Agrivoltaics: Integrating Solar Energy Generation with Livestock Farming in the Canterbury Region of Aotearoa New Zealand

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Abstract— **Agrivoltaics is the integration of agriculture and solar energy production and seeks to find synergies between the two to create a complementary system. With increased interest in energy generation with utility-scale solar photovoltaic (PV) systems in Aotearoa New Zealand, agrivoltaics provides the opportunity to increase the productivity of land, contribute to the generation of renewable energy without displacing food production, and potentially optimize farming and environmental outcomes. Case study analyses were carried out on a dairy farm and a sheep and beef farm, both located in the Canterbury region. These considered both technical designs and financial analyses. The sheep and beef case study analysis indicated a significant opportunity for farmers to increase their profitability by incorporating agrivoltaics into their farming enterprise. This comes at a time of increased interest in complementary revenue streams due to reduced farmgate product prices, increased working expenses, and increased compliance costs and associated administrative workload. The financial analysis of agrivoltaics for the dairy farm case study suggested it was significantly less lucrative and indicates that incorporating solar generation on these farms might be best suited to non-productive areas or the installation of panels on shed roofs, rather than agrivoltaics. The study provides evidence that agrivoltaics is worthy of further consideration, particularly due to the way in which it offers solutions to some of the major challenges of standard utility-scale solar PV generation. It is evident that the significant gaps in literature need to be addressed to further understand what the potential financial, environmental and social impacts are for the people of Aotearoa New Zealand.**

Keywords—solar PV, agrivoltaics, agriPV, dual-land usage.

I. INTRODUCTION

The latest Intergovernmental Panel on Climate Change [1] report emphasizes the importance of solar technologies for the energy transition to renewables at a global level. In Aotearoa New Zealand, renewable energy currently makes up around 83% of the net electricity generation mix and the Government has set a target of 100% by 2030 [2]. Disruptive scenarios for Aotearoa New Zealand also project that the current electricity generation capacity can be doubled by 2050 with, among others, utility-scale solar farms [3]. The fast-paced development of the sector has already commenced with the Electricity Authority indicating that nearly 80% of new generation projects – or just under 2 GW to be commissioned by 2025 – are solar farms [4]. Nevertheless, the IPCC report [1] notes that for the transition to be feasible at the necessary scale and speed both agriculture and centralized solar production must be integrated on the same land where possible. This is an opportunity to obtain multifunctional outcomes from the land and thereby maximize the current and future value of land resources in terms of net agricultural return, as well as reducing greenhouse gas emissions and delivering benefits for farming communities [5]. In addition, some countries, such as Italy and Germany, are restricting solar farm development to areas so as to not encroach on quality farmland [6].

To facilitate the integration of dual land usage Goetzberger and Zastrow [7] proposed agrivoltaic, or agriPV, systems as a solution in the early 1980s. Agrivoltaic systems establish synergistic combinations of agricultural production and electricity generation on the same land and are receiving much attention globally as a viable alternative to conventional large-scale solar photovoltaic (PV) installations – to create mutual benefits for each sector [8]. With agrivoltaics systems agricultural activities have an influence on solar generation and vice versa – positive and negative [8].

Agrivoltaic systems differ from conventional ground-mounted solar arrays in that the panels are typically given more ground clearance and are spaced further apart [9]. This provides enough space for farming equipment to operate and allows light to reach the crops below. A yield decrease can be expected due to the shadows under module arrays, but this amount depends on the climate as well as the specific crop [10]. On the other hand, if agrivoltaic systems are designed well, land productivity could rise by 60 to 70% compared to operating solar collection alone [5]. Additionally, agrivoltaic systems have been used in pastoral lands, with added shelter to protect livestock against heat stress and adverse winter weather [6].

A. *Objective of the paper*

The objective of this paper is to provide further insights into open-field agrivoltaic system configurations and their potential implications for livestock farming in the context of Aotearoa New Zealand, particularly the Canterbury region. Over half of Aotearoa New Zealand's land is agricultural, including livestock farming and horticulture. MacKenzie et al. [11] studied the suitability of agricultural land for agrivoltaic systems, taking inputs of a location's solar resource, slope, distance from transmission lines and aspect (north alignment). The subsequent pairwise comparison produced a 4-category map ranked by the potential for agrivoltaic systems (see Fig. 1).

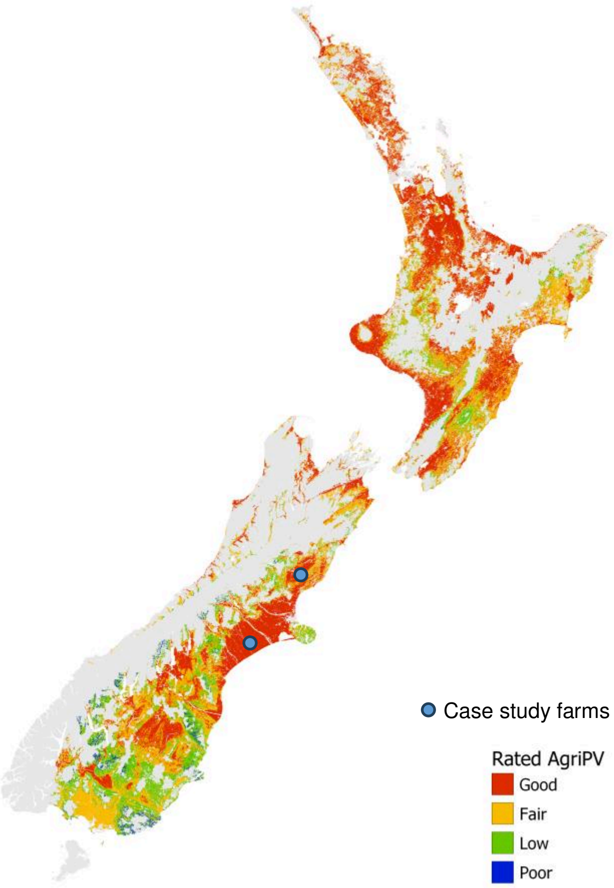


Fig. 1. Land suitability for agrivoltaic systems in Aotearoa New Zealand [11].

Over 80% of agricultural land in Aotearoa New Zealand was found as good or fairly suitable (around 10 million hectares). The total amount of grazing grassland with a good suitability rating is significantly larger than cropland. This suggests that small-scale agrivoltaics would be suitable for cropland and that grassland is more suitable for large-scale agrivoltaic systems.

II. METHOD

Two livestock farms (one sheep and beef, and the other diary) in the Canterbury region of Aotearoa New Zealand (see Fig. 1) were used as case studies to model, assess and analyze potential agrivoltaic designs and the likely impacts on the farm systems' financial outcomes. Physical details were unchanged but financial data was standardized to maintain confidentiality.

A. *General solar technical details*

The solar PV panels used in this assessment are CS7N-660MB-AG 1500V. They are 660W each and measure 2384 x 1303 x 35 mm. These panels are bifacial so can capture light from both sides during operation.

The case studies considered both fixed-tilt and tracking systems on the two farms. With fixed-tilt systems the rows span east-west, and the panels are tilted 25° from horizontal to face north. With tracking systems, the rows span north-south. Height for cattle systems were designed to exceed the height of cattle at 2.5 m ground clearance. Ground clearance is defined as the distance from ground to the lowest point of the solar panels.

Fig. 2 is a schematic of the Schletter FS Duo frame (fixed-tilt). Its dual pile design allows greater stability at high wind loads and can be placed in more soil types. The cattle system at the WCROC in Minnesota, USA, for example, uses a single pile system. However, framing suppliers have indicated that it may be difficult to engineer a cost-effective single pile system for Aotearoa New Zealand's wind speeds. The Schletter Solar Tracking System is shown in Fig. 3. It tilts the module array from east to west throughout the day to track the sun.

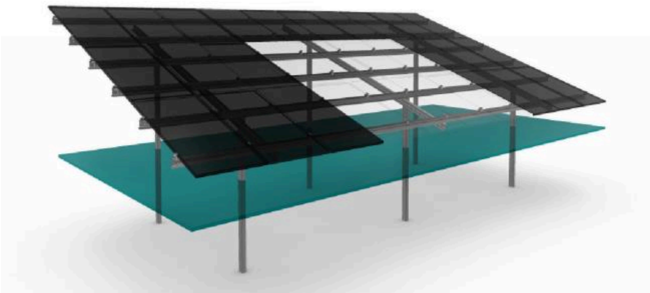


Fig. 2. Schematic of the Schletter FS Duo Frame (fixed-tilt).

Fig. 3. Schletter Solar Tracking System.

B. *Key assumptions*

System prices include all materials and installation needed for a typical system as delivered by an Engineering Procurement and Construction firm in Aotearoa New Zealand (Infratec), subject to further site investigations. Material prices, physical site conditions, local grid capacity, as well as division of scope with the landowner, will significantly impact costs.

Development and grid connection costs are indicative of a typical system that size but can vary significantly based on the studies required and potential line/grid upgrades.

Revenue (from electricity sales) is estimated based on historical average wholesale electricity prices subject to confirmation during project development.

Yield is estimated based on the specified system configuration and can vary significantly based on site location, shading elements, and further development of the design.

Space between the arrays for tracker systems is defined when the modules are tilted towards a horizontal position (minimum row space).

The specified panels are guaranteed to decay at a linear rate for 30 years. However, other components, such as inverters, will need maintenance and may require replacement during that project lifespan.

End of panel life replacement and safe disposal and recycling were not accounted for in the analysis. At present, there are no recycling facilities for solar waste in Aotearoa New Zealand, so it was not possible to cost this aspect.

Cost of borrowing was valued at 5.5%, which was used to reflect a 30-year average.

C. *Sheep and beef farm case study*

The sheep and beef farm that was modelled is a 1,300 ha (1,100 ha effective) property, wintering 7,500 stock units. The farm has approximately 800 ha of effective hill country and 300 ha of effective flats. The proposed site for an agrivoltaic system was an 8 ha paddock that had good vehicle access and proximity to the nearest electricity transformer.

D. *Dairy farm case study*

The dairy farm that was modelled has 235 ha of flat land with a total of 860 cows. An agrivoltaic system was proposed for a 2 ha dryland area on the edge of an irrigated paddock.

III. RESULTS AND DISCUSSION

A. *Sheep and beef farm case study*

Two layouts for the proposed site are shown in Fig. 4 and 5. These utilize most of the paddock but have wider inter-row clearances than typical solar farms to allow farm equipment to move between the rows to enable dual use of the paddock. There is also a large setback between the array and the paddock boundary. This ensures ease of access and maneuverability of the farming equipment.

Table I summarizes the technical aspects of the agrivoltaic systems, as well as the associated costs and revenues (from electricity sales). Fig. 6 shows an example of the energy production (for the fixed-tilt system) over a year, and Table II summarizes the financial analysis for the farming operation.

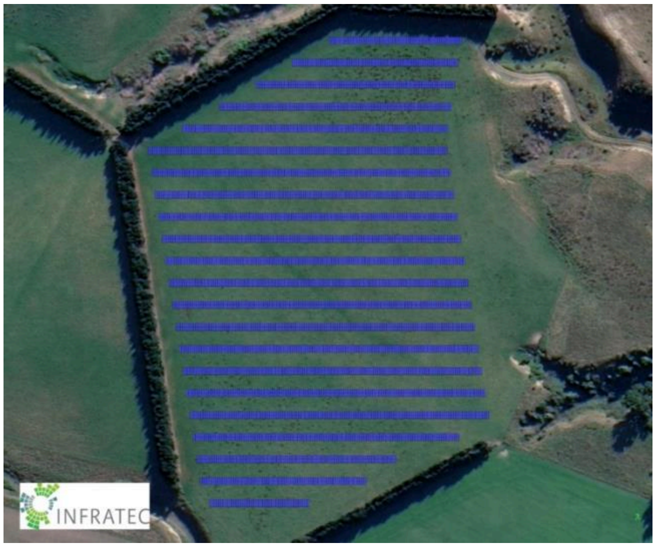


Fig. 4. Layout of the fixed-tilt agrivoltaic system.

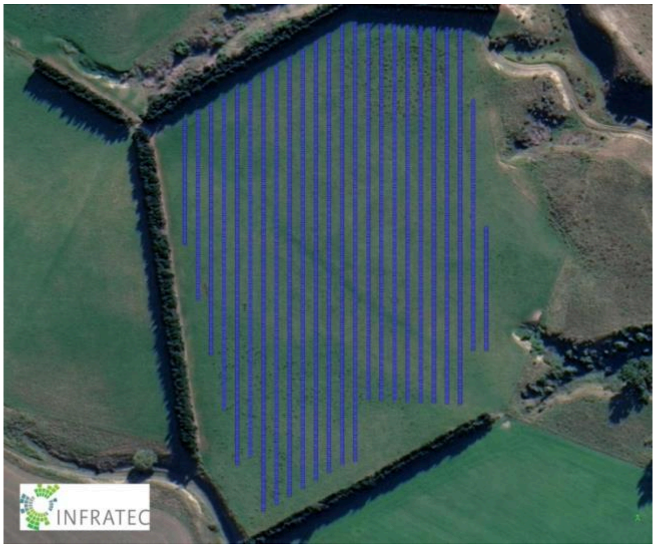


Fig. 5. Layout of the tracking agrivoltaic system.

Tracking systems are more expensive per installed power unit (kWp) but generate more electricity per panel and therefore the overall capital cost is lower. They are, however, more expensive to maintain and they can be more susceptible to weather conditions, especially if raised higher above the ground. Overall, the expected revenue is similar, and the choice of agrivoltaic system depends on how the land will be used.

For the financial analysis the following assumptions were applied:

- The carrying capacity of the area of the farm modelled for agrivoltaics is 10 stock units (su) per hectare.
- Scenario 1 is status quo with no implemented agrivoltaics.

TABLE I. TECHNICAL CHARACTERISTICS, COSTS AND REVENUE.

Global Horizontal Irradiance (W/m²)	1,418	
PV Array area (ha)	5.8	
Racking	**Fixed**	**Tracking**
Central inverter[a] (MW)	2.5	2.2
Row spacing (centre to centre) (m)	13.3	8.4
Space between rows (m)	9.0	6.0
Cover ratio (%)	35	28.9
DC size (kW)	3,346.2	2,692.8
AC size (kW_{ac})	2,500	2,195
Specific yield (kWh/kW_p)	1,533	1,802
Annual energy[b] (MWh)	5,129	4,852
Project Development, Consent, and Grid Connection (NZ$)[c]	625k	625k
Project Design and Build (NZ$)	4.7 - 6.3 million	4.3 - 5.7 million
Estimated revenue ($/MWh)	96-144	96-144
Estimated revenue (‘000 $/ha)	84-127	81-123

a. A central (single large) inverter was chosen due to the scale of the project.
b. Generation data applies for the project’s first year and will degrade over the project lifespan.
c. 1 NZ$ is approximately 0.6 US$ - in September 2023.

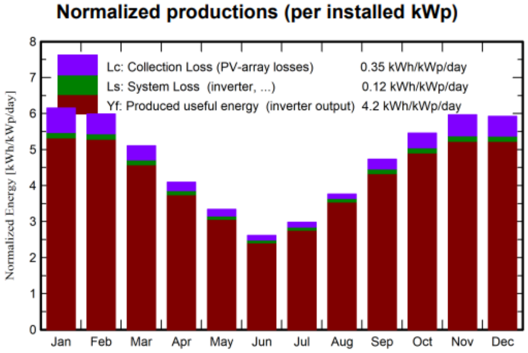
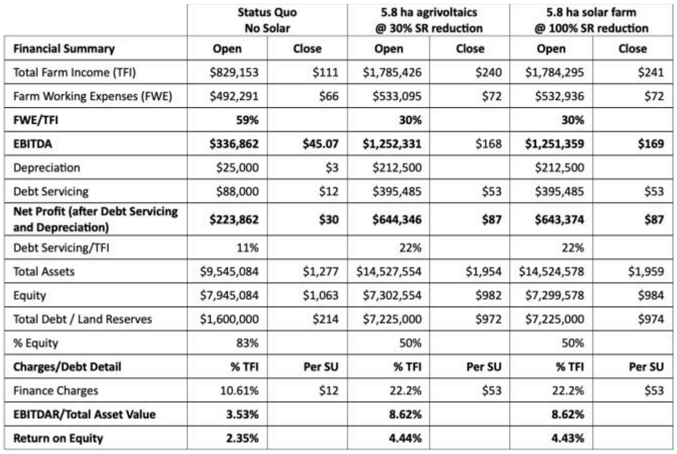


Fig. 6. Fixed-tilt monthly production per kilowatt-peak.

TABLE II. SHEEP AND BEEF FARM FINANCIAL ANALYSIS.



	Status Quo No Solar		5.8 ha agrivoltaics @ 30% SR reduction		5.8 ha solar farm @ 100% SR reduction	
Financial Summary	**Open**	**Close**	**Open**	**Close**	**Open**	**Close**
Total Farm Income (TFI)	$829,153	$111	$1,785,426	$240	$1,784,295	$241
Farm Working Expenses (FWE)	$492,291	$66	$533,095	$72	$532,936	$72
FWE/TFI	**59%**		**30%**		**30%**	
EBITDA	**$336,862**	**$45.07**	**$1,252,331**	$168	**$1,251,359**	**$169**
Depreciation	$25,000	$3	$212,500		$212,500	
Debt Servicing	$88,000	$12	$395,485	$53	$395,485	$53
Net Profit (after Debt Servicing and Depreciation)	**$223,862**	**$30**	**$644,346**	**$87**	**$643,374**	**$87**
Debt Servicing/TFI	11%		22%		22%	
Total Assets	$9,545,084	$1,277	$14,527,554	$1,954	$14,524,578	$1,959
Equity	$7,945,084	$1,063	$7,302,554	$982	$7,299,578	$984
Total Debt / Land Reserves	$1,600,000	$214	$7,225,000	$972	$7,225,000	$974
% Equity	83%		50%		50%	
Charges/Debt Detail	**% TFI**	**Per SU**	**% TFI**	**Per SU**	**% TFI**	**Per SU**
Finance Charges	10.61%	$12	22.2%	$53	22.2%	$53
EBITDAR/Total Asset Value	**3.53%**		**8.62%**		**8.62%**	
Return on Equity	**2.35%**		**4.44%**		**4.43%**	

- Scenario 2 includes 5.8 ha of panels and models a 30% reduction in stocking rate to reflect the 30% cover ratio of panels to the paddock area (agrivoltaics system).
- Scenario 3 includes 5.8 ha of panels and models a 100% reduction in stocking rate to reflect farm income implications of removing all grazing from that area other than for pasture/weed control (conventional solar farm).
- The reduction in stocking rate in both agrivoltaic scenarios has come from the 1-year trade ewes, which typically lamb in and around the paddock selected for the solar panel modelling.
- There are uncertainties regarding solar panel warranties and the use of fertilizer that would need to be investigated further.
- Practicalities and logistics would need to be considered before cropping or renewing pastures under the panels.
- Annual operating, maintenance and insurance costs for solar panels is based on 0.5% of the capital costs.
- Also included is the cost to replace the inverter in year 12-15. This cost of approximately $350,000 has been split over the 30-year lifespan for the purposes of this financial modelling.
- Depreciation of solar panels has been calculated over the expected lifespan of 30 years.
- End of panel life removal, waste management and remediation of the land back to farming or installing new panels were not included in the modelling.
- Tax was not calculated or included in the analyses.
- The analyses did not include principal repayments as the solar panel costs are covered through depreciation.

The key findings are then as follows:

- The farm income increased due to the additional solar revenue by $955,142.
- Expenses increased by $40,645, due to solar running costs.
- Depreciation lifted by $187,500, due to 30-year life span of solar panels.
- Net Profit (after debt servicing and depreciation) increased by $419,450.
- Return on Asset (EBITDAR/Total Asset Value) increased from 3.53% to 8.62%.
- Return on Equity (Net Profit/Equity) increased from 2.35% to 4.43%.

The analyses therefore indicate that the proposed site would be suitable and the technical requirements feasible to install an agrivoltaics system. Both the Return on Asset and Return on Equity are significantly greater with both the agrivoltaics and solar-only scenarios, compared to the status quo, indicating that incorporating solar onto this sheep and beef farm would have financial benefits for the landowner. The difference between the agrivoltaics (30% SR reduction) and conventional solar system (100% SR reduction) is minimal and this presents a challenge for agrivoltaics. If considering the proposition from a purely financial perspective, these results indicate that it would be a better financial return to use a standard PV design focused on maximizing solar generation. This results in panels being installed near each other, increasing the shading over the area, resulting in a significant reduction in pasture yield and livestock carrying capacity. Narrow row gaps would also make it more difficult to move livestock and vehicles between panel rows, again acting as a deterrent to utilize this area for farming purposes. It can be argued that the increased revenue could allow for investment in on-farm actions and projects that produce a greater overall benefit to the environment and rural community than would be achieved by modifying the design to better achieve an agrivoltaic outcome. However, there is no certainty that this would eventuate. In addition, the National Policy Statement on Highly Productive Land 2022, places limitations on development of Aotearoa New Zealand’s most fertile and versatile land and this will likely affect solar development applications. Given that the income from the agrivoltaics scenario is still significantly greater than the status quo, there is a good argument to pursue agrivoltaics, which creates less impact on the farming potential of the land.

B. Dairy farm case study

The two possible layouts - for fixed-tilt and tracking systems - are similar to the first case study. However, due to the available land area the technical aspects, associated costs, and potential revenue are somewhat different (see Table III).

TABLE III. TECHNICAL CHARACTERISTICS, COSTS AND REVENUE.

Site coordinates	43.761 °S, 172.206 °E	
Global Horizontal Irradiance (W/m²)	1,380	
PV Array area (ha)	2.0	
Racking	**Fixed**	**Tracking**
String inverters (kW)	10 x 110	9 x 110
Row spacing (centre to centre) (m)	10.3	6.4
Space between rows (m)	6.0	4.0
Cover ratio (%)	45	36
DC size (kW)	1,452	1,214.4
AC size (kW$_{\mathrm{ac}}$)	1,300	990
Specific yield (kWh/kW$_{\mathrm{p}}$)	1,408	1,649
Annual energy (MWh)	2,045	2,003
Project Development, Consent, and Grid Connection (NZ$)	390k	390k
Project Design and Build (NZ$)	2.6 - 2.9 million	2.1 - 2.7 million
Estimated revenue ($/MWh)	96-144	96-144
Estimated revenue (‘000 $/ha)	98-147	96 -144

For the financial analysis the following assumptions were specific to this dairy farm and different from the first case study:

- The annual pasture production from the 2 ha dryland area is 10.5 t/ha.
- Fertilizer and re-grassing costs would reduce by $775.80/ha.
- Supplement harvesting costs would be reduced by $893/ha, as the majority of the dryland feed is grown when there is a surplus.
- The reduction in pasture would be replaced by Palm Kenrel Extract (16t @ $480/t), which equates to $3840/ha.
- There would be additional running costs from the increase in bought-in supplements of $792/ha.

The key findings are then as follows:

- In the case of dairy, the capital cost is greater due to the increased height above the ground that the panels need to allow cows to graze underneath. However, there is a greater opportunity to use electricity generated in the dairy business to run the dairy shed, irrigation and potentially in the future any electric vehicles than there is in the sheep and beef case, due to the greater electricity demands of the dairy system.
- Income lifted due to additional solar income by $240,000.
- Expenses increased by $28,606, mainly due to solar running costs, but also additional supplement to offset the loss of dryland.
- Depreciation lifted by $104,000 due to 30-year life span of solar panels.
- The term loan increased by $3,120,000.
- Net Profit (after debt servicing and depreciation) dropped by $64,400 due to increased borrowing, as the 5.5% interest rate was not being covered by increased income.
- Return on Asset (EBITDAR/Total Asset Value) dropped from 7.98% to 7.76%.
- Return on Equity (Net Profit/Equity) dropped from 8.89% to $8.06%.

The analysis shows that agrivoltaic systems will likely have a smaller impact on dairy farm productivity, compared to sheep and beef farming. Indeed, both the Return on Asset and Return on Equity are less with a PV system installed than the status quo scenario. This reflects the greater return from the land asset generated by dairy compared to sheep and beef enterprises and the significant capital investment that is required for solar developments, since the solar panels would need to be elevated for the larger livestock to graze underneath, which would increase expenses and risk of wind shear. Incorporation of solar generation on dairy farms might be best suited to non-productive areas of the farm or on shed roofs.

IV. CONCLUSIONS

There is a lack of evidence in the literature in relation to the impact of agrivoltaics in an Aotearoa New Zealand context due

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This research project was supported by the Rural Professionals Fund 2022-23 of Our Land and Water, one of the National Science Challenges funded by the Aotearoa New Zealand government.

to minimal examples of agrivoltaic systems currently in existence in the country [12]. Based on overseas research, there are potential benefits for integrating solar production with agriculture in Canterbury and other regions of Aotearoa New Zealand. These include livestock wellbeing and productivity; pasture and crop production, particularly in dryland areas; and an increase in overall land productivity. However, potential downsides are also highlighted, particularly relating to pasture production losses due to shading, environmental impacts and economic outcomes compared to standard solar energy systems [12].

The risk of displacement of food production by traditional solar farm developments is a major contributor to the interest and investment in agrivoltaics system. However, without definitions of what constitutes agrivoltaics in Aotearoa New Zealand, there is a risk of green-washing, where standard utility-scale solar farms claim agrivoltaics status, simply by grazing sheep underneath panels, but without making any adaptations to designs to reduce food production losses and environmental impacts of the farmland it is situated on [12].

The outcomes of this research indicate that agrivoltaics is technically and economically feasible in the Canterbury region, and likely to be of particular interest to sheep and beef farmers, but less so for dairy farmers. Further agrivoltaic trials and modelling based in Canterbury and other regions of Aotearoa New Zealand will be critical to obtaining a more comprehensive understanding of how agrivoltaic systems might align with the country's long-term goals of increasing renewable energy production, without displacing food production or negatively affecting environmental outcomes. End of panel life recycling options also need to be developed and the environmental impacts explored in further detail. Finally, there is a need for further dissemination of information for farmers and support to build long-term trust-based relationships with potential investors and solar business partners [12]. It is intended that the agrivoltaics assessment tool and agrivoltaics information booklet produced as part of this research will begin to address this need [13].

ACKNOWLEDGMENT

The authors acknowledge staff at Tambo NZ and Infratec that contributed to the research in various ways, for the farmers of the case studies for participating in the research, and for Our Land and Water for providing financial support and disseminating the information to stakeholders in Aotearoa New Zealand.

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