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AgriPV Systems: Potential Opportunities for Aotearoa–New Zealand

A GIS Suitability Analysis

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Abstract. The efficient and effective use of land that agriPV, or agrivoltaic, systems offer is especially appealing for Aotearoa-New Zealand, since more than a third of its land area serves agricultural purposes. However, several factors might constrain the implementation of agriPV systems, and different values and preferences need consideration from a community acceptance perspective. As a first step, a high-level investigation into the potential suitability of agriPV systems in Aotearoa–New Zealand was undertaken. The different factors that influence performance of agriPV systems were considered. Then a GIS analysis was undertaken using the analytical hierarchy process – a multicriteria decision-making technique. The spatial data analysis provided insight to identify the regions in Aotearoa–New Zealand best suited to agriPV systems. Overall, it is estimated that 80 percent of the farmland in the country is either good or fairly suitable for agriPV developments with a number of regions identified as potential areas for further investigations.

Keywords: Agrivoltaics, Geographic Information Systems, Analytical Hierarchy Process, Multicriteria Decision Making.

1. Introduction

The potential of solar energy in Aotearoa–New Zealand has been recognised in both academic [1, 2, 3] and grey literature [4, 5, 6]. In particular, an update to the NZGP1 scenarios of Transpower [7] projects solar to generate between 700MW to 2600MW by 2050. Transpower [7] expects that distributed, small-scale solar photovoltaic (PV) systems, for example on rooftops, will provide at least half of the country's solar PV generation capacity by 2050, with land-based PV farms providing the remaining generation capacity.

Aotearoa–New Zealand, as an island nation, is land constraint with more than a third of its land area serving agricultural purposes – 9.6 million hectares [8]. The agricultural farmland may have the solar resource required for electricity generation [1, 9, 10]. This, however, may be a point of contention, due to potential land use conflicts between PV farm developments and the country's agricultural sector [11, 12]. The agricultural sector contributed 79.6 percent of the country's total exported goods in 2021 [13], and five percent to Aotearoa–New Zealand's gross domestic product [8]. The significance of Aotearoa–New Zealand's agriculture sector therefore provides a complex spatial challenge for large-scale PV developments.

One solution identified is the dual use or co-development of agricultural land for food production and PV power generation, otherwise known as agrivoltaic (or agriphotovoltaics, agriPV) systems; the intercropping of vegetation and rows of solar PV panels [14, 15]. The simultaneous land use between the agricultural and energy sectors (potentially) increases the land's productivity by over 70 percent, thereby increasing economic value when compared to conventional agriculture [14, 16, 17]. Additional benefits of agriPV systems may include an increase in crop resilience, reduction in evapotranspiration, and increased soil moisture retention [18].

This paper summarises an initial investigation of the potential opportunity of agriPV systems for Aotearoa–New Zealand. A high-level spatial analysis was undertaken using a combination of a multicriteria decision making (MCDM) technique – the Analytical Hierarchy Process (AHP) developed by Saaty [19], and Geographic Information Systems (GIS); to estimate the amount of land suitable for agriPV systems in Aotearoa–New Zealand. The resulting regional spatial data were analysed to gauge the potential of agriPV systems at a regional scale.

2. Method

The work of Munkhbat and Choi [20] and Han [21] guided the methodology for this analysis. Munkhbat and Choi [20] undertook a GIS-based suitability analysis for solar PV systems in Mongolia; ranking, then weighting variables that contribute toward solar panel efficacy using the AHP technique. Similarly, Han [21] used GIS and MCDM to generate a residential solar map for the city of Airdrie.

2.1 Selection of criteria and data

The paper considers the average global horizontal irradiance (GHI), slope, aspect (slope orientation), and distance to nearest transmission line as the important variables for determining the suitability of agriPV systems in Aotearoa–New Zealand. QGIS was used to undertake spatial analysis and create maps [22]. Average GHI data were retrieved from Solargis [23 in 1], transmission line data were retrieved from Transpower [24], and slope data were retrieved from the Land Resource Information Systems [25] portal. Aspect data were calculated using the aspect processing tool in QGIS [22]. Lastly, land use data for 2016 were retrieved from the Aotearoa–New Zealand Ministry for the Environment [26], and the shapefiles for the regions in Aotearoa–New Zealand were retrieved from Stats NZ [27].

2.2 Average GHI

A map of the long-term average of yearly totals of GHI in Aotearoa–New Zealand, during the period 2007 to 2018, is provided in [1]. The long-term average of yearly totals of GHI is highest along the coasts of the North Island; Marlborough and Nelson in the north of the South Island; and in the central Otago region of the South Island. It is lowest around the Tararua Forest Park of the North Island; the Southern Alps; and Stewart Island, off the southern tip of the South Island.

2.3 Slope and aspect

Slope describes the degree of steepness of a surface, while aspect describes the direction the slope is facing, namely north, south, and so forth. The slope and aspect of the land can determine both the amount of electricity generation and the construction costs of the agriPV development. Typically for agriPV developments, surfaces with low slopes are more suitable, while north-facing slopes are preferable (in the southern hemisphere).

The mountainous landscapes of Aotearoa–New Zealand means that most of the land having some degree of slope. Flat regions are predominant in the Canterbury and Southland regions of the South Island; and Hawke's Bay, the Bay of Plenty, and the Waikato, Taranaki, Manawatū-Whanganui, Wairarapa, as well as parts of Northland, regions of the North Island.

As the aspect data has a high resolution, it is difficult to identify specific regions with north-facing slopes.

2.4 Major power transmission lines

AgriPV developments should be within a certain distance from major power transmission lines, to reduce the construction costs of agriPV developments and the potential effects on the environment. While major power transmission lines reach most regions in New Zealand, it should be noted that major power transmission lines do not reach some of the eastern regions of the North Island that have a good solar resource.

2.5 Land cover

Lastly, agriPV systems should be developed on pre-existing agricultural land to protect conservation land. For this study, dairy grazing grassland, non-dairy grazing grassland, perennial cropland, and annual cropland were considered. There is a significant amount of dairy grazing and non-dairy grazing grassland in Aotearoa–New Zealand. Prominent regions include Otago and Canterbury on the South Island; and Wairarapa, Hawke's Bay, Gisborne, the Bay of Plenty, Waikato, and Taranaki on the North Island.

2.6 Rating criteria

As the suitability of agriPV systems is analysed through comparison, rating criteria must be set. The data accumulated from the produced maps were rated into four categories: "Good", "Fair", "Low", and "Poor". Rated values of 4, 3, 2 and 1 were assigned to these ratings. The details of the rating criterion for each variable are provided in Table 1.

Table 1. Rating criteria used in this study.

Variable	Poor (1)	Low (2)	Fair (3)	Good (4)
Average GHI (kWh/m^2)	< 1150	1150 - 1250	1250 - 1350	> 1350
Slope (degrees)	> 11	3 – 11	1 – 3	< 1
Distance from Transmission Line (km)	> 75	50 – 75	25 – 75	< 25
Aspect	South, Southwest, Southeast	East, West	Northeast, Northwest	North

2.7 Weighting criteria

As carried out by Munkhbat and Choi [20] and Han [21], the AHP method was utilised to determine the different weights of the selected variables. Developed by Saaty [19], the AHP method determines the weight of each variable by normalising the eigenvector associated with the maximum eigenvalue of a ratio matrix. The AHP method has three general steps:

- Develop a pairwise comparison matrix;
- Compute the criterion weights; and
- Estimate the consistency index (CI) value.

First, a pairwise comparison matrix was created to compare the relative importance of two given variables. Next, the criterion weights were computed by dividing each element of the column by the sum of the elements of the same column. This normalises the pairwise comparison matrix. The average rows of the normalised pairwise comparison matrix provides the required relative test weights. Table 2 shows the weighting process. Columns two to five show the pairwise comparison matrix, while columns six to nine show the normalised pairwise comparison matrix. Column ten shows the required relative test weights.

Table 2. Weighting criteria used in this study.

Variable	GHI	Slope	Distance	Aspect	Weight A	Weight B	Weight C	Weight D	Average Weight
GHI (A)	1	2	4	5	0.51	0.55	0.47	0.42	**0.49**
Slope (B)	0.5	1	3	4	0.26	0.28	0.35	0.33	**0.30**
Distance (C)	0.25	0.33	1	2	0.13	0.09	0.12	0.17	**0.13**
Aspect (D)	0.2	0.25	0.5	1	0.10	0.07	0.06	0.08	**0.02**
Total	1.95	3.58	8.5	12	1	1	1	1	1

3. Results

The agriPV suitability map for dairy grazing grassland, non-dairy grazing grassland, perennial cropland, and annual cropland in Aotearoa–New Zealand, is shown in Figure 1. Farmland is rated overall as having good, fair, low and poor conditions for agriPV developments.

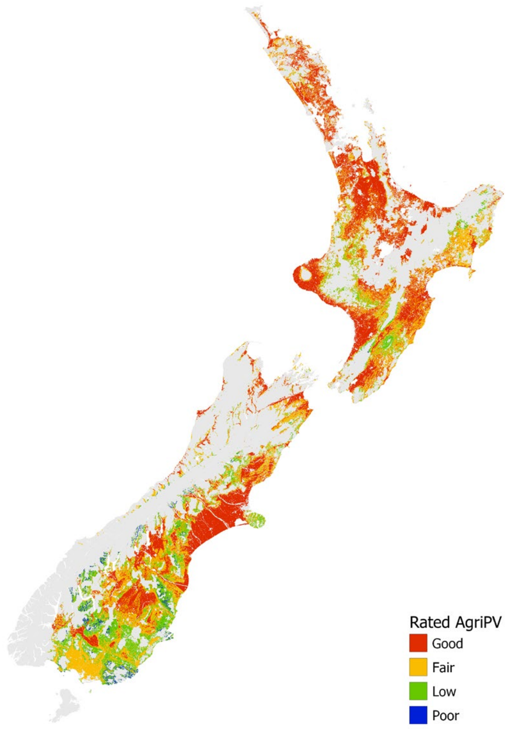

Figure 1. AgriPV suitability for Aotearoa–New Zealand.

4. Analysis

4.1 AgriPV for different land uses

Table 3 shows the total amount of land categorised under each rating, for each of the four farm types.

Table 3. Area of rated farmland for agriPV in Aotearoa–New Zealand.

Land use	Poor		Low		Fair		Good	
	km^2	%	km^2	%	km^2	%	km^2	%
Dairy Grazing Grass-land	25	0.1	561	3	4,901	25	14,248	72
Non-Dairy Grazing Grassland	1,654	2.0	22,243	22	44,395	43	34,163	33
Perennial Cropland	0	0	1	0	63	6	976	94
Annual Cropland	0.2	<0.1	24	1	282	8	3,441	92
Total	1,679	1	22,830	18	49,640	39	52,829	42

From the analysis it is estimated that 42 percent of active farmland in Aotearoa–New Zealand have a good suitability rating, with a further 39 percent of farmland having a fair suitability rating. It is also observed that while perennial cropland and annual cropland have a higher proportion of good suitability ratings (94 and 92 percent respectively), the total amount of grazing grassland with a good suitability rating is significantly larger than cropland. This suggests that small-scale agriPV would be suitable for cropland and that grassland is more suitable for large-scale agriPV systems.

4.2 AgriPV for different regions

Table 4 shows the total amount of land categorised under each rating, for each region in Aotearoa–New Zealand.

Table 4. Area of rated farmland for agriPV in regions of Aotearoa–New Zealand.

Region	Poor		Low		Fair		Good	
	km^2	%	km^2	%	km^2	%	km^2	%
Auckland	0	0	9	0.4	75	27	201	73
Bay of Plenty	0.07	<0.1	41	1	683	23	2,233	76
Canterbury	268	1	4,661	17	8,905	33	13,347	49
Gisborne	9	0.2	718	19	2,485	66	527	14
Hawke's Bay	1	<0.1	254	3	3,768	46	4,096	50
Manawatu-Wanganui	16	0.1	2,472	18	5,953	44	5,113	38
Marlborough	149	4	372	10	2,019	56	1,093	30
Nelson	0	0	0.37	1	27	59	18	40
Northland	0	0	70	1	2,014	35	3,615	63
Otago	736	3	8,837	37	9,605	40	4,713	20
Southland	480	4	4,047	34	5,894	50	1,399	12
Taranaki	0	0	345	9	941	25	2,514	66
Tasman	0.39	<0.1	85	7	466	36	748	58
Waikato	0	0	414	3	3,701	27	9,350	69
Wellington	1	<0.1	305	8	1,773	46	1,780	46
West Coast	19	1	200	13	754	51	515	35
Total	1,679	1	22,830	18	49,640	39	52,829	42

These results show that Auckland, Bay of Plenty, Northland, Taranaki and Waikato regions have the greatest proportion of farmland with a good suitability rating for agriPV developments. These five regions are all on the North Island of Aotearoa–New Zealand, which suggests agriPV developments in the North Island would be more effective than the South Island. However, Manawatu-Wanganui, Waikato, Canterbury, Otago and Tasman have the largest total amount of farmland with a good suitability rating for agriPV developments, the latter three of which form part of the South Island. This suggests that large tracts of available farmland may be more suitable for large-scale agriPV developments.

5. Conclusion

This paper investigated the suitability of agriPV systems in Aotearoa–New Zealand. A GIS analysis of selected variables that influence AgriPV developments was conducted. These variables were then rated and weighted using the Analytical Hierarchy Process, to produce an agriPV suitability map of Aotearoa–New Zealand. The spatial data was then analysed to draw conclusions on the best regions for agriPV developments in the country.

From the analysis it is determined that while cropland has a higher proportion of land that is suitable for agriPV, grassland used for grazing has a significantly greater area. The agriPV systems may offer particular benefits for farmlands in the regions of Aotearoa–New Zealand. The Canterbury and Otago regions (on the South Island), for example, have large flat surface areas that are good for agriPV developments. While the agriPV systems will increase the land's overall productivity, the additional benefit of decreased soil evapotranspiration and increased soil moisture retention would decrease the need to irrigate water for farmland in the region. Further studies of these additional benefits of agriPV in the Canterbury and Otago regions should be investigated, either through a GIS analysis using remote sensing or a field study.

The effects of agriPV on dairy cattle should also be investigated further, in areas such as the Taranaki and Waikato regions. The two regions are significant contributors to Aotearoa–New Zealand's dairy industry, with roughly 7,100 km^2 of Dairy Grazing Grassland between them. The effects of shading on bovine welfare and production should be investigated to help understand the extent of the benefits. A field study would be necessary to assess the behaviour of Aotearoa–New Zealand cattle under agriPV systems.

Lastly, agriPV on cropland should be investigated in areas such as the Bay of Plenty, Gisborne, Hawke's Bay and Marlborough. In particular, the effects of east-west bifacial agriPV on the country's vineyards should be investigated, to help understand the extent agriPV would benefit the wine industry. The effects of agriPV systems elevated above kiwifruit trees should also be investigated.

There are a few limitations to this study. Firstly, this study did not investigate the effects of agriPV in suboptimal winter conditions. This would likely see a decrease in agriPV suitability on the South Island, as the average GHI in winter is significantly lower than in summer. Secondly, this study solely observed the potential effects of agriPV based on the resources in the region. This study provided no estimations or modelling of the extent of these effects, leaving room for potential further studies. Furthermore, this study analysed agriPV suitability between regions of Aotearoa–New Zealand through comparison and therefore the rated values of the variables were given on a relative scale of good, fair, low, or poor. This study also investigated the effects of four variables on agriPV systems, while more variables are expected to influence the appropriateness of agriPV systems. Additional variables that could be investigated are annual rainfall, proximity to residential areas, and soil quality. Also, the economic value of dual land usage – for the different regions and farming practices – needs further investigation. The value of electricity is often much higher than that of the agricultural produce, and additional costs for agriPV systems, compared to ground-mounted panels, can be higher than the revenue from the produce. Therefore, the careful selection of the best combinations (with synergies between panels and produce) is required. Finally, field work is needed to gauge community acceptance in order to conclusively decipher the suitability of agriPV systems in Aotearoa–New Zealand.

Data availability statement

The spatial, GIS data that supports the results can be obtained through the Chair in Sustainable Energy Systems at Victoria University of Wellington: http://www.wgtn.ac.nz/sustainable-energy-systems.

Underlying and related material

The GIS maps that underpin the results can be obtained through the Chair in Sustainable Energy Systems at Victoria University of Wellington: http://www.wgtn.ac.nz/sustainable-energy-systems.

Author contributions

Donald MacKenzie 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. James Hinkley and Daniel Burmester edited the final draft.

Competing interests

The authors declare no competing interests.

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