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Agrivoltaic Systems: Potential Opportunities for South Africa

A GIS Analysis

Alan C. Brent[1,2][https://orcid.org/0000-0003-3769-4512], Nicholas Chapman[2][https://orcid.org/0009-0001-8219-1351], and Imke H de Kock[2][https://orcid.org/0000-0003-4136-7418]

[1] Victoria University of Wellington, Aotearoa New Zealand

[2] Stellenbosch University, South Africa

Abstract. South Africa has seen a drastic uptake of solar photovoltaic (PV) systems with an increasing number of solar farms over the last decade. From an available land perspective, there is also much potential to significantly expand the generation capacity, when compared to the rest of the world. More than 80% of the land area has a solar resource greater than 1600 kWh/m^2/yr. Over 79% of the land is used for agricultural purposes, yet only 22.5% of the installed PV capacity is in the agricultural sector. This highlights the potential of dual land usage with agrivoltaic systems. This paper investigates the opportunities to develop such systems by considering agricultural production in South Africa that may be suitable – to pave the way forward for the implementation of appropriate agrivoltaic systems in the country. A Geographic Information System (GIS) analysis was undertaken, considering the solar resource and land with a slope of less than 2 degree – to minimise construction costs. Current large-scale solar projects in South Africa indicate that at least 0.6 GWh of electricity can be generated annually per hectare. The current total capacity (of all sources) generated around 237 TWh of electricity in 2022. To generate an equal amount of electricity with agrivoltaic systems would then (roughly) require less than 400 thousand hectares of agricultural land; or less than 2% of the available land suitable for agrivoltaic systems (depending on the designed panel density). Further site-specific techno-economic analyses are underway to provide greater insight into the potential opportunities for South Africa.

Keywords: Agrivoltaics, Geographic Information System, Grazing, Maize, Fruit.

1. Introduction

The solar resource of South Africa is exceptional (see Figure 1). Except for parts of the coast and mountainous areas, more than 80% of the country has a resource above 1600 kWh/m^2/yr. The potential for electricity generation with utility-scale solar photovoltaic (PV) systems is therefore also enormous; more than 1600 kWh/kW$_p$ installed. Currently the country has an installed capacity of 2.3 GW [1], mainly driven by the Renewable Energy Independent Power Producer Programme [2], generating in the order of 16.2 TWh of electricity per year [1].

A major challenge for the country is that the current electricity generation capacity is insufficient to meet the demand, which has led to consistent controlled outages – called load shedding – since 2007 to maintain the grid [3]. The need for additional infrastructure has also meant significant increases in electricity prices since 2008 (see Figure 2).

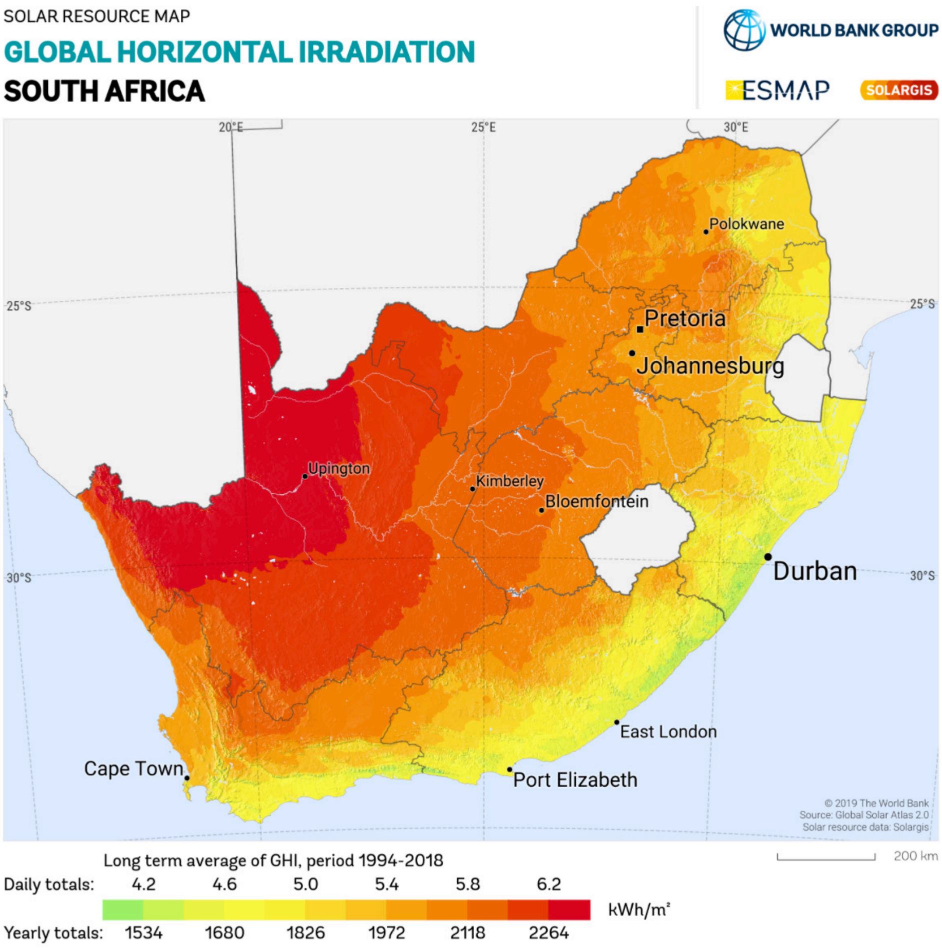

Figure 1. Solar resource of South Africa [4].

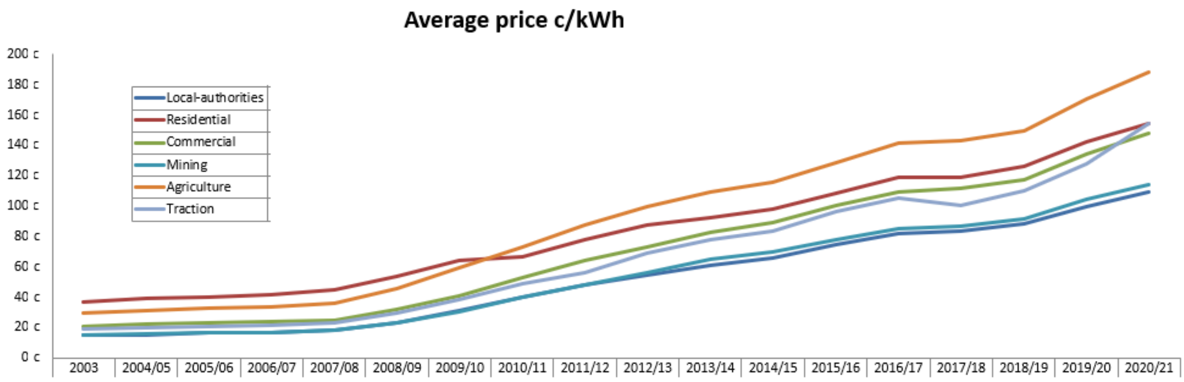

Figure 2. The national utility (Eskom) tariff rates for various sectors [5].

This means that the country will see continued growth in solar PV systems, both for distributed and utility-scale generation. The latter may mean implications for the agriculture sector in terms of competition for land. Rather than installing traditional PV farms, agrivoltaic systems provide a better way forward for increasing PV capacity by taking advantage of South Africa's vast amount of agricultural land.

The agriculture sector is a corner stone for the economy. Although significantly declining from accounting 10% of the country's GDP in 1962 to 0.4% in 2010, the agriculture industry still has a major impact on GDP accounting for 6.3 billion South African Rand (ZAR) in 2010, or US$ 347 million [6]. But the largest impact is in terms of employment with agriculture being responsible for more than 8% of total employment in the country, or a total of 860 thousand people at the end of 2022 [7]. By implementing agrivoltaic solutions instead of conventional PV farms new opportunities for employment can be created without the loss of previous jobs, as workers will be required for both the agriculture production and to build and maintain the PV systems. Losing land would also impact the food situation of the country as, for example, maize is estimated to be consumed by 21% of the population [8], and is a staple source of food for many families with limited choices due to income. This also means that due to crop shade intolerance (of maize) any agrivoltaic implementation would also have to carefully consider shading so that the implementation does not result in significant crop yield losses.

The objective of this paper is to investigate the potential opportunities to develop agrivoltaic systems by considering agricultural production in South Africa that may be suitable – to pave the way forward for the implementation of appropriate agrivoltaic systems in the country.

2. Method

A Geographic Information System (GIS) [9] analysis was undertaken to establish the land availability for agrivoltaic systems, focussing on different agricultural practices on land with slopes of less than 2 degrees – to minimise construction costs. Therefore, areas such as conservation land were excluded. Available land area was the main criterion, but the economic value of agriculture production was a further consideration and, subsequently, the operational implications for different agriculture practices were considered from a suitability perspective (in the qualitative analyses). From this several crops falling under different classes of land use in the categories of grazing, grain and fruit were selected (see Table 1). Over 31 million hectares of land, or about 30% of all agricultural land, were then analysed across all scenarios.

Table 1. Crop land use classes included in the GIS analysis.

Class Name	Classification	Grazing	Grain	Fruit
low shrubland (other)	Shrubland	Y	N	N
low shrubland (succulent karoo)	Shrubland	Y	N	N
low shrubland (nama karoo)	Shrubland	Y	N	N
natural grassland	Grassland	Y	N	N
commercial annual crops pivot irrigated	Cultivated	N	Y	N
commercial annual crops non-pivot irrigated	Cultivated	Y	Y	N
commercial annual crops rain-fed / dryland	Cultivated	Y	Y	N
fallow land & old fields (trees)	Cultivated	Y	N	N
fallow land & old fields (bush)	Cultivated	Y	N	N
fallow land & old fields (grass)	Cultivated	Y	N	N
fallow land & old fields (bare)	Cultivated	Y	N	N
fallow land & old fields (low shrub)	Cultivated	Y	N	N
cultivated commercial permanent orchards	Cultivated	N	N	Y
cultivated commercial permanent vines	Cultivated	N	N	Y
cultivated commercial sugarcane pivot irrigated	Cultivated	N	N	Y
cultivated commercial permanent pineapples	Cultivated	N	N	Y
cultivated commercial sugarcane non-pivot	Cultivated	N	N	Y
cultivated emerging farmer sugarcane non-pivot	Cultivated	N	N	Y

3. Results

The types of land usage that were considered for the GIS analysis are shown in Figure 3. Tables 2 to 4 summarise the potentially suitable land for agrivoltaic systems in thousands of hectares (kha), for the nine provinces: Eastern Cape (EC), Free State (FS), Gauteng (GP), KwaZulu-Natal (KZN), Limpopo (LP), Mpumalanga (MP), Northern Cape (NC), Northwest (NW) and Western Cape (WC).

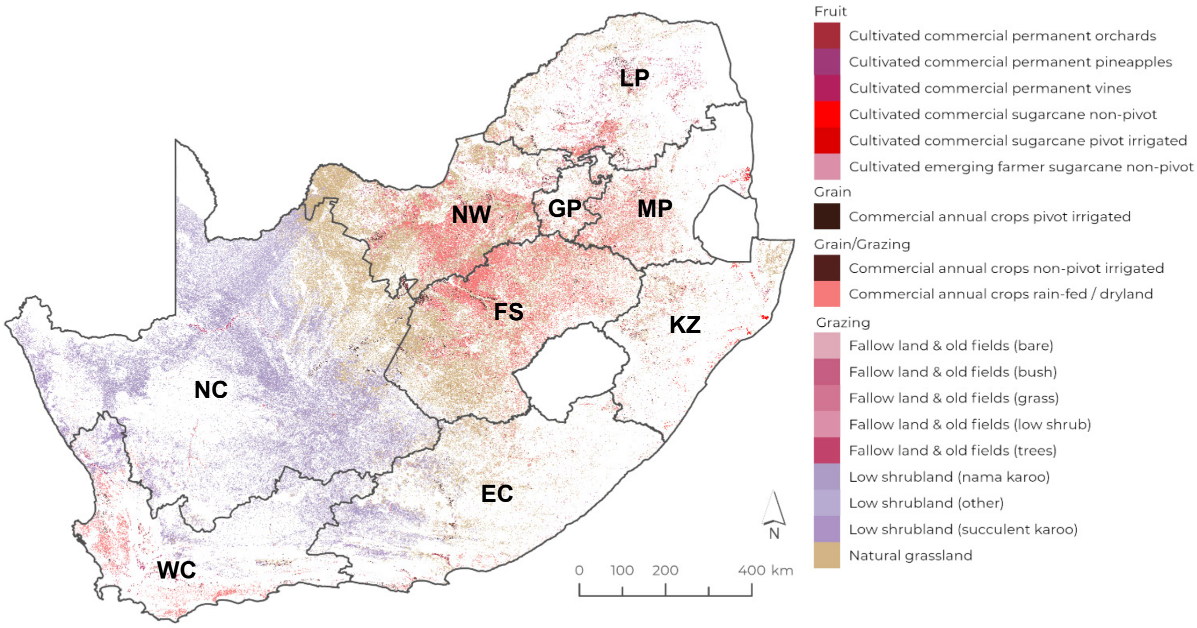

Figure 3. Agricultural practices on land with slopes of less than 2 degrees.

Table 2. Grazing lands suitable for agrivoltaic systems (kha).

Class Name	Provinces									National
	EC	FS	GP	KZN	LP	MP	NC	NW	WC	
low shrubland (other)	198	61	0	0	0	0	2738	59	88	3144
low shrubland (succulent karoo)	92	0	0	0	0	0	759	0	465	1316
low shrubland (nama karoo)	623	46	0	0	0	0	5520	0	473	6662
natural grassland	1123	3189	149	439	570	504	2638	3082	104	11798
fallow land & old fields (trees)	13	2	2	12	53	8	1	5	4	100
fallow land & old fields (bush)	1	16	6	2	266	18	11	177	1	498
fallow land & old fields (grass)	54	175	32	75	38	115	17	295	5	806
fallow land & old fields (bare)	1	1	1	4	1	1	10	2	2	23
fallow land & old fields (low shrub)	7	1	0	0	0	0	37	2	81	128
Total	2113	3490	190	531	928	645	11732	3622	1223	**31113**

Table 3. Maize and grains lands suitable for agrivoltaic systems (kha).

Class Name	Provinces									National
	EC	FS	GP	KZN	LP	MP	NC	NW	WC	
commercial annual crops pivot irrigated	36	137	15	35	119	33	62	80	32	549
commercial annual crops non-pivot irrigated	25	21	1	5	2	1	5	8	21	90
commercial annual crops rain-fed / dryland	149	2354	168	100	356	620	57	1457	475	5737
Total	210	2512	184	141	477	654	124	1545	528	**6376**

Table 4. Fruit cultivated lands suitable for agrivoltaic systems (kha).

Class Name	Provinces									National
	EC	FS	GP	KZN	LP	MP	NC	NW	WC	
cultivated commercial permanent orchards	17	2	1	3	31	10	10	3	26	101
cultivated commercial permanent vines	0	0	0	0	0	0	26	0	39	66
cultivated commercial sugarcane pivot irrigated	0	0	0	4	0	6	0	0	0	10
cultivated commercial permanent pineapples	2	0	0	2	0	0	0	0	0	5
cultivated commercial sugarcane non-pivot	0	0	0	52	0	16	0	0	0	68
cultivated emerging farmer sugarcane non-pivot	0	0	0	9	0	6	0	0	0	15
Total	19	2	1	70	31	38	36	3	65	**264**

4. Discussion

The GIS analysis reveals that three agricultural activities may offer the best opportunities for agrivoltaic systems: grasslands for livestock grazing, maize and other grains, and fruit.

As seen in Table 2, grazing accounts for a vast amount of non-cultivated available land with just over 31 million hectares (or around 80%) of land suitable for agrivoltaic systems. Most of the grazing areas are concentrated in the central regions of the country where the solar resource is also best (see Figures 1 and 3). Most of the grazing areas are taken up by natural grasslands spread out through the Free State, Northwest and Northern Cape Provinces. These regions are often drought stricken and the livestock are subjected to heat stress, which makes agrivoltaics a very good proposition, especially reducing the water loss of the pastures beneath the panels, as well as reducing the water consumption of the animals [10]. Construction of the systems – at the necessary height of 2.8 metres for cattle [11] – is not technically challenging provided the materials and equipment can reach the location. The latter might be an issue in some areas as the lands are not formally cultivated and remote meaning there will not necessarily be roads to transport the equipment or nearby electrical lines to connect to the grid. Access also has implications from a maintenance perspective, and therefore fixed-tilt systems should be the most feasible.

Maize and other grains make up the most cultivated lands with over 6 million hectares (or around 20%) of the land suitable for agrivoltaic systems. The available land stretches across multiple provinces, especially in the northeast side of the country as shown in Table 3. Maize offers an interesting case to explore for agrivoltaic installations. With most of the land being used for dryland farming in the Free State and Northwest Provinces, there is much benefit to installing agrivoltaic systems in these areas from a soil water retention perspective [12]. This can greatly help crop production given the effect of shading does not negate any benefits gained by the water retention. Because most of the areas do not utilise irrigation there is no need to worry about making space for pivots or other irrigation systems. On the other hand, if irrigation is practiced the racking system can be used to integrate irrigation infrastructure. In either case the only concern will be harvester clearance when it comes to deciding the dimensions of the racking system – with at least 4 metres required in most instances.

Fresh fruit production only makes up around 0.5%, or a quarter million hectares, of the suitable land (see Table 4). However, it does account for over 50% of agricultural exports [13]. The potential implications of agrivoltaic systems on the productivity of this sub-sector is therefore also of interest. Orchards make up most of land used for fruit with vines and sugarcane second – all in the outer Provinces of South Africa. The integration of agrivoltaic systems with sugarcane production will be challenging and costly – maintenance and construction of the racking systems – because of the high density of the crop and the heights it reaches. Vines on the other hand are very viable with multiple studies conducting studies on wine farms utilising agrivoltaics in different countries [14] [15]. Many of the orchard and vineyard production falls in the Western Cape Province, which is already water-constrained [16] – a clear potential benefit of agrivoltaic systems. The sub-sector, in the South African context, is typically also more labour intensive and less reliant on large, heavy equipment, which may be more amenable for the integration and operation of agrivoltaic systems.

5. Conclusions

South Africa, with its excellent solar resource and vast tracks of land allocated to agriculture production, has much potential for the significant uptake of agrivoltaic systems. Indeed solar PV uptake has seen substantial growth to meet the increasing demand and address the challenges that the electricity network has been experiencing, as well as mitigating the carbon emissions of the energy sector.

This study has undertaken a GIS analysis of suitable land, which shows that livestock grazing (over 31 million hectares), maize and other grains (over 6 million hectares), and fresh fruit production (over 260 thousand hectares) offer the best opportunities for the integration of agrivoltaics. Current grazing and maize production should be targeted in the Northern, Free State, and Northwest Provinces – especially those areas with dryland farming practices. The orchards and vineyards in the Western Cape Province should receive the most attention, since it is already water stressed – to reap the water retention benefits that agrivoltaics may offer.

Current large-scale solar projects in South Africa indicate that at least 0.6 to 1.5 GWh of electricity can be generated annually per hectare [17]. The current total capacity (of all sources) generated around 237 TWh in 2022 [18]. To generate an equal amount of electricity with agrivoltaic systems would then (roughly) require less than 400 thousand hectares of agricultural land; or less than 2% of the available land suitable for agrivoltaic systems (depending on the designed panel density). Further site-specific techno-economic analyses are underway to provide greater insight into the potential opportunities for South Africa.

Data availability statement

The spatial, GIS data that supports the results can be obtained through the Engineering Management – Sustainable Systems research group of the Department of Industrial Engineering at Stellenbosch University: https://ie.sun.ac.za/research/sustainable-systems/.

Underlying and related material

The GIS maps that underpin the results can be obtained through the Engineering Management – Sustainable Systems research group of the Department of Industrial Engineering at Stellenbosch University: https://ie.sun.ac.za/research/sustainable-systems/.

Author contributions

Nicholas Chapman undertook the data curation, formal analysis, visualization, and writing of the original draft. Alan Brent conceptualized the research, obtained the necessary funding, administered the project, validated the outcomes, and edited the original draft. Imke de Kock edited the final draft.

Competing interests

The authors declare no competing interests.

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