

The potential of concentrating solar power in South Africa

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ABSTRACT

In this paper all provinces of South Africa with a good potential for the implementation of large-scale concentrating solar power plants are identified using geographic information systems. The areas are assumed suitable if they get sufficient sunshine, are close enough to transmission lines, are flat enough, their respective vegetation is not under threat and they have a suitable land use profile. Various maps are created showing the solar resource, the slope, areas with “least threatened” vegetation, proximity to transmission lines and areas suitable for the installation of large concentrating solar power plants. Assuming the installation of parabolic trough plants, it is found that the identified suitable areas could accommodate plants with a nominal capacity of 510.3 GW in the Northern Cape, 25.3 GW in the Free State, 10.5 GW in the Western Cape and 1.6 GW in the Eastern Cape, which gives a total potential nominal capacity of 547.6 GW for the whole country.

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1. Introduction

In two recent reports (Energy Research Centre, 2007; Banks and Schäffler, 2005) the implementation of large concentrating solar power (CSP) plants has been proposed as one of the main contributors to greenhouse gas emission reductions in South Africa. Both studies envisage an installed CSP capacity of above 20 GW by 2035. Currently, no CSP plants are installed in the country, and none are under construction. In Spain, which has a significantly poorer solar resource, several parabolic trough plants with a nominal capacity of 50 MW and up to 7 h storage are under construction. This sudden boom has been facilitated by a renewable energy feed-in tariff (REFIT), which is currently at €0.28/kWh. A REFIT has recently also been announced for South Africa (NERSA, 2009). Even though, at ZAR 2.10 (which is equivalent to € 0.18 at the exchange rate of 21st May 2009), the local REFIT for CSP is significantly lower than the one in Spain, it should still be adequate to spur the local implementation of the technology.

In the South African energy debate, it is usually assumed that CSP plants would be located in the Northern Cape Province, because of its excellent solar resource and its vast, sparsely populated areas. As a result of this assumption, policy makers in other provinces are likely to take little interest in CSP. Also, sceptics are quick to presume that those potential sites in the Northern Cape are far from transmission lines, load centers and access to water.

In the present study all provinces of South Africa with a good potential for large-scale CSP are identified, and their respective potential is assessed using geographic information systems (GIS). As parabolic trough plants are the only established CSP technology, the use of this technology is assumed here.

2. Literature review

Similar potential assessments for renewable energy and CSP have been performed for other regions: Bravo et al. (2007) define the capacity and generation ceiling for renewable energy technologies for Spain. The electricity generating technologies considered are wind turbines, solar photovoltaics (PV), CSP and biomass. For CSP they include all areas which have a suitable slope (gradient below 7% for slopes facing SE to SW or below 2% for all other orientations), a suitable land use profile and average direct normal solar irradiation values above 4.1 kWh/m²/d (1500 kWh/m²/a). Assuming the use of parabolic trough plants with 6 h thermal storage, they find a generation ceiling which is 35.34 times above the electricity demand projected for 2050.

Pletka et al. (2007) present a renewable energy assessment for Arizona. The electricity generating technologies considered in their study are solid biomass, biogas, CSP, PV, hydro, wind and geothermal. For CSP they include all areas with a suitable slope (gradient below 1%), a suitable land use profile and average direct normal solar irradiation values higher than 6.75 kWh/m²/d. They identify four main locations for parabolic trough power plants and postulate that a first 100 MW plant of this type will go online in Arizona in 2011 and two to four 200 MW plants per year will follow between 2013 and 2019. They take Phoenix, Arizona, as the

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reference location, which has an annual daily average direct normal irradiation (DNI) of 6.9 kWh/m^2 . They further assume a land use of 7 acres/MW (= $28 \text{ km}^2/\text{GW}$). For a parabolic trough plant with 6 h storage they predict a capacity factor of 38.8%.

Similar assessments to the one of Pletka et al. (2007) have been performed for other areas in the US by Dahle et al. (2008), Karstaedt et al. (2005) and Kirby et al. (2003). Broesamle et al. (2001) assess the potential of CSP for North Africa and Trieb et al. (2002) for Morocco. Broesamle et al. (2001) assume a land use of $20 \text{ km}^2/\text{GW}$ installed capacity.

Availability of water is an important criterion for the feasibility of current technology CSP plants, which require water, mainly for cooling purposes in the steam cycle, but also to clean the vast mirror areas. Cohen et al. (1999) present results of the operation and maintenance improvement program for the parabolic trough power plants at Kramer Junction, California. One of the aims of the program was to reduce the water consumption of the plants; the water consumption was reduced from 4.16 m^3 (1100 gallons) to 3.27 m^3 (865 gallons) per MWh as a result of the program. The study also shows that about 94% of the total water use is due to the wet cooling tower. Hence, introducing dry cooling can tremendously reduce the water consumption of such a plant. Also note that the cleaning of the mirrors only takes up around 1.4% of the overall water use.

3. Method

A similar approach is taken as in the publications of Dahle et al. (2008), Karstaedt et al. (2005) and Kirby et al. (2003); first, data for the area of interest is gathered, then, appropriate screens for the GIS analysis are developed and, finally, the sites with potential are identified. The data sets used in the present study are discussed in this section.

Solar radiation data derived from satellite imagery by the United States National Renewable Energy Laboratory (NREL) and the United States National Aeronautics and Space Administration (NASA) can be retrieved from the Solar and Wind Energy Resource Assessment website (SWERA, 2008). The respective spatial resolution is $40 \times 40 \text{ km}$ (NREL) and $80 \times 110 \text{ km}$ (NASA). This study uses the data from NREL, which have an estimated accuracy of 10% (SWERA, 2008). In Fig. 1 maps derived from these data are presented. They show the average daily (DNI) for South Africa for the whole year and for the months of March, June, September and December. Only sites with an annual average daily DNI higher than 7.0 kWh/m^2 are assumed suitable.

Mucina and Rutherford (2004) present shape files of a vegetation map of South Africa. The areas are categorized as “critically endangered”, “endangered”, “vulnerable” and “least threatened”. In the present study, only areas which are categorized as “least threatened” are assumed suitable as potential sites for CSP, as this will make the approval of the environmental impact assessments easier. Fig. 2 shows all the areas of South Africa populated with “least threatened” vegetation. Comparing Fig. 2 to 1 it appears that most of the areas with high solar irradiation are populated with “least threatened” vegetation.

A digital elevation model (DEM) with a 90 m spatial resolution, the Shuttle Radar Topography Mission (SRTM) 90 m DEM, was used to identify the areas with a suitable slope ($< 1\%$). Fig. 3 gives a map of South Africa showing the slope. Nature conservation areas (BGIS, 2008) and other unsuitable land use areas, such as water surfaces, built-up areas, military bases and air ports (CD:SM, 2008), have also been excluded. Transmission data have been obtained from the local utility (ESKOM, 2008).

Out of all the remaining sites, after all the above criteria have been tested, only parcels with an area of at least 2 km^2 are

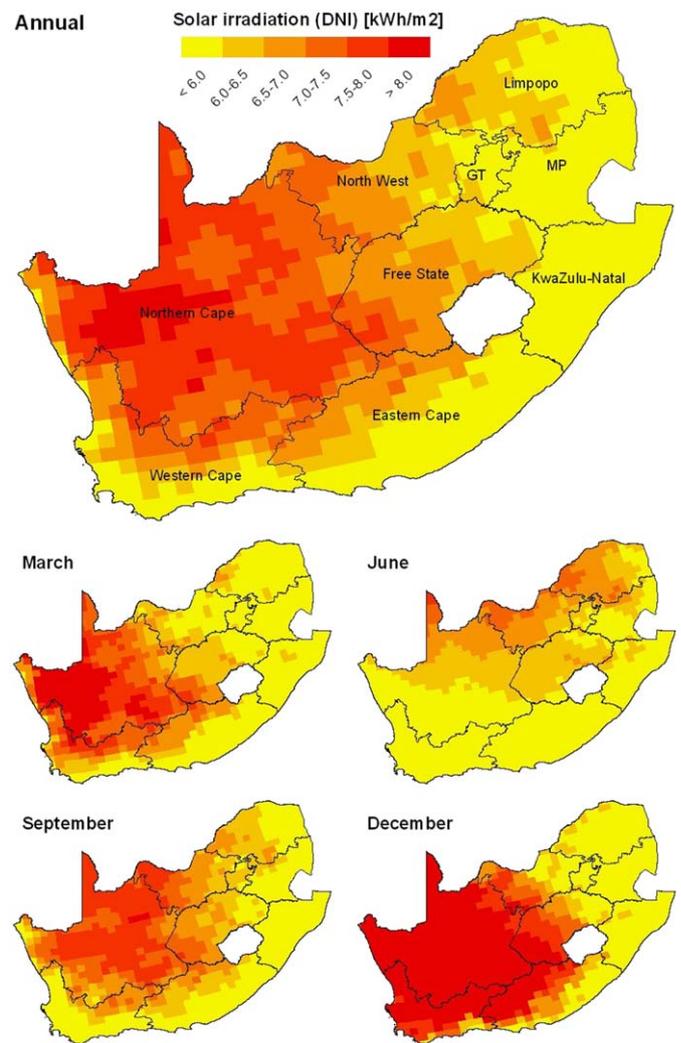


Fig. 1. Maps derived from NREL data showing the average daily direct normal irradiation (DNI) for South Africa for the whole year and for the months of March, June, September and December (GT: Gauteng; MP: Mpumalanga).

assumed suitable in this study. Table 1 compares the screens employed in the present study to the ones of previous publications and shows that the screens employed here are rather conservative.

4. Results and discussion

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 $7.0 \text{ kWh/m}^2/\text{d}$, but in the North West Province these areas are located too far from transmission lines (Fig. 4).

After all the screens have been applied the Northern Cape shows, as expected, the best potential for large-scale CSP in South Africa with a total area of $14,288 \text{ km}^2$ of potential sites, which, assuming a land use of $28 \text{ km}^2/\text{GW}$ (Pletka et al., 2007), translates into a power generation capacity of 510.3 GW (see Tables 2–4). The Free State and the Western Cape also show considerable potential with site areas of 886 and 294 km^2 and power generation capacities of 25.3 and 10.5 GW respectively. The Eastern Cape also has some potential, with suitable areas of

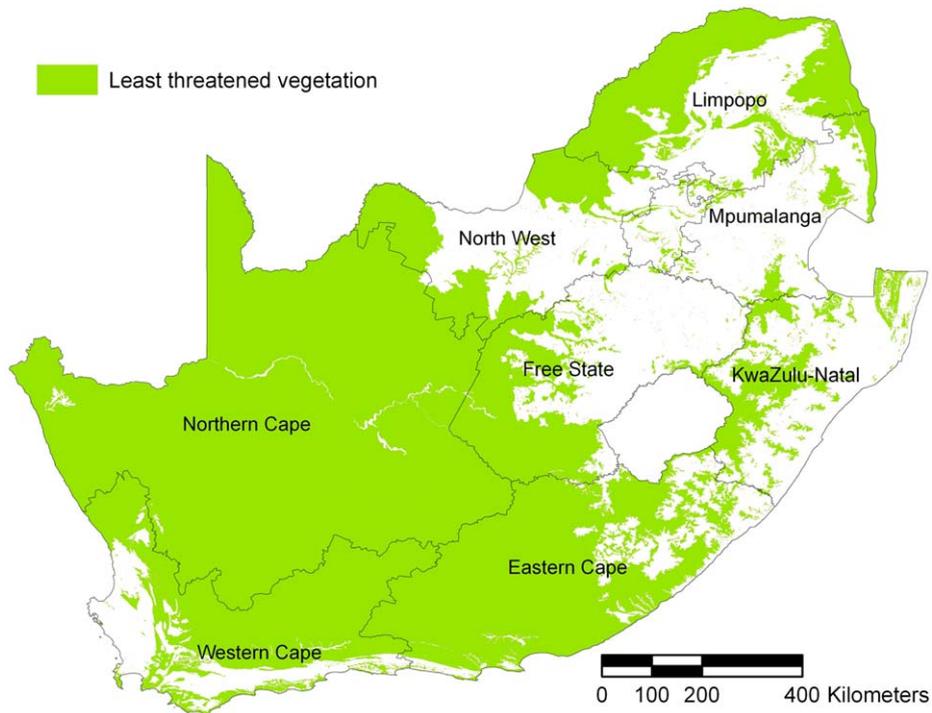


Fig. 2. Map of South Africa showing areas with vegetation categorized as “least threatened”. Source of data: Mucina and Rutherford (2004).

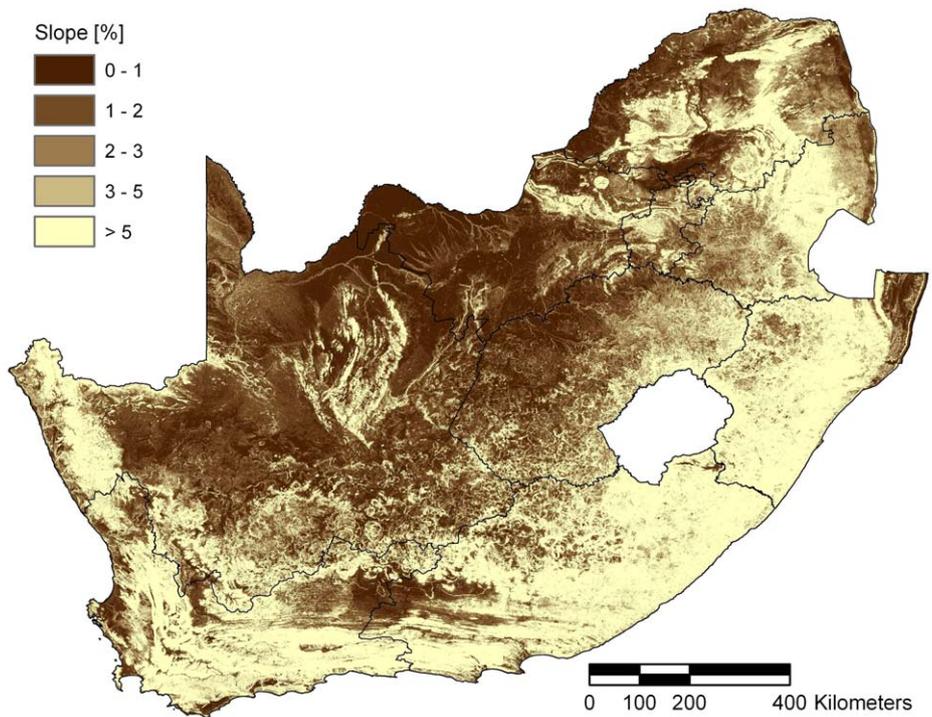


Fig. 3. Map of South Africa showing the land slope derived from a digital elevation model. Source of data: Shuttle Radar Topography Mission (SRTM) 90 m DEM.

Table 1
Screens of the present study compared to previous publications.

	Pletka et al. (2007)	Dahle et al. (2008)	Bravo et al. (2007)	Present study
Slope	<1%	<1%	<7% (SE to SW) <2% (other)	<1%
Proximity to transmission lines	<1 km	<25 miles	Not considered	<20 km
Solar radiation (DNI) (kWh/m ² /d)	>6.5	>6.75	>4.1	>7.0

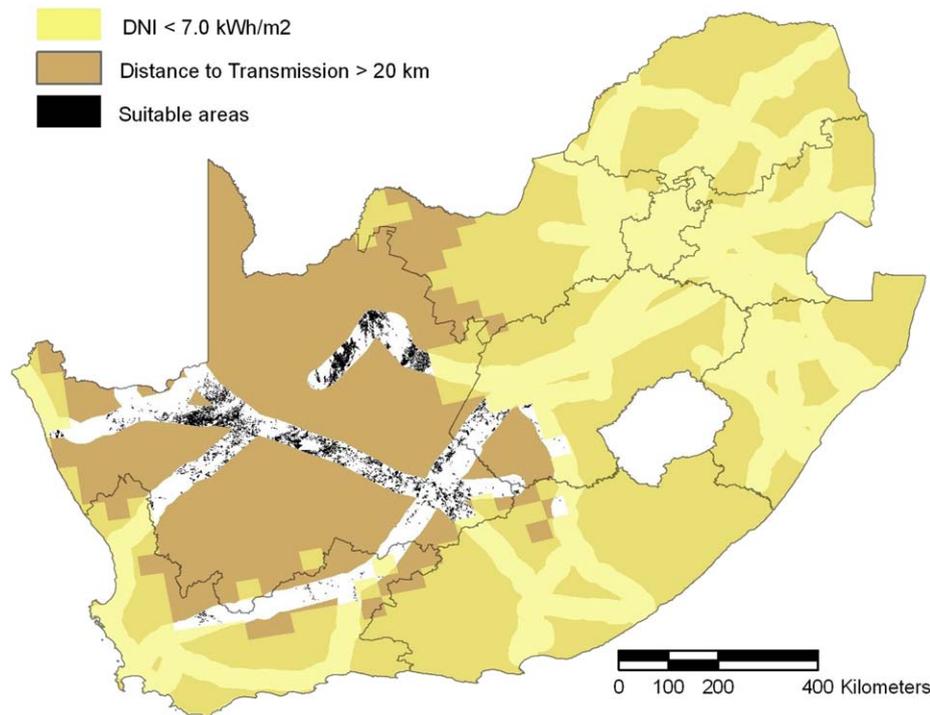


Fig. 4. Map of South Africa indicating areas which are suitable for the installation of large concentrating solar power plants. The screens for proximity to transmission lines and for solar irradiation are also shown. *Source of data: ESKOM (2008) (transmission) and SWERA (2008) (solar resource).*

Table 2

Suitable areas for large-scale CSP in various provinces of South Africa (km²).

	NC		FS		WC		EC	
	<20	<10	<20	<10	<20	<10	<20	<10
Proximity to transmission, km:	<20	<10	<20	<10	<20	<10	<20	<10
Average DNI: 7.0–7.5 kWh/d	2963	1539	694	326	278	132	44	3
7.5–8.0 kWh/d	7291	4095	14	14	16	0	0	0
>8.0 kWh/d	4034	2345	0	0	0	0	0	0

Table 3

Power generation potential for large-scale CSP in various provinces of South Africa (GW).

	NC		FS		WC		EC	
	<20	<10	<20	<10	<20	<10	<20	<10
Proximity to transmission, km:	<20	<10	<20	<10	<20	<10	<20	<10
Average DNI: 7.0–7.5 kWh/d	105.8	55.0	24.8	11.6	9.9	4.7	1.6	0.1
7.5–8.0 kWh/d	260.4	146.3	0.5	0.5	0.6	0	0	0
>8.0 kWh/d	144.1	83.8	0	0	0	0	0	0

44 km² and a power generation capacity of 1.6 GW. The potential capacity for the whole country is 547.6 GW.

The values for the latter three provinces seem small relative to the potential of the Northern Cape, but they are significant, seeing that the total currently installed power generation capacity in South Africa is 39.5 GW. It is important to note, however, that the CSP plants will not run at nominal capacity all year round but with a capacity factor of around 40%, depending on plant configuration and site location. Assuming that all the potential sites would be utilized and that the plants would operate with an average capacity factor of 38.8% (Pletka et al., 2007), a net annual energy

Table 4

Power generation potential, net energy generation and water requirements for large-scale CSP plants in various provinces of South Africa.

	NC	FS	WC	EC	Total
Suitable land area, km ²	14288.0	708.0	294.0	44.0	15334.0
Power generation potential, GW	510.3	25.3	10.5	1.6	547.6
Net energy generation, TWh/a	1734.4	85.9	35.7	5.3	1861.4
Water requirement (wet cooling), million m ³ /a	5671.5	281.0	116.7	17.5	6086.7

Table 5

Potential for development requiring additional water consumption in water management areas with CSP potential (DWAF, 2004).

Water management area	Potential for development (million m ³ /a)
10 Lower vaal	0
13 Upper orange	900
14 Lower orange	150
15 Fish to tsitsikamma	85
16 Gouritz	110
17 Olifants/doring	185

generation of 1861 TWh could be achieved (see Table 4), which is 3.3 to 5.4 times more than the total electricity requirement forecast for South Africa for the year 2025 (NERSA, 2006).

Assuming specific water requirements for these plants of 3.27 m³/MWh in the case of wet cooling Cohen et al., 1999, it can be shown that a tremendous amount of water would be required (see Table 4). The availability of water was not applied as a screen in the present study, due to the lack of detailed data. However, the impact of the availability of water on the implementation of CSP in SA will be discussed here. The National Water Resource Strategy

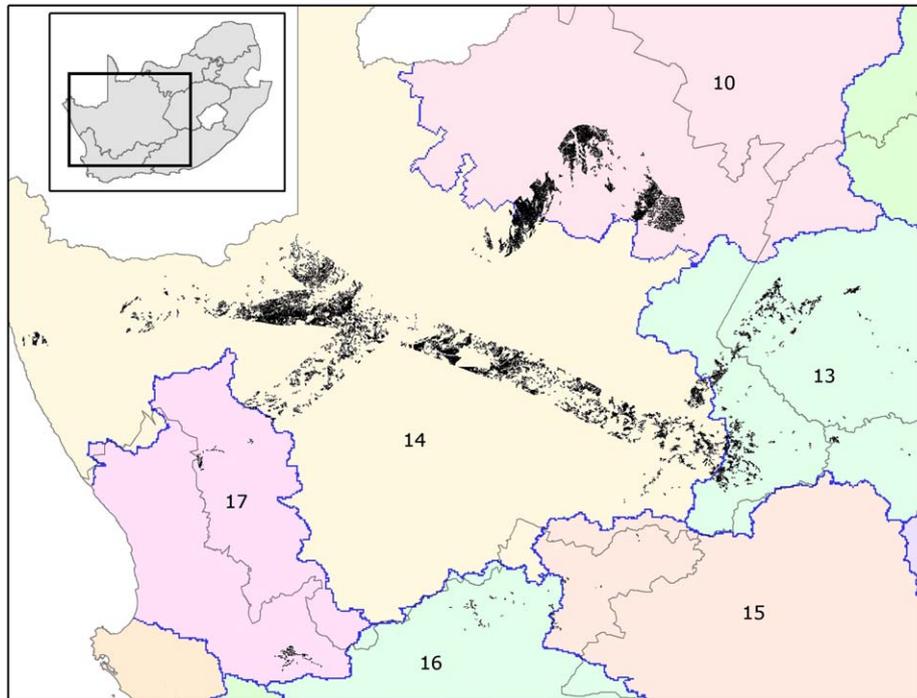


Fig. 5. Map overlaying areas which are suitable for the installation of large concentrating solar power plants on water management areas. Source of data: DWAF (2009).

(NWRS) report (DWAF, 2004) outlines water availability in the various water management areas (WMAs) of South Africa. The potential for future development requiring additional water consumption for the six WMAs relevant to the present study varies between 0 and 900 million m³/a (Table 5). (Fig. 5). Most of the potential CSP sites are located in WMA 14 and WMA 10 (Fig. 5), which have rather little or no potential for future development requiring additional water use. The NWRS provides only a coarse assessment, and availability of water will have to be assessed at each specific site. Nevertheless, it is evident that a multi-GW roll-out of CSP in South Africa will only be feasible if dry or other water-wise cooling methods are implemented. Also, the lack of water in the Northern Cape is likely to push a large portion of the development into other provinces.

5. Conclusions

The relevant data for South Africa have been gathered and implemented in a geographic information systems program. Several maps have been created and potential sites for the implementation of large-scale concentrating solar power plants are identified, taking the following criteria into account: solar resource, proximity to transmission lines, land use profile and slope. The main conclusion of this study is that there is indeed a huge potential for CSP in the country and that the potential sites are not only located in the Northern Cape but also in the Free State, the Western Cape and, to a minor degree, in the Eastern Cape. The total potential CSP generation capacity for South Africa is 547.6 GW. The availability of water in the relevant areas is also discussed, and it is shown that the lack of water in the Northern Cape is likely to push a big portion of a large-scale roll-out of CSP into other provinces.

The present paper presents a high level assessment of the potential of large-scale CSP in South Africa. To draw up a roadmap for the implementation of the technology in this country further studies are necessary; specific sites will have to be assessed in

detail, and the existing technologies will have to be adapted to the local situation.

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References

- Banks, D., Schäffler, J., 2005. The Potential Contribution of Renewable Energy in South Africa. Earthlife Africa, Johannesburg, South Africa.
- BGIS, 2008. National and provincial maps of conservation areas. Biodiversity GIS, South African National Biodiversity Institute, 22 May 2008. Online at <<http://bgis.sanbi.org/mapsearch.asp>>.
- Bravo, J., Casals, X., Pascua, I., 2007. GIS approach to the definition of capacity and generation ceilings of renewable energy technologies. Energy Policy 35, 4879–4892.
- Broesamle, H., Mannstein, H., Schillings, C., Trieb, F., 2001. Assessment of solar electricity potentials in North Africa based on satellite data and a geographic information system. Solar Energy Journal 70, 1–12.
- CD:SM, 2008. Digital topographic information of high resolution (1:50 000 map series). Chief Directorate: Surveys and Mapping, South Africa.
- Cohen, G., Kearney, D., Kolb, G., 1999. Final Report on the Operation and Maintenance Improvement Program for Concentrating Solar Power Plants. Technical Report: SAND99-1290.
- Dahle, D., Elliot, D., Heimiller, D., 2008. Assessing the Potential for Renewable Energy Development on DOE Legacy Management Lands. NREL, Golden, Colorado.
- DWAF, 2004. National Water Resource Strategy, First ed Department: Water Affairs and Forestry, Republic of South Africa.
- DWAF, 2009. Water Management Areas. Department: Water Affairs and Forestry. Online at <<http://www.dwaf.gov.za/BI/Mapshop>>.
- Energy Research Centre, 2007. Long Term Mitigation Scenarios: Technical Report, Prepared by H. Winkler, Department of Environment Affairs and Tourism, Pretoria, South Africa.
- ESKOM, 2008. Private communication with Joan Hartmann on 15th May 2008.
- Karstaedt, R., Dahle, D., Heimiller, D., Nealon, T., 2005. Assessing the Potential for Renewable Energy on National Forest System Lands. US Department of Energy, Oak Ridge, Tennessee.
- Kirby, M., Dahle, D., Heimiller, D., 2003. Assessing the Potential for Renewable Energy on Public Lands. US Department of Energy, Oak Ridge, Tennessee.

- Mucina, L., Rutherford, M.C. (Eds.), 2004. Vegetation Map of South Africa, Lesotho and Swaziland: Shapefiles of Basic Mapping Units. National Botanical Institute, Cape Town (electronic CD release, Beta version 4.0, February 2004).
- NERSA, 2006. Stage 2 Report—Electricity Consumption and Demand Forecast for Development of Third National Integrated Resource Plan for South Africa. National Energy Regulator of South Africa, Online at <<http://www.nersa.org.za>>.
- NERSA, 2009. South Africa Renewable Energy Feed-in Tariff (REFIT) – Regulatory Guidelines. National Energy Regulator of South Africa, Online at <<http://www.nersa.org.za>>.
- Pletka, R., Block, S., Cummer, K., Gilton, K., R., O., Roush, B., Stoddard, L., Tilley, S., Woodward, D., Hunsaker, M., 2007. Arizona Renewable Energy Assessment. Black & Veatch Corporation, Overland Park, Kansas.
- SWERA, 2008. Solar irradiation datasets for the use with geographic information systems. Solar and Wind Energy Resource Assessment, 18 May 2008. Online at <<http://swera.unep.net>>.
- Trieb, F., Quaschnig, V., Schillings, C., Kronshage, S., Brischke, L., Czisch, G., 2002. Potenziale, Standortanalysen, Stromtransport. FVS Themenheft, 36–43.