energies

Article

Optimising the Concentrating Solar Power Potential in South Africa through an Improved GIS Analysis

Dries. Frank Duvenhage [1,*], Alan C. Brent [1,2], William H.L. Stafford [1,3] and Dean Van Den Heever [4]

1 Engineering Management and Sustainable Systems, Department of Industrial Engineering, the Solar Thermal Energy Research Group and the Centre for Renewable and Sustainable Energy Studies, Stellenbosch University, Stellenbosch 7602, South Africa; alan.brent@vuw.ac.nz (A.C.B.); wstafford@csir.co.za (W.H.L.S.)
2 Sustainable Energy Systems, School of Engineering and Computer Science, Victoria University of Wellington, Wellington 6140, New Zealand
3 Green Economy Solutions, Natural Resources and the Environment, Council for Scientific and Industrial Research, Stellenbosch 7600, South Africa
4 Legal Drone Solutions, Stellenbosch 7600, South Africa; deanvdh@gmail.com
* Correspondence: dfrankduv@gmail.com

Received: 11 May 2020; Accepted: 16 June 2020; Published: 23 June 2020

Abstract: Renewable Energy Technologies are rapidly gaining uptake in South Africa, already having more than 3900 MW operational wind, solar PV, Concentrating Solar Power (CSP) and biogas capacity. CSP has the potential to become a leading Renewable Energy Technology, as it is the only one inherently equipped with the facility for large-scale thermal energy storage for increased dispatchability. There are many studies that aim to determine the potential for CSP development in certain regions or countries. South Africa has a high solar irradiation resource by global standards, but few studies have been carried out to determine the potential for CSP. One such study was conducted in 2009, prior to any CSP plants having been built in South Africa. As part of a broader study to determine the impact of CSP on South Africa's water resources, a geospatial approach was used to optimise this potential based on technological changes and improved spatial data. A tiered approach, using a comprehensive set of criteria to exclude unsuitable areas, was used to allow for the identification of suitable areas, as well as the modelling of electricity generation potential. It was found that there is more than 104 billion m^2 of suitable area, with a total theoretical potential of more than 11,000 TWh electricity generating capacity.

Keywords: concentrating solar power; geographic information systems; potential assessment; renewable energy; solar thermal; South Africa; CSP

1. Introduction

Global interests in CSP is said to grow with 87% by 2021 [1], with South Africa likely to undergo various possible development scenarios [2]. The approach applied in literature for determining potential CSP capacities for a region or country typically follows a generic tiered approach using geographical information systems (GIS) [3]. First, certain spatial zones within a region are removed from consideration based on explicit exclusion criteria, while others are regarded as more suitable based on preferred inclusion criteria. Thereafter, considerations are made for distance to and from required supporting infrastructure, such as the electrical transmission network, roads and water sources. Once these limits have been implemented, suitable zones are then identified within the respective region or country.

Second, the CSP potential of these suitable zones are then calculated based on assumptions regarding Land Use Efficiencies (LUE, %) or Power Densities (km^2/GW). Due to the complex nature of multiple criteria being used, these zones can also be ranked based on certain economic, social or technical criteria, according to a multi-criteria decision-making method, such as an analytical hierarchy process (AHP). An AHP makes use of hierarchal structures to represent a problem and incorporates priority scales based on key criteria to inform decision making [4]. Third, and finally, the potentials for generation are then aggregated and/or ranked according to administrative borders, or some other spatially explicit boundaries of interest. Once this has been done, estimations can be made of the amount of potential energy that can be generated, based on further assumptions regarding plant capacity factor and location-specific conditions. This method is illustrated in Figure 1.

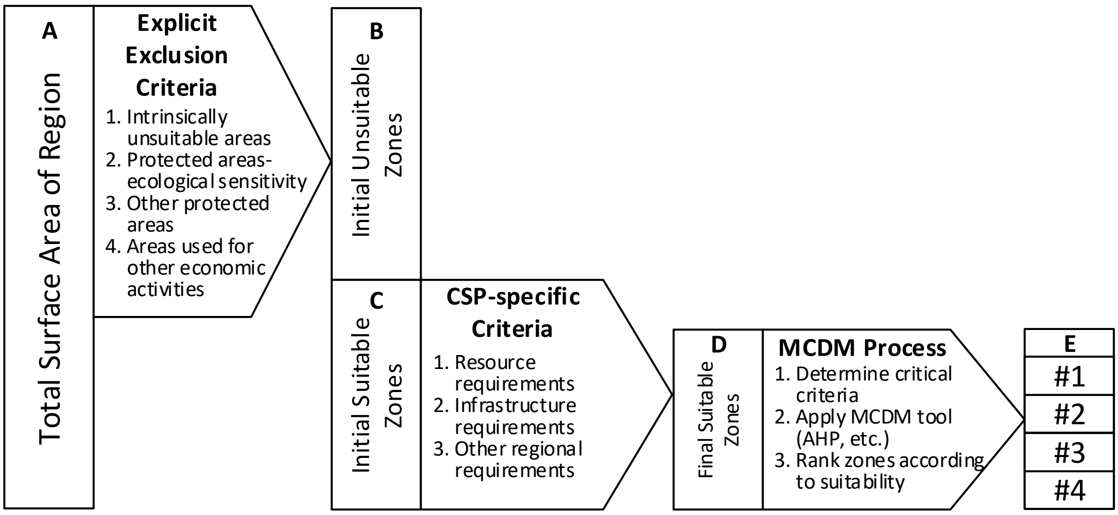


Figure 1. Standard approach for Concentrating Solar Power (CSP) potential studies.

A detailed account of the suitability criteria from various CSP potential studies using the process depicted in Figure 1 is given in [5]. The ranking of suitable zones in step E is optional. Typically, after identifying the final suitable zones in Step D, calculations are done to determine the potential CSP capacity associated with those zones. This, of course, requires that certain assumptions are made regarding the CSP technology; the plant configuration and site-specific solar resource, particularly that of Direct Normal Irradiance (DNI); and meteorological conditions. Finally, as mentioned before, these capacities can be represented as installed power or total annual electricity generated, and are then aggregated according to user-defined discrete borders, such as administrative boundaries of provinces or districts, economic development areas or some other definition of interest.

The aim of this paper is to apply this approach to optimise the theoretical potential of CSP in South Africa, by considering recent technology changes and improved spatial data that is now available.

2. Materials and Methods

Before determining whether a certain area is technically suitable for the development of a CSP plant, all explicitly non-suitable areas are to be excluded. These areas generally constitute "no-go" areas for infrastructure development due to intrinsic unsuitability, or because of a conflict of some sort. In the case of South Africa (SA), these areas can be grouped into intrinsic unsuitability, ecological and economic conflict.

2.1. Exclusion Criteria: Intrinsically Unsuitable Areas

As CSP requires large areas of reflective mirror surfaces, typically unsuitable areas include surface water (rivers and dams) and steep slopes. Rivers can be classified based on how their water flows vary seasonally (class) and what order they are within a catchment (1 to 7). The class can be perennial, non-perennial or dry, while the order refers to how many river-branches have joined upstream of a certain river-segment. For example, if Streams A and B converge to form Stream C, but Streams A and B have no converging streams upstream of them, then Streams A, B and C have orders of 1, 1 and 2, respectively. These two classifications are important when deciding which streams can easily be diverted in large, flat catchments and which cannot. Therefore, streams which adhere to the following classifications have been excluded: (Class = Perennial), AND (Order > = 5). This implies that dry river beds in large flat areas, for example, are considered technically suitable areas, while large perennially flowing rivers with many upstream converging rivers are not. An arbitrary buffer of 5 m was applied to the rivers data file. All dams are excluded, with a 500 m buffer around their polygons. The data files for these exclusion criteria are from the Department of Water and Sanitation of SA, and are available online. Figure 2A shows the rivers and dams.

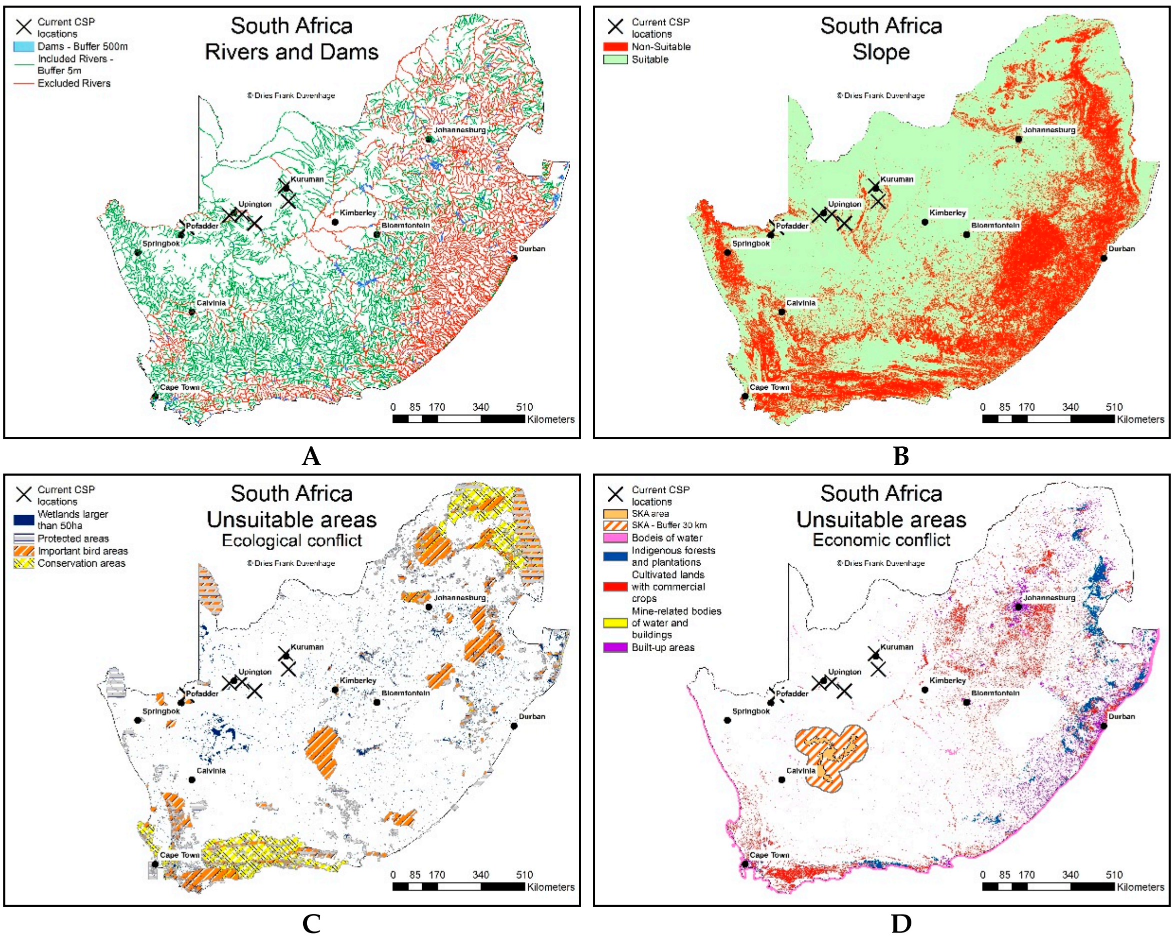


Figure 2. Maps of South Africa showing excluded areas due to (**A**) rivers and dams, (**B**) slope, (**C**) unsuitable areas—ecological conflict and (**D**) unsuitable areas—economic conflict.

The second most critical technical feasibility criterion for a CSP plant is whether it is physically possible to construct the plant on the ground. The major criterion is slope, or the rate of change in vertical altitude over a certain horizontal distance. This can be expressed in degrees or % change in altitude per horizontal distance. The two existing commercial CSP technologies—Parabolic Troughs (PT) and Central Receivers (CR)—are capable of being constructed on surfaces that have a slope of between 1% (0.57°) and 7% (4.00°), relating to a rise of between 1 m and 7 m over a horizontal distance of 100 m [6]. Surfaces with slopes steeper than this range would require intensive civil works and ground preparation to construct the long rows of mirrors required for PT or complicate the construction and layout of the thousands of heliostats used to reflect sunlight onto the receiver mounted on a high tower, in the case of CR. The slope used in this study is 3%, in accordance with the slope found at existing CSP sites in SA, as shown in Table 1, and with the previous study for South Africa [7]. A digital elevation model raster file, showing height above sea level, from the South African Environmental Observation Network, was used, with a spatial resolution of 90 m × 90 m. A slope raster, using the ESRI ArcGIS®® (ESRI, Redlands, CA, USA) Spatial analyst slope toolbox, was generated, shown in Figure 2B.

Table 1. Suitability conditions at existing CSP plants in SA.

CSP Plant Name	CSP + Cooling Type	Location (Decimal Degrees)	DNI (kWh/m^2/y)	Slope (%)	Km to Excl. Water Body	Km to Ecological Conflict Area *	Km to Economic Conflict Area	Km to Tx Liné **
Kaxu and Xina	PTDC	−28.89, 19.59	2927	1.17	<27	<1 (IBA)	<26	<4 (Ex)
Khi Solar One	CRDC	−28.54, 28.08	2922	0.58	<11	<12 (wet)	<8	<4 (Pl)
Kathu Solar Park	PTDC	−27.61, 23.04	2801	0.44	<50	<0.5 (wet)	<7	<9 (Ex)
Bokpoort	PTWC	−28.78, 21.96	2930	2.44	<2	<5 (wet)	<5	<0.4 (Pl)
Illanga	PTDC	−28.49, 21.52	2912	2.44	<12	<0.3 (wet)	<11	<31 (Pl)
This study	NA	NA	>2400	<3.00	5 m	NA	NA	<20

* IBA: important bird areas, wet: Wetalnds; ** Ex: Existing Tx lines, Pl: Planned Tx lines.

2.2. Exclusion Criteria: Unsuitable Areas due to Ecological Conflict

Regarding CSP development, the same basic ecological exclusion criteria apply as to any large infrastructure project. In SA, the following national areas are always considered "no-go" areas: important bird and biodiversity areas, conservation areas, protected areas and wetlands.

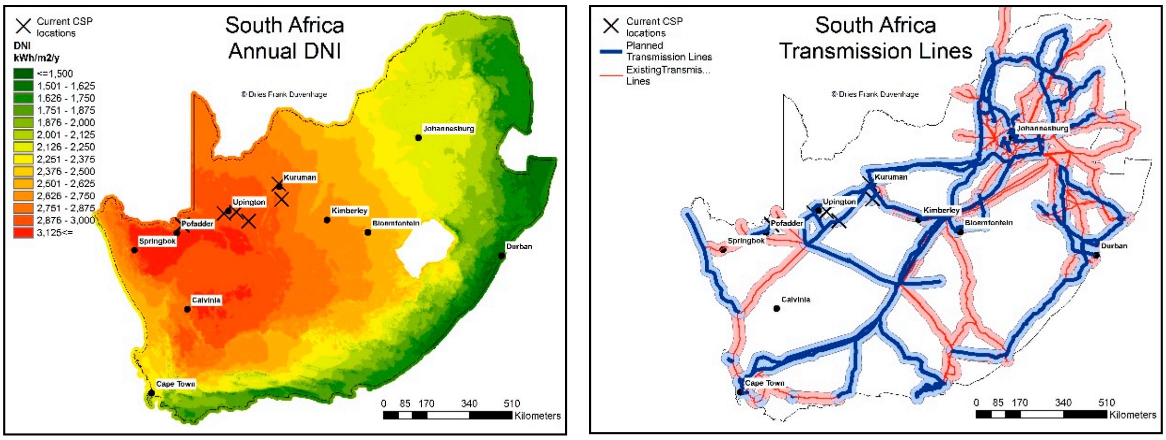
Conservation and protected areas are determined by the national Department of Environmental Affairs under the Protected Areas Act of 2003. These databases contain areas under formal legislative protection, of which the legal statuses of these areas are audited against official gazettes before inclusion. The inclusion of certain areas into the database is governed by the relevant environmental conventions of the Act and is updated at quarterly intervals. The types of areas considered as conservation or protected include biosphere reserves, botanical gardens, wetlands, forest nature reserves, forest wilderness areas, marine protected areas, mountain catchments, national parks, nature reserves, protected and special nature reserves and world heritage sites. For wetlands, only those larger than 0.5 km^2 were excluded. Important bird areas (IBA), compiled by Birdlife South Africa, are objectively determined using globally accepted criteria. An IBA is selected based on the presence of the following bird categories: bird species of global or regional conservation concern, assemblages of restricted range bird species, assemblages of biome-restricted bird species and concentrations of congregatory bird species [8]. These unsuitable areas are shown in Figure 2C.

2.3. Exclusion Criteria: Unsuitable Areas due to Economic Conflict

Another basis on which any new large-scale infrastructure development can be excluded from consideration in a particular area is the likely conflict with existing economic activities. In SA, agriculture uses a significant portion of land to support many people's livelihoods and contribute to the economy. In order to determine which areas are not suited to CSP plants because of a conflicting economic activity, the 72-class 2013–2014 South African National Land-Cover Dataset was used, which is a 30 × 30 m raster for the entire SA. This dataset was compiled by Geoterraimage for the Department of Environmental Affairs [9] Since the list of excluded classes totals 59, only a brief overview of these shall be given, and readers are invited to review the relevant document, available online, for more detail. Naturally, areas classified as bodies of water were excluded (class 1–2). Indigenous forests were also excluded since special environmental permits are required to clear these for infrastructure developments (class 4). Cultivated lands with commercial annual rainfed and irrigated crops, commercial permanent crops, and commercial sugarcane crops were excluded due to their high economic value (classes 10, 11, 13–17, 19, 20, 22, 26–31). All forest plantations were excluded (classes 32–34), as well as mine-related bodies of water and buildings (classes 37–39). Finally, all built-up areas were excluded due to conflict with human settlements (classes 42–72). Another type of area excluded from consideration is the area dedicated to the construction and development of the Square Kilometer Array (SKA). This is an international project to build the world's largest radio telescope, with eventually over a million square meters of collecting area. The area within SA which has formally been dedicated to the SKA, is located in the Northern Cape Province, and is shown in Figure 2D, along with the other excluded areas from the land cover dataset. This area includes a buffer of 30 km for electrical infrastructure with a rating of greater than 100 kVA, to prevent interference with the sensitive radio telescope equipment [10].

2.4. CSP-Specific Suitability Criteria: DNI

The most critical suitability criterion for the determination of CSP potential is Direct Normal Irradiance (DNI), measured in kWh/m^2 per time period (day, month or year). This is the amount of direct irradiance incident on a surface normal to the direction of the sunrays. The amount of DNI which reaches the earth's surface is influenced by the relative position of the earth to the sun (season and time of day), position on the surface of the earth (elevation, latitude and longitude) and atmospheric conditions (aerosols, dust, water vapour and most importantly clouds) [11]. As DNI is the primary energy source for a CSP plant, it is the major determining factor of a plant's techno-economic feasibility. For this reason, the general consensus is that the minimum required DNI is between 1800 and 2000 kWh/m^2/y, with increases in DNI directly related to reductions in cost of generated electricity [12]. The threshold DNI employed in any CSP potential study is relative to the average DNI in the study area. The inclusion of areas with lower DNI, even though it might be equal to or larger than 1800 kWh/m^2/y, will only result in the consideration of areas that are less favourable than others. SA has a minimum, average and maximum DNI of 1290 kWh/m^2/y, 2397 kWh/m^2/y and 3141 kWh/m^2/y, respectively. The annual DNI data source used in this study is from SolarGIS ®®, and is a raster file with a spatial resolution of 30 arc-seconds, shown in Figure 3A [13]. Based on the high average DNI of SA, the DNI threshold selected in this study is 2400 kWh/m^2/y, as opposed to the minimum of 2000 kWh/m^2/y used in other study areas with substantially lower average DNI.



A **B**

Figure 3. Maps of South Africa showing CSP-related suitability criteria (**A**) Direct Normal Irradiance (DNI) and (**B**) transmission network.

2.5. CSP-Specific Suitability Criteria: Distance to Required Infrastructure

Theoretically, CSP infrastructure only requires suitable land and high DNI to be feasible. However, for this infrastructure to be economically and logistically practical, it must be located near adequate transport, transmission and water supply infrastructure. In fact, water is the only other natural resource on which CSP depends [3]. The co-location of theoretically suitable areas and artificial infrastructure can be directly due to the development of the CSP infrastructure, or due to independent, existing infrastructure expansion plans. In the case of the former, the costs associated with these infrastructure developments must be added to those of the CSP plant, but not necessarily in the case of the latter.

The same distance to transmission (Tx) infrastructure will be used as in [7], namely less than, or equal to, 20 km. The use of 20 km as the limit for distance to transmission infrastructure is to ensure continuity with previous the study done for CSP potential in South Africa. Ultimately, the selection of this limit should be based on careful techno-economic modelling of the selected CSP technology configuration's performance at a particular location, and its resulting profit (a function of performance and power purchase tariffs) and weighed against the cost of transmission network connection. These considerations are, however, beyond the scope of this study. This study does, however, expand on these criteria by comparing it to that of actual CSP plants built in South Africa (Table 1), and by the inclusion of Planned transmission lines, as indicated by the national, fully vertically integrated electricity supplier, Eskom.

This study did not include consideration for transport infrastructure, as dirt roads are a low-cost option for accessing highly suitable areas. Furthermore, no consideration has been given to proximity to water infrastructure, as was the case in [7], and is not included here, although it is the focus of further research efforts [14]. This work includes new planned Tx lines in its analysis to explore likely future CSP potential in these areas. The transmission network in SA can be seen in Figure 3B, acquired from the national utility, Eskom.

2.6. Suitability Conditions at Existing CSP Plants in SA

To align the assumptions used in this work with the actual conditions at existing CSP plants in SA, the available GIS datasets were used to evaluate the locations of these plants. The results are summarized in Table 1 for PT with wet cooling (PTWC) and dry-cooling (PTDC), and CR with wet-cooling (CRWC) and dry-cooling (CRDC).

The DNI at all locations of existing operational CSP plants in South Africa is above 2800 kWh/m^2/y, compared to the generally accepted minimum of 2000 kWh/m^2/y. The slope at these sites varies between 0.4% and 2.5%, therefore the use of a maximum acceptable slope of 3% in this study. Generally, the sites are located relatively far from economic exclusion areas. It is apparent that the sites are also mostly near to high-voltage Tx lines, and that some of the plants have been built near to those considered "under planning", indicating that these lines might already have existing by the time the plants were connected to the grid.

3. Results

The final aim of the greater project, which this work forms part of, is to model monthly CSP operation and water consumption across large geographical areas. To simplify this, SA was divided into a 1 × 1 km grid. Blocks within the grid were then excluded if more than 50% of their area (0.5 km^2) intersected with any of the explicit shapefiles of the various exclusion criteria. The exclusion reason(s) for a certain block was recorded as attribute data in that block. The result was a grid leaving only suitable blocks, either located near Existing or Planned Tx lines, shown in Figure 4A,B, respectively. Thereafter, the DNI values intersecting with these suitable areas were stored as attribute data in each block.

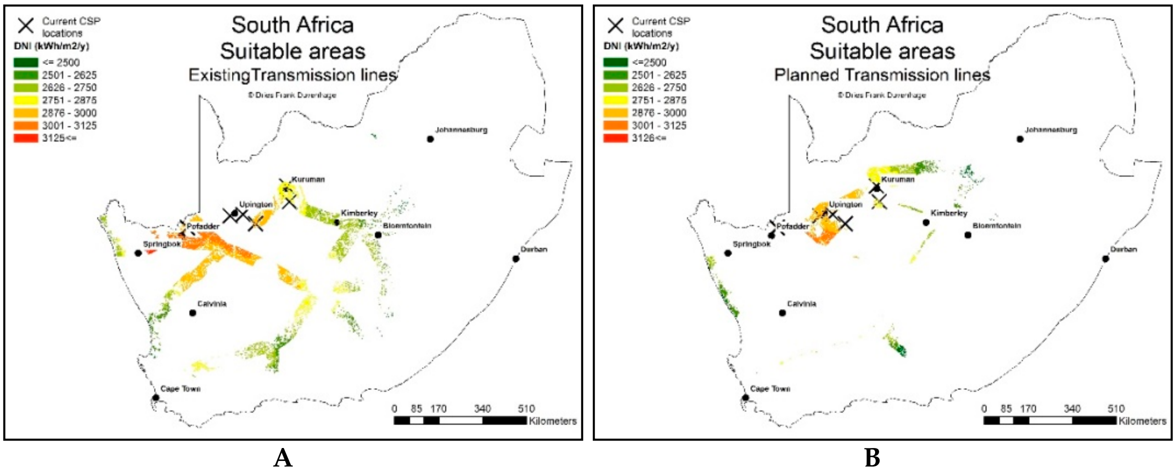


Figure 4. Maps of South Africa showing suitable areas near (**A**) existing Tx lines and (**B**) planned Tx lines.

CSP Potential Modelling

The potential amount of electrical energy generated from a CSP plant in a specific location depends on the CSP technology configuration in use and the solar resources at that location. The CSP technology configuration used depends greatly on the business model used to generate profit, the tariff structure and various financially driven criteria. However, to determine the theoretical potential at a location, certain high-level assumptions can be made based on the fundamental energy conversions taking place in a CSP plant, and these assumptions can be used to estimate the amount of electricity, in GWh, a CSP plant can generate, based on knowledge of the prospective location's DNI. A common approach is using efficiencies for the energy conversions in a CSP plant. This process was explained in detail, with relevant equations and assumptions, in [5]. For clarity, the governing equations are given in Equation (1).

$$Q_{ELNET} = LUF \times N_{SE} \times DNI \times A, \tag{1}$$

Q_{ELNET} represents the net electrical energy (GWh) that is generated, based on the Land Use Factor (***LUF***) and area (***A***). ***LUF*** refers to the ratio between total footprint and solar field area. The assumptions used in this work, to calculate total annual generation potential, are given in Table 2. The Solar-to-electric efficiency (STE) values were determined by modelling the annual operation of a 50 MW PTWC, PTDC, CRWC and CRDC plant, with 9 h of storage at the locations of the five existing CSP plants in SA [15]. A storage capacity of 9 h was arbitrarily selected based on the maximum storage capacity of an operational CSP plant in South Africa (Bokpoort). This value has minimal effect on the annual STE of a CSP plant. Furthermore, if a simplified STE is used to calculate electrical energy generation potential, the thermal storage required can be calculated if a specific installed generation capacity is specified. The annual average STE depends greatly on seasonal variations in DNI, solar geometry and atmospheric conditions (temperature and relative humidity). Monthly simulations were therefore carried out at each of the locations identified and summed over a period of 12 months to determine annual results, as explained in detail in [15].

Table 2. Efficiency assumptions used.

Parameter Description	Symbol	Unit	PTWC	PTDC	CRWC	CRDC
Land Use Factor	*LUF*	%	28	28	23	23

4. Conclusions

This paper applied a standard approach to optimise the theoretical potential of CSP in South Africa and showed how recent technology changes and improved spatial data need to be considered for a comprehensive analysis. An expanded version of Equation 1 was used to calculate the monthly generation potential from the four different CSP and cooling technology configurations for each block in the suitable areas grid. This study calculated the potential for both PT and CR CSP technologies, as well as in combination with wet- or dry-cooling, to reflect the impact that such design decisions will have. In Figure 5, the annual generation potential in GWh per 1 × 1 km block is shown for the wet-cooled options for PT and CR, near existing and planned Tx lines, respectively. The total suitable area identified is 104,709 km^2, which is less than 9% of the total SA surface area.

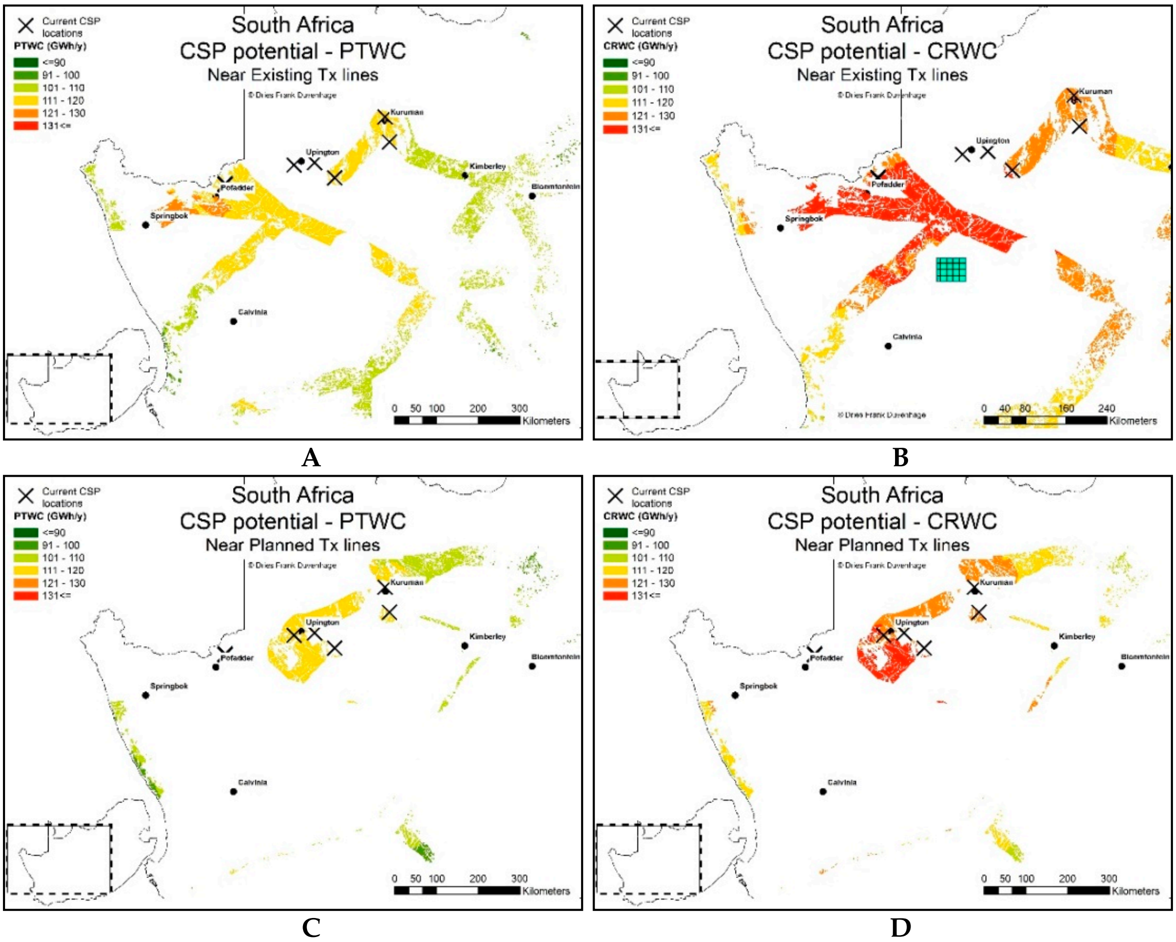


Figure 5. Maps of South Africa showing Annual generation potential from CSP: (**A**) PT with wet cooling (PTWC) near existing Tx lines, (**B**) CR with wet-cooling (CRWC) near existing Tx lines, (**C**) PTWC near planned Tx lines and (**D**) CRWC near planned Tx lines.

The higher efficiency of CR plants results in the generally higher annual electricity generation reflected in the colour scale. The quantitative results are given in Table 3. The annual generation potential from CSP at all suitable locations identified in this study exceeds the national annual demand for electricity in South Africa by between 4.768% and 5.184%. In fact, it would require less than 2400 km^2, or 0.2% of the total SA surface area (2% of the identified suitable areas) with the highest DNI, covered with the least efficient PTDC configuration to generate the annual electricity demand of 231.5 TWh for 2018 [16]. This surface area is shown in Figure 5B, for spatial reference, and depends on the DNI of the locations selected, but serves as a general indication of relative size.

Table 3. Summary of CSP potential results in identified suitable areas.

Transmission Line	Area (km^2)	PTWC (TWh/y)	PTDC (TWh/y)	CRWC (TWh/y)	CRDC (TWh/y)
Existing	71,457	7695	7532	8191	8069
Planned	33,252	3581	3505	3811	3754
Total	104,709	11,276	11,037	12,002	11,823
% SA Total *	8.59%	4.87%	4.77%	5.11%	5.18%

* SA area: 1,221,037 km^2. SA 2018 electricity demand: 231.5 TWh, [16].

To put this into perspective, the total amount of electricity generated from all RETs in South Africa in 2018 was 10.483 TWh, less than 4.53% of the 2018 annual electricity demand [17]. The major advantage of CSP, in comparison to PV and wind without storage, is that it is inherently capable of large-scale storage for dispatchable generation. This is a critical benefit over these RETs, as the energy generated from CSP can coincide with the times of day when it is needed from the grid, not only when the resource is available, as is the case for PV and wind. However, in light of the recent decline in battery storage costs (−85% compared to 2010 values), and cost of generation from PV and wind (−85% and −49% compared to 2010 values, respectively), a more detailed economic evaluation of CSP generation potential in SA is needed to fairly compare it with other RET and storage options [18].

However, the value that CSP can hold for longer duration energy storage and dispatch in countries with high DNI generation potential, like that pointed out in this study for South Africa, should be included in planning models. This is of particular importance when planning the replacement of fossil-fuel based dispatchable energy (coal, diesel and natural gas) in the electricity supply mix, and to assist in transitioning to a cleaner energy mix dominated by renewables.

Author Contributions: All authors have read and agree to the published version of the manuscript. Conceptualization, D.F.D.; methodology, D.F.D.; software, D.V.D.H.; validation, D.F.D.; formal analysis, D.F.D.; investigation, D.F.D.; data curation, D.V.D.H.; writing—original draft preparation, D.F.D.; writing—review and editing, A.C.B. and W.H.L.S.; visualization, D.F.D.; supervision, A.C.B. and W.H.L.S. project administration, A.C.B.

Funding: This research received no external funding.

Acknowledgments: This work was partially funded by Stellenbosch University's Solar Thermal Energy Research Group and Industrial Engineering Department. Thanks go out to the various data sources, as referenced. All glory to God.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. IEA. *World Energy Outlook 2018*; IEA: Paris, France, 2018. Available online: https://www.iea.org/reports/world-energy-outlook-2018 (accessed on 18 March 2019).
2. Duvenhage, D.F.; Craig, O.O.; Brent, A.C.; Stafford, W.H.L. Future CSP in South Africa—A review of generation mix models, their assumptions, methods, results and implications. *AIP Conf. Proc.* **2018**, *2033*, 120002. [CrossRef]
3. Duvenhage, D.F.; Brent, A.C.; Stafford, W.H.L. The need to strategically manage CSP fleet development and water resources: A structured review and way forward. *Renew. Energy* **2019**, *132*, 813–825. [CrossRef]
4. Ziuku, S.; Seyitini, L.; Mapurisa, B.; Chikodzi, D.; Van Kuijk, K. Potential of Concentrated Solar Power (CSP) in Zimbabwe. *Energy Sustain. Dev.* **2014**, *23*, 220–227. [CrossRef]
5. Duvenhage, D.F.; Brent, A.C.; Stafford, W.H.L.; Craig, O.O. Water And CSP—A Preliminary Methodology for Strategic Water Demand Assessment. *AIP Conf. Proc.* **2019**, *2126*, 220002. [CrossRef]
6. Ramdé, E.W.; Azoumah, Y.; Brew-Hammond, A.; Rungundu, A.; Tapsoba, G. Site Ranking and Potential Assessment for Concentrating Solar Power in West Africa. *Nat. Resour.* **2013**, *04*, 146–153. [CrossRef]
7. Fluri, T.P. The potential of concentrating solar power in South Africa. *Energy Policy* **2009**, *37*, 5075–5080. [CrossRef]
8. Marnewick, M.; Retief, E.; Theron, N.; Wright, D.; Anderson, T. BirdLife South Africa. Important Bird and Biodiversity Areas of South Africa: Johannesburg, South Africa, 2015.

9. GEOTERRAIMAGE. *2013–2014 South African National Land Land-Cover Dataset*; GEOTERRAIMAGE: Pretoria, South Africa, 2015; Volume 2.
10. Government Gazette. *Regulations On The Protection Of The Karoo Central Astronomy Advantage Areas in Terms Of The Astronomy Geographic Advantage Act, 2007*; Government Gazette: Pretoria, South Africa, 2017; pp. 171–226.
11. Sengupta, M.; Habte, A.; Kurtz, S.; Dobos, A.; Wilbert, S.; Lorenz, E.; Stoffel, T.; Renné, D.; Gueymard, C.; Myers, D.; et al. *Best Practices Handbook for the Collection and Use of Solar Resource Data for Solar Energy Applications*; NREL/TP-5D00-63112; NREL: Golden, CO, USA, 2015.
12. Kearney, A.T. ESTELA Solar Thermal Electricity 2025. Available online: https://www.estelasolar.org/portfolio_page/solar-thermal-electricity-2025/ (accessed on 12 November 2018).
13. SolarGIS Solar Resource Maps of South Africa. Available online: https://solargis.com/maps-and-gis-data/download/south-africa (accessed on 22 March 2018).
14. Duvenhage, D.F.; Brent, A.C.; Stafford, W.H.L.; Grobbelaar, S. Water and CSP—Linking CSP water demand models and national hydrology data to sustainably manage CSP development and water resources in arid regions. *Sustainability* **2020**, *12*, 3373. [CrossRef]
15. Duvenhage, D.F. Sustainable Future CSP Fleet Deployment in South Africa: A Hydrological Approach to Strategic Management. Ph.D.Thesis, Stellenbosch University, Stellenbosch, South Africa, 2019. Ph.D.Thesis, Stellenbosch University, Stellenbosch, South Africa, 2019.
16. *Statistics South Africa, Electricity Generated and Available for Distribution (Preliminary)*; Statistics South Africa: Pretoria, South Africa, 2019.
17. IPP Office. *Independent Power Producers Procurement Programme An Overview December 2018*; IPP Office: Pretoria, South Africa, 2018.
18. Bloomberg New Energy Finance. *New Energy Outlook*. 2019. Available online: https://about.bnef.com/new-energy-outlook/#toc-download (accessed on 21 January 2020).