.00 | |
| SWH replacement cost at year 25 | R7 795.47 | |
| Generic domestic external plumbing kit | R2 500.00 | |
| Pressure control valve | R495.00 | |
| Geyser timer | R963.00 | |
| Installation/labour costs | R2 310.00 | |
| Fuel allowance costs | R125.00 | |
| | | |
| **Total SWH installation costs** | **R27 474.47** | |
| | | |
| **Total PV, SWH and roof installation costs** | **R760 462.21** | |
| | | |
| Annual costs (loan repayments) | R70 692.27 | |
| Annual costs (loan repayments) less SWH savings | R68 712.27 | |
| **Initial cost share of electricity costs** | **R6.85** | **kWh** |
| | | |
| O&M costs | | |
| | | |
| Annual O&M costs | R1 555.00 | |
| **O&M costs share of electricity costs** | **R0.15** | **kWh** |
| | | |
| **Final PV, SWH and roof electricity costs** | **R7.00** | **kWh** |
| | | |
| Carbon credits | | |
| Emission factor | 1.2 | kg $CO_2$/kWh |
| Annual PV and roof carbon savings | 12 045.6 | kg $CO_2$ |

| | | |
|---|---|---|
| | 12.05 | tonne $CO_2$ |
| Annual SWH carbon savings | 4 320 | kg $CO_2$ |
| Total annual PV and SWH carbon savings | 16 365.6 | kg $CO_2$ |
| | 16.37 | tonne $CO_2$ |
| CER price | 10 | €/tonne $CO_2e$ |
| CER price at R10.80/€ | R108.00 | tonne $CO_2e$ |
| Total annual PV and SWH carbon savings in cash | R1 767.48 | |
| | | |
| Annual costs (loan repayments) less CERs | R66 944.79 | |
| **Initial cost share of electricity costs with CERs** | **R6.67** | **kWh** |
| | | |
| **Final PV and SWH electricity costs including CERs** | **R6.82** | **kWh** |

## Table 7.6: Initial cost of electricity of a Lomold PV roof tile system in R/kWh

| **Lomold PV system (R/kWh)** | | |
|---|---|---|
| System life | 25 | + 15 years |
| System size | 5 | kW |
| Solar radiation (SA annual average) | 5.5 | kWh/kW/day |
| Capacity factor | 23% | |
| Annual electricity generation | 10 038 | kWh |
| | | |
| Financed over | 40 | years |
| Interest | 9% | |
| | | |
| **Initial costs** | | |
| Capex (just PV) | R28.08 | W |
| Capex (with total installation costs) | R58.45 | W |
| Total PV system costs | R140 410.00 | |
| System replacement cost at year 25 | R82 384.61 | |
| Project management | R6 000.00 | |
| Design | R2 100.00 | |
| On-site visits | R4 500.00 | |
| System commissioning | R600.00 | |
| Travel | R3 500.00 | |

| | | |
|---|---|---|
| | | |
| 5 kW inverter | R20 824.60 | |
| 5 kW inverter replacement costs at year 25 | R12 218.69 | |
| | | |
| | | |
| Web-box | R12 428.96 | |
| Web-box replacement costs | R7 292.61 | |
| | | |
| | | |
| **Total PV installation costs** | **R292 259.47** | |
| | | |
| Annual costs (loan repayments) | R27 168.33 | |
| **Initial cost share of electricity costs** | **R2.71** | **kWh** |
| | | |
| **O&M costs** | | |
| | | |
| Annual O&M costs | R1 555.00 | |
| **O&M cost share of electricity costs** | **R0.15** | **kWh** |
| | | |
| **Final PV electricity costs** | **R2.86** | **kWh** |
| | | |
| Carbon credits | | |
| Emission factor | 1.2 | kg $CO_2$/kWh |
| Annual PV carbon savings | 12 045.6 | kg $CO_2$ |
| | 12.05 | tonne $CO_2$ |
| CER price | 10 | €/tonne $CO_2e$ |
| CER price at R10.80/€ (16 Sep 2009) | R108.00 | tonne $CO_2e$ |
| Total annual PV carbon savings in cash | R1 300.92 | |
| | | |
| Annual costs (loan repayments) less CERs | R25 867.40 | |
| **Initial cost share of electricity costs with CERs** | **R2.58** | **kWh** |
| | | |
| **Final PV electricity costs including CERs** | **R2.73** | **kWh** |

**Table 7.7: Initial cost of electricity of a Lomold residential solar power system (Lomold PV roof tile system and SWH including roof costs) in R/kWh**

| Lomold PV and SWH (R/kWh) | | |
|---|---|---|
| System life | 25 | +15 years |
| System size | 5 | kW |
| Solar radiation (SA annual average) | 5.5 | kWh/kW/day |
| Capacity factor | 23% | |
| Annual electricity generation | 10 038 | kWh |
| | | |
| Financed over | 40 | years |
| Interest | 9% | |
| | | |
| SWH savings | | |
| Monthly SWH electricity savings | 300 | kWh |
| Municipal electricity cost | R0.65 | kWh |
| Monthly cash savings | R195.00 | |
| Annual cash savings | R2 340.00 | |
| | | |
| Initial costs | | |
| Capex (just PV) | R28.08 | W |
| Total PV system costs | R140 410.00 | |
| PV system replacement cost at year 25 | R82 384.61 | |
| Project management | R6 000.00 | |
| Design | R2 100.00 | |
| On-site visits | R4 500.00 | |
| System commissioning | R600.00 | |
| Travel | R3 500.00 | |
| | | |
| 5 kW inverter | R20 824.60 | |
| 5 kW inverter replacement costs at year 25 | R12 218.69 | |
| | | |
| | | |
| Web-box | R12 428.96 | |
| Web-box replacement costs | R7 292.61 | |
| | | |
| | | |

| | | |
|---|---|---|
| | | |
| **Total PV installation costs** | **R292 259.47** | |
| | | |
| SWH costs | R13 286.00 | |
| SWH replacement cost at year 25 | R7 795.47 | |
| Generic domestic external plumbing kit | R2 500.00 | |
| Pressure control valve | R495.00 | |
| Geyser timer | R963.00 | |
| Installation/labour costs | R2 310.00 | |
| Fuel allowance costs | R125.00 | |
| | | |
| **Total SWH installation costs** | **R27 474.47** | |
| | | |
| **Total PV and SWH installation costs** | **R319 733.94** | |
| | | |
| Annual costs (loan repayments) | R29 722.35 | |
| Annual costs (loan repayments) less SWH savings | R27 382.35 | |
| **Initial cost share of electricity costs** | **R2.73** | **kWh** |
| | | |
| O&M costs | | |
| | | |
| Annual O&M costs | R1 555.00 | |
| **O&M costs share of electricity costs** | **R0.15** | **kWh** |
| | | |
| **Final PV, SWH and roof electricity costs** | **R2.88** | **kWh** |
| | | |
| Carbon credits | | |
| Emission factor | 1.2 | kg $CO_2$/kWh |
| Annual PV and roof carbon savings | 12 045.6 | kg $CO_2$ |
| | 12.05 | tonne $CO_2$ |
| Annual SWH carbon savings | 4 320 | kg $CO_2$ |
| Total annual PV and SWH carbon savings | 16 365.6 | kg $CO_2$ |
| | 16.37 | tonne $CO_2$ |
| CER price | 10 | €/tonne $CO_2e$ |
| CER price at R10.80/€ (16 Sep 2009) | R108.00 | tonne $CO_2e$ |
| Total annual PV and SWH carbon savings | R1 767.48 | |

| | | |
|---|---|---|
| | | |
| Annual costs (loan repayments) less CERs | R25 614.86 | |
| **Initial cost share of electricity costs with CERs** | **R2.55** | **kWh** |
| | | |
| **Final PV and SWH electricity costs including CERs** | **R2.71** | **kWh** |