ROADMAP FOR THE DEPLOYMENT OF CONCENTRATING SOLAR POWER IN SOUTH AFRICA

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Abstract

To identify suitable sites in the Republic of South Africa for short-, medium- and long-term implementation scenarios for concentrating solar power (CSP) plants, geographical information system (GIS) technology was used by the researchers. An area was assumed suitable if it receives a satisfactory amount of annual irradiation; is close enough to suitable transmission substations; the transmission lines feeding these substations adhere to certain criteria; the area is flat enough; there are sustainable water sources close by; and it has a suitable landuse.

For immediate implementation, various sites near substations in the provinces of the Free State-, Northern Cape- and North West- in South Africa were identified. DNI-levels at sites in the Northern Cape, for instance, reached levels of up to 2900 kWh/m^2/a.

In the medium-term, a number of high-voltage transmission line- and substation projects that are currently under development or construction in the Northern Cape will strengthen the energy grid in this province significantly, and will substantially increase the viable CSP-areas. It will further increase the current generation limit of the transmission system in the Northern Cape from 1129 MW to an estimated figure up to 3000 MW.

For long-term planning, several additional areas were identified that are not currently viable. In this scenario it is assumed that low-water consumption technologies, such as the Brayton Cycle Central Receiver, will become commercially viable.

Keywords: CSP, South Africa, DNI, roadmap, solar, GIS.

1. Introduction

When the National Energy Regulator of South Africa (NERSA) announced the implementation of renewable energy feed-in tariffs (REFIT) in March 2009 [1] and again in October 2009 [2], the interest of various renewable energy participants were stimulated. Developers consequently became eager to construct renewable energy power plants, including CSP-plants, in South Africa. For the first time in South Africa’s history, independent power producers (IPPs) became viable - not simply to sell electricity into the grid under the REFIT-programme, but also by means of wheeling (willing buyer-willing seller) agreements.

Developing countries are typically characterised by a midday electricity peak. South Africa is however different in this regard and has a morning and more pronounced evening peak between 18:00 and 21:00; both in summer and winter [3]. This characteristic, along with the country having some of the highest DNI-levels in the world [4][5][6] and a general lack of natural gas as co-firing fuel, makes CSP with storage a very attractive technology to generate electricity on a large scale to supply to the national grid.

In this paper the short-, medium- and long -term implementation scenarios of CSP-plants in South Africa are discussed. The short- term scenario considers sites that are currently viable for CSP, whilst the medium-term scenario examines sites that will become available by 2017 when the necessary and already approved grid expansion projects will be completed. The long-term scenario investigates the effect that waterless CSP-technologies will have on the implementation of CSP in South Africa.

2. Short-term scenario (2011 – 2017)

2.1. Current status of CSP in South Africa

A number of CSP-projects are planned under the first phase of REFIT, in which 1025 MW was allocated to renewable energy [7]. No CSP-project has yet been constructed and no power purchase agreement (PPA) has been awarded. The CSP-projects under development in South Africa include (only projects where the Environmental Impact Assessment (EIA) study and/or ground solar measurements have been commissioned form part of the list) [8]:

- 150 MW, near Pofadder in the Northern Cape by Kaxu CSP;
- 75 MW, near Groblershoop in the Northern Cape by Solafrica Thermal Energy;
- 100 MW, near Kathu in the Northern Cape by Renewable Energy Investments South Africa (REISA)
- 125 MW, near Upington in the Northern Cape by Ilangalethu Solar Power;
- 110 MW, near Upington in the Northern Cape by Khi CSP South Africa;
- 100 MW, near Kimberley in the Northern Cape by Afri-Devo;
- 30 MW, near Daniëlskuil in the Northern Cape by Afri-Devo; and
- 100 MW, near De Aar in the Northern Cape byAfrican Clean Energy Developments, (ACED).

In addition to these plants, Eskom has been in the process of timeously planning a 100 MW Central Receiver with salt storage near Upington in the Northern Cape for more than ten years[8]. This brings the total CSP-projects under development to 890 MW.

2.2. GIS study

2.2.1 Background

In order to assess the CSP potential of South Africa, a study incorporating geographical information system (GIS) technology was conducted. Through the study the researchers identify viable South African locations for CSP-plants, and were able to calculate an estimated total installed capacity for CSP.

2.2.2 Method

A similar approach was taken to that of Fluri [9]. Appropiate screens for a GIS-analysis are defined and applied to gathered data for the area of interest; allowing the identification of potential CSP- sites.

Satellite-derived DNI, obtained from the United States’ National Renewable Energy Laboratory (NREL) is used. The spacial resolution is 40 km by 40 km. Annual sums based on the long-term averages from 1985 to 1991 is used. The data is freely available on the Solar and Wind Energy Resource Assessment (SWERA) website [6], and has an estimated accuracy of 10 % [6]. In figure 1 a map derived from this data is depicted, along with South Africa’s province names. Only sites with an average annual sum of 2400 kWh/m^2 and above are furthermore considered.

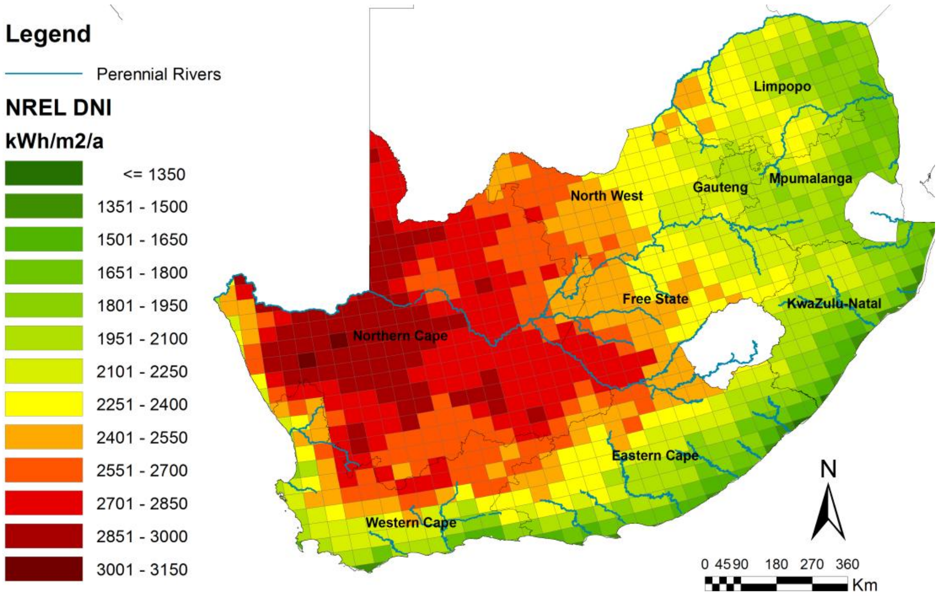

Fig. 1. DNI-map of South Africa, including main perennial rivers.

A digital elevation model (DEM), the Shutter Radar Topography Mission (SRTM) 90 m DEM with a 90 m spatial resolution, was used to identify areas with a suitable slope. Only areas with a slope less than 2° (in any direction) were considered. Developers and technology suppliers consider sites with a slope up to 3° as viable for CSP-plants [10].

Transmission line- and substation data was obtained from the local utility, Eskom [11]. In this study transmission lines are defined as lines with a voltage of 220 kV and above. Only areas within a 30 km radius from transmission substations were considered, as portrayed by figure 2. Substations consisting of only series capacitor banks, and therefore no transformers, were excluded; and substations that have a feed-in capability of 50 MW and above alone were considered. Only substations that are fed by multiple transmission lines (220 kV and above) were furthermore considered. In certain instances, if a 132 kV was present, the site was included.

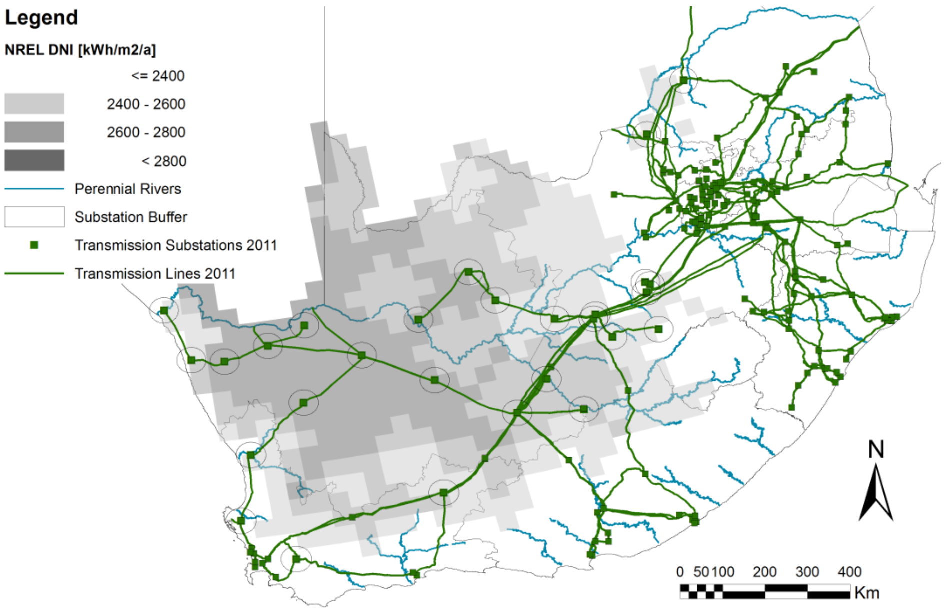

Fig. 2. Transmission network map of South Africa, including areas with annual DNI above 2400 kWh/m^2 and 30 km buffer around substations.

Built-up areas; water bodies and wetlands; mines and quarries; forests; parks and conservation areas were excluded from a suitable CSP-site.

Only areas that are within 20 km from suitable water sources were furthermore considered. For the purposes of the study a suitable water source was defined as selected perennial rivers with a suitable supply of water [12].

After all these criteria were applied, parcels with an area of at least 2 km^2 were considered. In table 1 the criteria of this study is compared to that of Fluri [9]'s previous study. The final result is reflected in figure 3. From this figure, a total area of 14 666 km^2 is considered viable. This relates to 262 GW. CSP-plant land requirements were based on that of parabolic through with seven hours of thermal storage - 56 km^2/GW [13]. Only 51 % of the viable sites (134 GW) are in the Northern Cape due to the low number of viable substations near water resources.

Criteria	Fluri [1]	Present Study
Slope	< 1°	<2°
Grid	<20 km from transmission lines	<30 km from transmission substations
DNI	>2555 kWh/m^2/a (>7 kWh/m^2/d)	>2400 kWh/m^2/a (>6.58 kWh/m^2/d)

Table 1. Criteria comparison

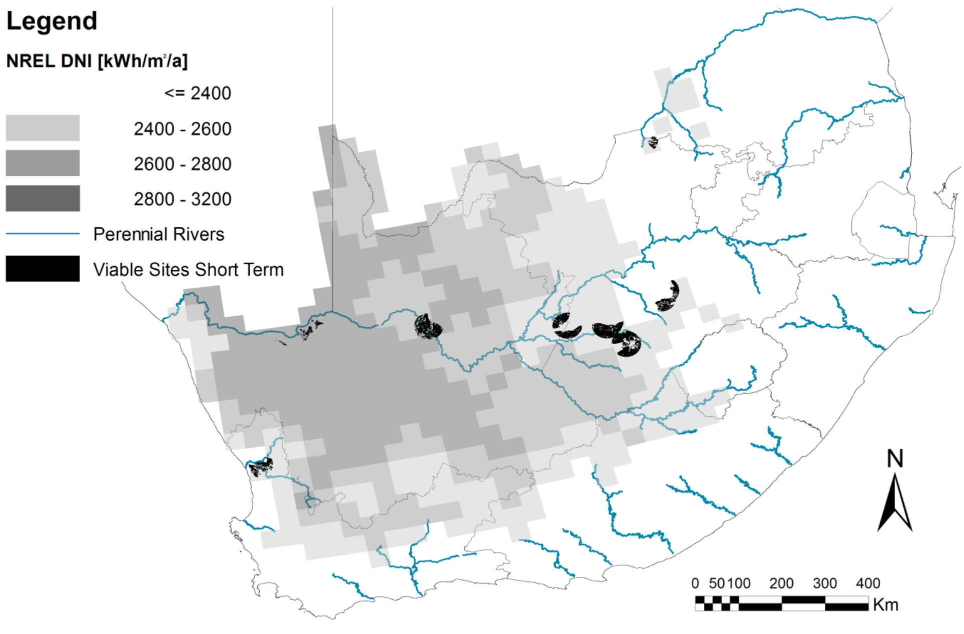

Fig. 3.Viable short-term CSP-sites.

2.3. Current grid

The total capacity for connections on the transmission level that can be fed into the national transmission grid of the North Zone (comprising of the Northern Cape and parts of the Free State) is 1000 MW [14], as indicated by figure 4b. A similar figure for the North Zone on sub-transmission level is 129 MW [14]. The total feed-in capacity of the North Zone is therefore 1129 MW. The potential CSP capacity identified (262 GW) far exceeds this number. In order to increase the feed-in capability, the Northern Cape grid must be strenghened.

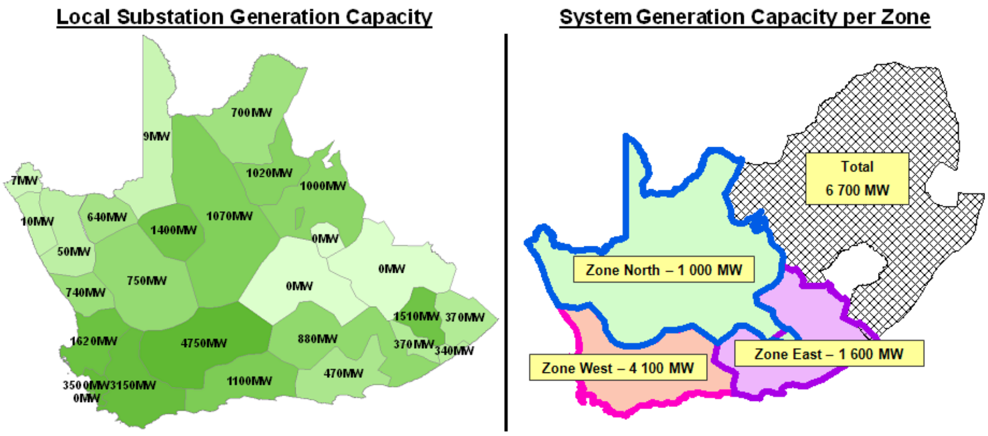

Fig. 4.Feed-in capabilities of a) substation capacity b) Eskom zone capacity [14].

3. Medium- term scenario (2018 – 2025)

3.1. Current grid expansion projects

A number of grid expansion projects are being implemented [15] and estimated to be in operation by between 2013 and 2017. As indicated by figure 5, the projects that are of significance for this study include:

- North-West Strengthening Phase;
- Northern Cape Reinforcement Ferrum–Garona–Nieuwehoop and Sishen-Saldanha traction upgrade; and
- Namaqualand Upgrade.

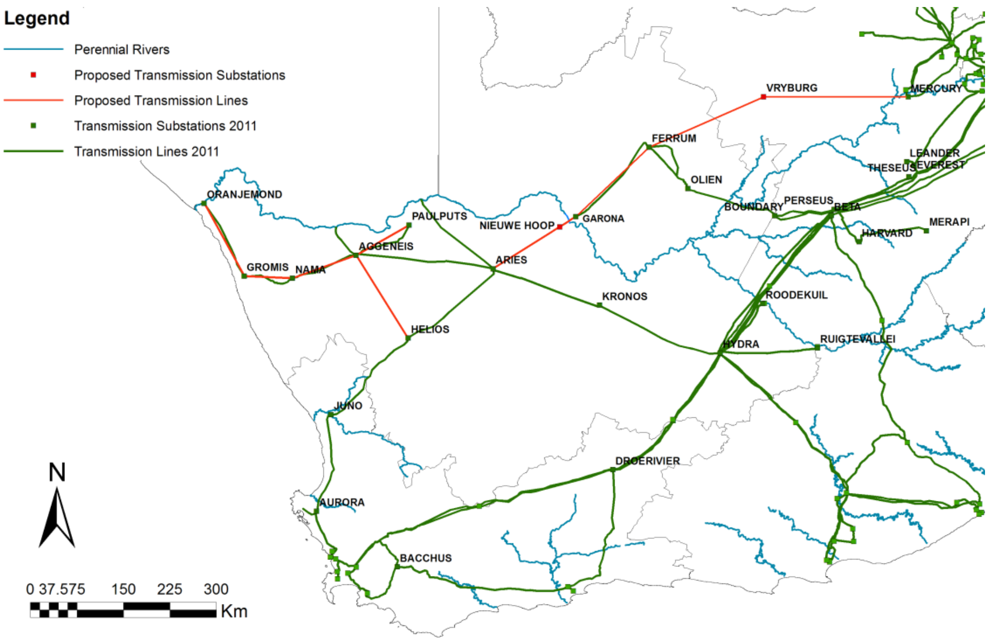

Fig. 5. Grid expansion project in the North Zone (redrawn with data obtained from [15]).

3.1.1 North West Strengthening

This project will significantly increase the amount of power that can be generated in the North Zone and transmitted to the Gauteng province (North East); and will include the contraction of a new substation near Vryburg. The phases of this project include:

- Construct the Ferrum-Vryburg first 400kV line (2013);
- Construct the Mercury-Vryburg first 400kV line (2013); and
- Construct the Vryburg 400/132kV substation (2013).

3.1.2. Northern Cape Reinforcement Ferrum–Garona–Nieuwehoop and Sishen-Saldanha traction upgrade

This project will link with the North West Strengthening project and Ferrum with Aries; and will result in significant upgrading of Garona and a new substation South-East of Upington, called Nieuwehoop. The project will consist of:

- 125 MVA 400/132 kV transformer at Garona (2017);
- Ferrum – Garona 400 kV line (2017);
- Garona – Nieuwehoop 400 kV line (2017); and
- Nieuwehoop – Aries 400 kV line (2017).

3.1.3 Namaqualand Upgrade

This project will significantly strengthen the North-West corner of the country and will result in the increased capabilities of a substation that previously had a low feed-in capability (refer to Fig 4a). This project will consist of:

- Paulputs second 220/132kV 125MVA transformer (2015);
- Aggeneis-Helios 400kV line (2017);
- Aggeneis-Nama-Gromis-Oranjemund second 220kV line (2017); and
- Aggeneis-Paulputs second 220kV line (2017).

3.4. Results of grid expansion projects

The result of the grid strengthening project will be that about 2000 - 3000 MW - significantly more power that can currently be generated in the Northern Cape and transmitted to the large load centres [16]. Figure 6 shows the new CSP locations that become viable due to the planned Eskom expansions. The CSP potential for the Free State does not change. The Northern Cape potential increases with 2625 km^2 (49 GW) to 183 GW (261 GW for the North Zone). One site that is without fresh water supplies but located less than 30 km from the ocean was included. Sea water can be utilised for the condenser and may be desalted for make-up and mirror-cleaning purposes. There is also the possibility that off-shore natural gas may become available on the West coast in the future [17].

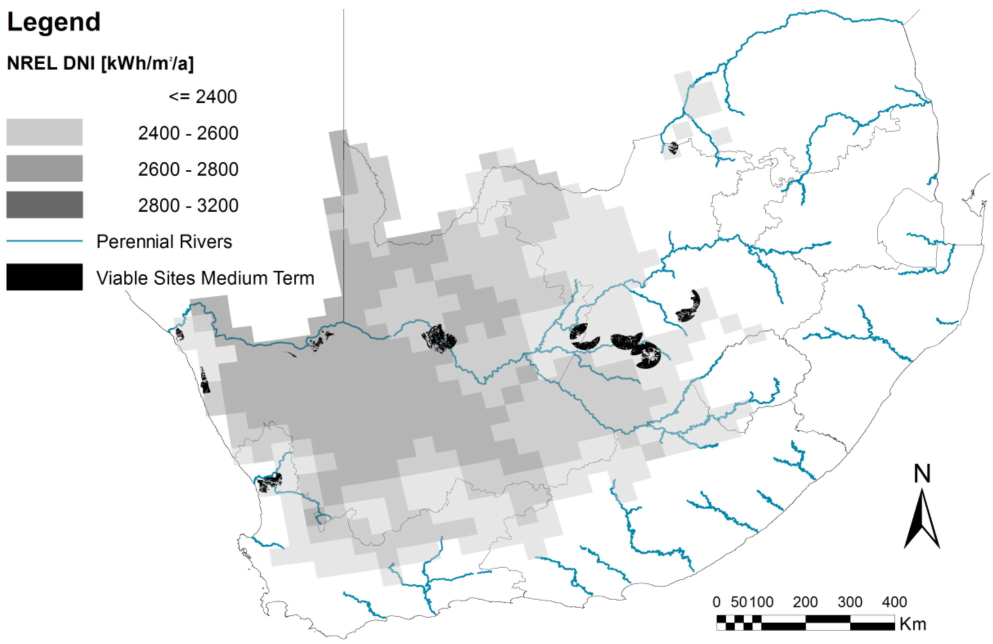

Fig. 6. Viable CSP locations after Eskom grid expansions.

4. Long-term scenario (2026 and beyond)

4.1. Waterless CSP

Most CSP-plants currently rely on the availability of water, which is used mainly for evaporative cooling. Water is used in the steam cycle as make-up water (8 %); for wet cooling (90 %); and for cleaning mirrors (2 %) [18]. If dry (air-cooled) condensers are employed, the water consumption is reduced to about 10 % of the water needs of a wet-cooled plant [19].

Only one CSP-plant has been fitted with a dry air-cooled condenser up to date, namely the 1.4 MW linear Fresnel PE1 plant in Spain [20]. Developers of 33 % of the 5 934 MW of CSP-plant that are under construction worldwide have indicated that they will employ air-cooled condensers [21]. Air-cooled condensers reduce the annual efficiency of a CPS-plant by about 5 % [19]. In the warm, arid areas of South Africa, with high DNI levels, this is not an attractive option, but may still be employed. An alternative is hybrid cooling, which functions primarily as an air-cooled condenser but uses water during midday periods.

Nearly waterless mirror cleaning has been employed on the 1.4 MW PE1-plant. A “robot” that is placed on the mirrors operates with a brush to clean the surfaces [22].

The next generation CSP-plants cycles may be waterless. If a gas turbine (Brayton cycle) is employed rather than a steam turbine (Rankine cycle), the water required for both the make-up water and the condenser becomes absolute. A 100 kW demonstration has been commission in Israel in 2009 [23]. If a waterless mirror-cleaning device can be employed, the water requirement for this type of CSP-plant becomes virtually zero.

4.2. Locations with high DNI

The possibility of a waterless CSP-plant will unlock areas that were previously not viable for CSP-plants, depicted in figure 7.

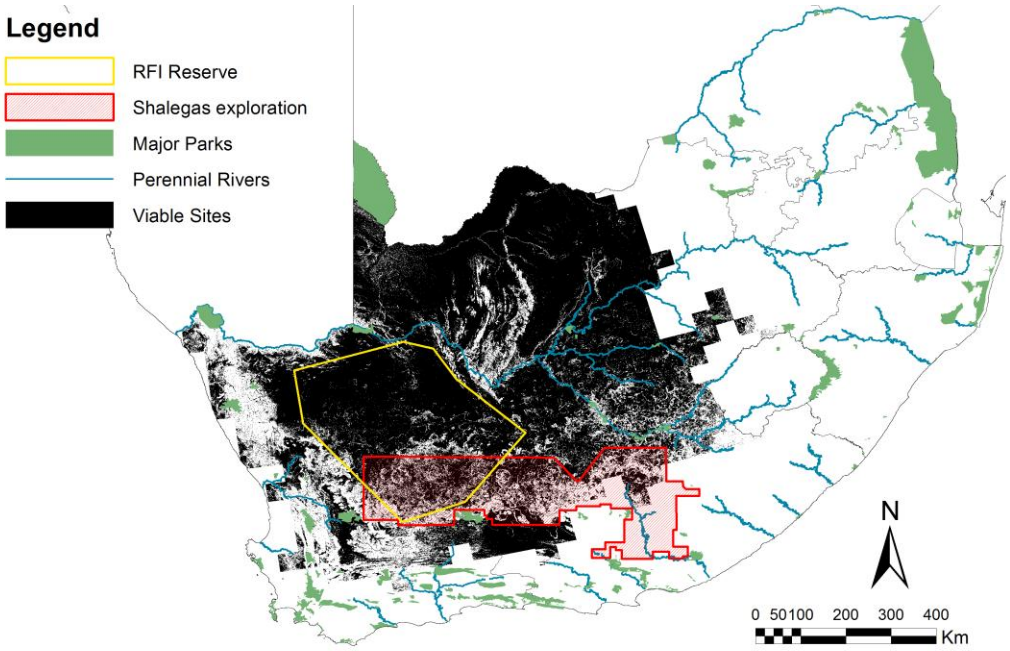

Fig. 7. Viable CSP locations for waterless CSP-plants.

Large parts of the country that currently have a low population density; are viable for waterless CSP-plants. It has been noted that shale gas could in the future be present [24] in areas that overlap with viable CSP locations indicated in figure 7 [25]. If the gas may be produced in an environmentally-accepted method, it will increase the viability of this area for CSP-plants and will guarantee base load capabilities for the long-term replacement of coal.

One possible constraint to the area identified is the implementation of a Radio Frequency Interference (RFI)-free reserve that was promulgated in 2007 in terms of the Astronomy Geographic Advantage Act [26]. This reserve requires low levels of RFI for the KAT7 radio telescope and the construction of the MeerKAT radio telescope and the bid for a larger similar project, the Square Kilometer Array (SKA).

In addition to the area identified in figure 7, a large portion of southern and central Namibia as well as large parts of southern Botswana would also be viable using the same criteria. This may result in the export of large quantities of electricity from these countries to other African countries, including South Africa.

4.3. Strategic grid planning

The area identified in figure 7 will require new grid infrastructure to export the electricity to the load centres that are mainly located in the northern parts of the country. If a viable thermal storage technology can be incorporated with the waterless CSP-technology, the area identified could potentially power the entire Southern Africa.

5. Conclusion and Recommendations

One of the large technical limits for the implementation of CSP plants in South Africa is the weak transmission grid in the areas with high DNI values. The Eskom grid expansion project that was discussed in this paper deserves prioritisation in order to increase the amount of power that can be generated and fed into the grid in the viable CSP areas.

The immediate implementation of CSP under REFIT Phase 1 is an important field that deserves government support. CSP with storage should be encouraged in order to further develop these technologies and to demonstrate that it is able to supply energy efficiently during the evening peak demand. Air-cooled and hybrid condensers should be encouraged in order to minimise the consumption of fresh water; a commodity that is under substantial pressure in South Africa.

Waterless CSP-technologies should be a research focus and strategic grid planning should be made in order to expand the grid to areas that will become viable once this technology is commercially available.

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