Cultivating the sun:

Challenges and opportunities of solar farming for drystock farm diversification

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Table of contents

Table of figures

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Artificial Intelligence (**AI**), specifically ChatGPT was used to double check thematic analysis of interview transcripts. The methodology section of this report highlights how AI was used.

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Abbreviations

Aotearoa New Zealand	NZ
Consumer Price Index	CPI
Electricity Distribution Businesses	EDBs
Fast Track Approvals Bill	The Bill
Fast-Track Consenting Act	The Act
Global Horizontal Irradiance	GHI
Kilovolts	kV
Levelised Cost of Energy	LCOE
Megawatts	MW
National Policy Statement for Highly Productive Land	NPS-HPL
National Policy Statement for Renewable Electricity Generation	NPS-REG
Net Zero Grid Pathways 1	NZGP1
Not In My Back Yard	NIMBYism
Overseas Investment Act	OIA
Photovoltaic	PV
Resource Management Act	RMA
United States	US

Executive Summary

Aotearoa New Zealand (**NZ**) has attracted significant interest as a potential location for solar farming in recent years. Solar panels located on land presents both opportunities and challenges to conventional pastoral farming systems.

This report investigates the challenges and opportunities of solar farming as a potential diversification strategy for drystock farming (beyond just self-sufficiency for powering homes or farm energy demands). The objectives of this study were to:

- Investigate and analyse the current challenges and opportunities in NZ.
- Inform policy makers, drystock farmers, and other agricultural stakeholders about the potential implications of integrating solar farming as part of a diversified farm strategy, and
- Propose future recommendations for industry, Government, and drystock farmers looking to potentially diversify with solar farming.

A literature review was undertaken to understand existing knowledge. To gain a better understanding in a NZ context, thirteen semi-structured interviews were completed. An inductive thematic analysis method was used to interpret themes in the context of Rogers diffusion of innovations theory.

Findings reveal that solar farming has potential to be a viable diversification strategy, however, based on location and network limitations, it will not be a silver bullet solution for every drystock farmer. For farmers that can viably consider it, lease terms with solar development companies can provide significant returns compared to traditional drystock farming. Agrivoltaics has potential to address environmental, economic and social effects associated with solar farming. However, it needs to be appropriately managed through regulation and collaboration, to address challenges and optimise solar integration with NZ agriculture.

Recommendations for industry and Ministry for the Environment, Ministry for Business, Innovation and Employment, and Ministry for Primary Industries include:

- NZ based research to inform policy and challenges and opportunities for NZ pastoral systems and climate. Investment in research is needed.
- Development of publicly available resources for both drystock farmers and communities. This should include a guide to solar farming and agrivoltaics for farmers, which should share learnings of solar farming and agrivoltaics to date in NZ. There is also a need for resources including performance standards.

For drystock farmers specifically, recommendations include:

- Having clarity on long-term aspirations for farming operation and community.
- Having discussions with developers, or local Electricity Distribution Business.
- Due diligence is important, such as finding a developer that aligns with aspirations, and seeking legal and financial advice where appropriate.
- Thinking about how diversification with solar may change management practices moving forward and talking to other farmers to understand the practicalities of going down this path.

1. Introduction

Electricity plays a pivotal function in everyday life. From switching on a light, to powering a milking shed, cooking a meal, running a woolshed, or moving a centre pivot around a paddock for irrigation demands. Aotearoa New Zealand (**NZ**) inherently relies on electricity for a functioning society, and economy.

The natural climate and geography of NZ means an abundance of renewable energy sources can be harnessed to meet the energy needs of the population. NZ has a range of electricity sources, such as hydroelectric, geothermal, coal, natural gas, and wind. However, a surge in opportunity in the solar energy space has begun in recent years. NZ has attracted significant interest as a location for potential solar development because of its sunlight hours, expansive rural landscapes (Hinds et al., 2023), and the growing demand for power.

The need and desire for solar panels to be located on land (and often land currently used for primary production) presents both opportunities and challenges to conventional pastoral farming systems in NZ.

The following research report will delve into those challenges and opportunities of solar as a potential diversification strategy for drystock farming businesses. Specifically, this report looks at drystock farms installing large collections of panels beyond just self-sufficiency for powering their homes or farm energy demands. This is achieved by diversifying part of their farming operations to have mixed land use with solar. For the purposes of this report, drystock refers to sheep, beef and deer farming.

1.1 What is solar farming?

Solar farming refers to a large collection of photovoltaic (**PV**) solar panels located on land, that absorb energy from the sun. Absorbed energy is converted into electricity, which is fed into the national or local power grid which distributes electricity across NZ (Manawa Energy, n.d.).

The integration of agriculture and solar energy on the same piece of land, referred to as 'agrivoltaics', seeks to find synergies between both practices to create a complimentary system (Vaughan et al., 2023). Successful agrivoltaic systems require consideration in the design stage and has the potential to increase land productivity by essentially 'capturing' the sun twice (i.e., on the PV panels, and on the pasture beneath it).

For the purposes of this research report, the challenges and opportunities cover both solar farming (i.e., placing PV panels on land) and agrivoltaics (i.e., PV panels and continued drystock farming beneath them).

1.2 Renewable energy in Aotearoa New Zealand

The NZ government has ambitious goals to meet when it comes to reducing greenhouse gas emissions. Some key policy settings include (Ministry for the Environment, 2023a):

- The domestic target under the Climate Change Response Act is net zero emissions of all greenhouse gas emissions (other than methane) by 2050. For methane, a 24 to 47 percent reduction below 2017 biogenic emissions by 2050 are required, including 10 percent reduction below 2017 biogenic methane emissions by 2030.
- Under the Climate Change Response (Zero Carbon) Amendment Act 2019, carbon dioxide and nitrous oxide should be net zero by 2050.
- NZ has an international target under the United Nations Paris Agreement 2020-2030, to reduce emissions to 50 percent below 2005 levels by 2030.

Electricity has a role to play in achieving these climate ambitions. Decarbonising the electricity sector involves significantly reducing the use of fossil fuels. It will also involve increasing the use of electrification for transportation, and process heat used in industrial processes (Electricity Authority Te Mana Hiko, n.d.).

In 2022, 87 percent of the electricity generated was from renewable sources, with hydroelectric generation accounting for 60 percent of this. Reaching 100 percent renewable electricity requires a pragmatic approach to account for a dry year (meaning hydroelectricity is not operating at its peak), and a forecasted decline in the gas sector (Ministry of Business, Innovation & Employment Hīkina Whakatutuki, 2023a).

In addition to the push towards 100 percent renewable, forecasts are also predicting an unprecedented level of growth in demand for electricity. This will in part be driven by a switch from fossil fuel-based energy to renewable electricity. Analysis predicts that electricity demand by 2050 will increase anywhere between 70 to 170 percent above current levels. This exponential increase will require significant increase in generation, transmission, and distribution infrastructure, and at a large scale (Ministry of Business, Innovation & Employment Hīkina Whakatutuki, 2023b).

1.2.1 Current and future state of play for solar

Solar energy has the potential to play a key role in future generation as the demand for electricity increases. In recent years, falling module costs have made large scale solar farms commercially viable in the NZ electricity generation market, and this decrease in costs is expected to continue. In 2021, solar PV accounted for 1 percent of NZ electricity supply, and forecasts suggest that it has the potential to increase up to 6 percent by 2035 (Energy Efficiency & Conservation Authority Te Tari Tiaki Pūngao, n.d.).

The Net Zero Grid Pathways 1 (**NZGP1**) Major Capex project investigation scenarios of Transpower projects solar to generate between 700 megawatts (**MW**) to 2600MW of energy by 2050 (Transpower New Zealand, 2021). For comparison, the total generation capacity across all sources in 2022 was 9,790 MW (Ministry of Business, Innovation & Employment Hīkina Whakatutuki, 2023a). Transpower expects that distributed, small-scale solar PV systems, for example on roof-tops, will provide at least half of NZ solar PV generation capacity by 2050, with land-based PV farms providing the remaining generation capacity (Transpower New Zealand, 2021).

1.2.2 Generation and distribution

In NZ, most of the power generation is by 'Gentailers' which are companies that both generate and retail electricity. They account for about 90 percent of the power consumed (Ara Ake Future Energy Development, 2023). The remaining portion comes from independent entities known as Independent Power Producers and individuals or organisations with small scale projects (such as solar). This diversification supports the transition towards a more resilient and suitable energy system for the country (Ara Ake Future Energy Development, 2023).

1.3 The need for farm diversification

Farm diversification refers to a farm varying its operation by taking a portfolio approach. This can be by producing alternative products, species or mixed land use activities to protect against potential market downturns. Often, this takes the form of a proportion of land being dedicated to niche production, while the main farming operation continues (Bayne & Renwick, 2021). Ultimately, diversification requires a change in thinking about the way the land is used and adapting part of the farm for a different purpose.

Solar farming may be considered for farm diversification for two key reasons:

1. To produce an alternative income stream, and/or:
2. To lower the farming operation carbon footprint.

For the sheep and beef sector, it could be argued that farm diversification is more relevant now than ever before. It is forecasted for the 2023/24 season that total gross farm revenue per hectare will be $894.43, with total farm expenditure at $805 per hectare (Beef + Lamb New Zealand, 2024). Forecasts estimate that farm profits (before tax) will decrease 54 percent compared to 2022/23 season, to an average of $62,000 per farm (Burtt et al., 2024). The expected decrease follows a decrease of 29 percent the previous year. Adjusted for inflation, the level of profitability forecasted for this season is broadly similar to the 1980s and early 1990s and is the lowest since the 2007/08 season (Burtt et al., 2024).

The forecasted fall in profit is being driven by lower gross farm revenue, and increased farm expenditure. The lower gross farm revenue results from a 7 percent decrease in cattle revenue, and 18 percent lower sheep revenues. Farm expenditure is forecast to increase 0.7 percent to an average of $563,500 per farm. With lower cashflow and profitability for the sector this season, debt reduction is unlikely, meaning farmers will have less in their back pockets after meeting other financial obligations. This has flow on effects with less to spend in their local communities (Burtt et al., 2024).

Modern deer farming in NZ is often run as part of a wider farming operation with sheep and/or beef livestock (Hall, 2023). For the deer industry, most processors are currently paying around $8.70 per kilogram of carcass weight excluding premiums for venison (Hillhorst, 2024). Deer velvet exports are in an interesting period, with the average farm gate price per kilo for the 2022/23 season of $105 per kilogram (Deer Industry New Zealand, n.d.). However, China as the largest market for this product as of 1 May 2024 no longer accepts frozen velvet and instead will only accept it in a dried state (Hillhorst, 2024).

A turbulent primary sector can place immense pressure on farmers particularly in an economic and social context, and therefore diversification presents an opportunity to spread risk during volatile times.

2. Research aims and objectives

The aim of this research was to investigate the challenges and opportunities of solar farming as a potential diversification strategy for drystock farms in NZ. This research project provides an examination of the challenges, and opportunities of solar farming as a farm diversification strategy. The key research question was:

What are the challenges and opportunities of solar as a diversification strategy for drystock farms in Aotearoa, New Zealand?

With a focus on diversification by changing part of the farming operation (i.e., a portion of the farm changing land use to solar), the objectives of this research report were to:

- Investigate and analyse the current challenges and opportunities of solar diversification for drystock farmers in an NZ context.
- Inform policy makers, farmers, and other agricultural stakeholders (such as rural professionals) about the potential implications of integrating solar farming as part of a diversified drystock farm strategy.
- Propose recommendations for industry and government to better understand and navigate solar and agrivoltaics in NZ, and.
- Propose future recommendations specifically for drystock farmers considering solar as a diversification strategy.

3. Methodology

3.1 Data collection

3.1.1. Literature review

A literature review was undertaken to understand what existing knowledge was available regarding solar in NZ as a diversification strategy for drystock. The review highlighted that there is a lack of literature in the NZ context, due to the relatively new nature of solar farming in the country. A second literature review was undertaken with a global perspective to understand challenges and opportunities at a global scale, that could have relevance to the NZ setting.

A variety of literature sources have been employed in this review, including research reports, journal articles, peer reviewed research papers, and websites.

Approximately six key themes of research appeared. Literature was found to relate to both agrivoltaics and solar farming, and development of farmland. These themes are expanded on in the following sections of this report.

3.1.2 Semi-structured interviews

To gain a better understanding of the research topic in a NZ context, thirteen semi-structured interviews were undertaken with a range of industry representatives. Participants were found online, and by approaching industry contacts for relevant participants. The aim of the semi-structured interviews was to explore to perceptions, attitudes, and experiences of solar farming as a farm diversification strategy. Four of the thirteen interviews conducted were with multiple people, to ensure that knowledge on the topic was captured by the right people from various parts of the sector. A total of 17 people were interviewed for the purposes of this report.

A list of the types of interviewees as well as the questions asked during interviews can be found in Appendix 1.

3.2 Data analysis

3.2.1 Thematic analysis

Thematic analysis is a qualitative research method used for identifying, analysing, and reporting patterns within data (Braun & Clarke, 2006). Thematic analysis can be a constructionist method which examines the ways in which meanings, realities, experiences and events are the effects of a range of discourses operating within society (Braun & Clarke, 2006).

An inductive thematic analysis method was used to analyse interview transcripts, to identify key themes as they relate to the opportunities and challenges related to the adoption and diffusion of solar farming for drystock farmers.

Themes were determined by transcribing semi-structured interview answers and using the 'Delve' online coding software to organise findings into key themes and sub themes. Themes from this analysis were reviewed and combined (where considered appropriate), with key results summarised. The 'Miro' online tool was used to create a thematic analysis map, showing the relationship between themes to provide an overarching thematic framework.

Artificial intelligence (**AI**) was employed in this research project to check thematic analysis undertaken and highlight any missing information. Specifically, ChatGPT 4.0 was used to summarise coded data for key themes, and this was compared against thematic data analysis completed using the Delve software tool.

3.3 Interpretation

3.3.1 Rogers diffusion of innovations theory

Everett Rogers diffusion of innovations theory (Rogers, 1983) explains how, over time, an idea gains momentum and 'diffuses' or spreads, through a specific population or social system. The result of this diffusion is that people, as part of a social structure, adopt a new idea, or behaviour.

Adoption does not happen simultaneously in a social structure, rather it is a process whereby some people are more likely to adopt the innovation than others. There are five established adopter categories, as summarised below and demonstrated in Figure 1 (Rogers, 1983):

1. Innovators (venturesome) – this refers to people who want to be the first to try an innovation. They are interested in new ideas, and willing to take risk. An innovator may not be respected by the other members of a social system, but they play a key role in the diffusion process and the flow of new ideas into a social system. Very little, if anything, needs to be done to appeal to this population.
2. Early Adopters (respectable) – this refers to people who are more integrated into the local social system than innovators and has the greatest degree of opinion leadership in most social systems. Potential adopters look to early adopters for advice and information, and they are aware of the need to change and so are very comfortable adopting new ideas. Strategies to appeal to this population include how-to manuals and information sheets on implementation.
3. Early Majority (deliberate) – these people adopt new ideas just before the average member of a social system and are an important link in the diffusion process. They may deliberate for some time before adopting a new idea. These people are rarely leaders, but they do adopt new ideas before the average person. Strategies to appeal to this population include success stories and evidence of the innovation's effectiveness.
4. Late Majority (sceptical) – These people are sceptical of change and will only adopt an innovation after it has been tried by the majority. Strategies to appeal to this population include information on how many other people have tried the innovation and have adopted it successfully.
5. Laggards (traditional) – These people are last to adopt an innovation. While most individuals in a social system are looking to the road of change ahead, the laggard's attention is fixed on the rear-view mirror. Strategies to appeal to this population include statistics, and pressure from people in the other adopter groups.

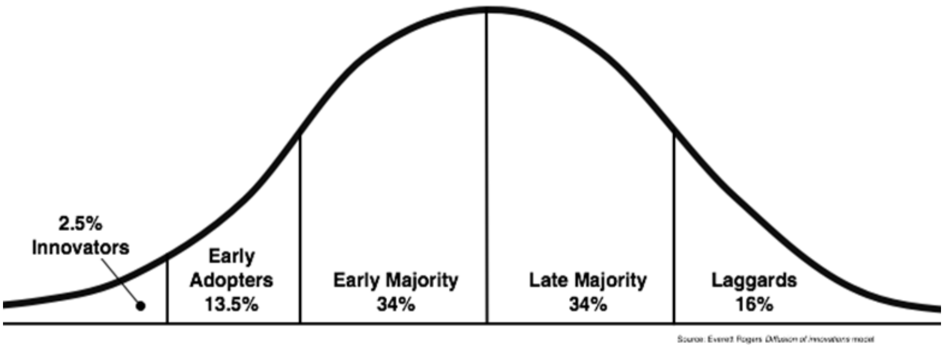

***Figure 1**– Rogers (1983) established adopter categories (page 247).*

The adoption of solar farming as a diversification strategy is identified as an idea or innovation that at present has been introduced to the rural community in NZ. Therefore, the diffusion of innovations theory can be used to analyse the current situation of solar in the context of a diversification strategy for drystock farmers.

There are five main factors that influence the adoption of an innovation. These include (Rogers, 1983):

1. Relative advantage – the degree to which an innovation is seen as better than the idea it replaces.
2. Compatibility – how consistent is the innovation with the values, experiences and needs of potential adopters.
3. Complexity – how difficult is the innovation to understand and/or use.
4. Triability – the extent to which an innovation can be tested or experimented before a commitment to adoption.
5. Observability – the extent to which an innovation provides tangible results.

Research themes found through thematic analysis were interpreted in the context of Rogers diffusion of innovations theory, considering how identified challenges and opportunities in the NZ context influence the diffusion of solar farming.

By applying Rogers diffusion of innovations theory as a qualitative methodology, it is intended to gain a nuanced understanding of the contextual challenges and opportunities underlying the adoption and diffusion of solar farming as a diversification strategy for drystock farmers in NZ.

Discussion on these known challenges and opportunities will allow for recommendations and potential next steps for the NZ context.

4. Literature review

4.1 Introduction

This literature review critically evaluates a range of NZ and international literature to explore solar farming and agrivoltaics in the context of drystock farm systems, and the rural sector. The review covers relevant literature that describes the challenges and opportunities of solar farming as a diversification strategy for drystock farmers. NZ literature in this field has been discussed, however is quite sparse. International research has also been analysed to inform current knowledge in this space.

Application of Rogers diffusion of innovations theory in the context of solar has also included in this literature review.

4.2 Diffusion of innovations theory in solar farming

Observability, relative advantage and compatibility have been identified as critical components of Rogers diffusion of innovation for farmer adoption of agrivoltaic technology. When considering barriers to farmer adoption, long term land viability and land productivity and economic concerns were raised as barriers to adoption (observability). Farming is accompanied by risks, and certainty in productivity and security in investment are vital.

Participants felt that the market unknowns of solar were more critical than the technical unknowns of agrivoltaics (Pascaris et al., 2020). The degree to which agrivoltaics is advantageous to current practice is an important element in considering adoption, and the relative advantage of doing so. A considerable opportunity for farmers in agrivoltaic projects is the potential for integration of the solar (as the innovation) into their current farm operation. The compatibility was viewed favourably. Barriers to adoption are not insurmountable and can be sufficiently addressed through prudent planning and mutually beneficial land agreements between solar and the agriculture sector (Pascaris et al., 2020).

4.3 Solar farming and rural communities

4.3.1 Solar potential for Aotearoa NZ farmland

Land use suitability is a key consideration for solar potential. This requires both consideration of the solar irradiance (Global Horizontal Irradiance – **GHI**), utility scale solar output at each location, and the proximity to electricity grid infrastructure (both transmission and distribution). Utility scale solar systems of capacity between 1 MW and 200 MW would typically involve dedicated land purchase, or lease for the purpose of solar generation (Miller 2020).

NZ studies have investigated the suitability of farmland for solar generation, which considers the solar resource of areas of farmland, and proximity of land to the electricity transmission grid and distribution network through information and proxies (Miller 2020, and MacKenzie et al., 2022). An example is provided in Figure 2 below.

Solar should be within a certain distance from major power transmission lines (which reduces the cost of construction and effects on the environment). Major power transmission lines reach most regions in NZ; however, some major power transmission lines do not reach some of the eastern regions of the North Island which have a good solar resource (MacKenzie et al., 2022).

Further to these considerations, the slope and aspect of the land can determine both the amount of electricity generation and the construction costs of solar development. Typically, surfaces with low slopes are more suitable, while north-facing slopes are preferable (in the southern hemisphere) (MacKenzie et al., 2022).

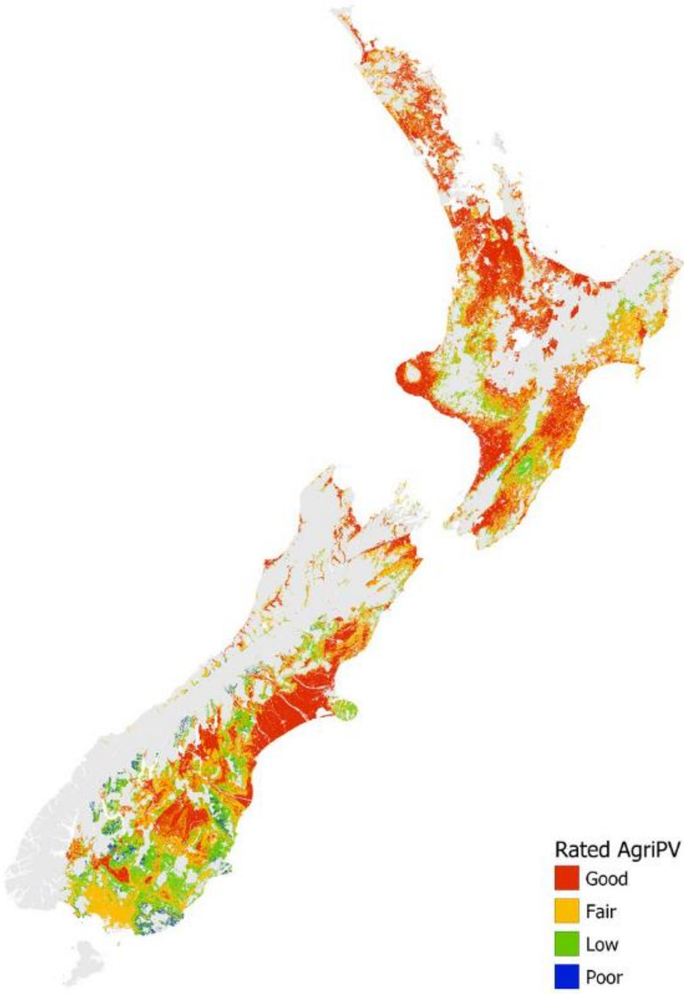

Figure 2 *– MacKenzie et al (2022) - AgriPV suitability map for dairy grazing grassland, non-dairy grazing grassland, perennial cropland, and annual cropland (page 4).*

It is estimated that 33 percent of non-dairy grazing grassland has a 'good' suitability rating, with a further 43 percent having a 'fair' suitability rating for solar potential in NZ. It was observed that while perennial cropland and annual cropland have a high proportion of 'good' suitability ratings (94 percent and 92 percent respectively), the amount of non-dairy grazing grassland with a 'good' suitability rating is larger than cropland. It is suggested that small scale agri-solar developments would be suitable for cropland, and larger scale developments would be more suitable on grassland (MacKenzie et al., 2022).

In the NZ context, it is noted that farms are usually owner operated and have space and access to sunlight, that positions them well to provide mid-scale solar electricity solutions (i.e., 100 kilowatts to 10MW) of generation). They are also often close to medium-voltage electricity networks, meaning that farms with mid-scale solar generation and access to medium voltage networks can usually export as much electricity as their grid connection size allows (Thorn & Casey, 2024). It is also noted that battery banks provide an option for adding significant resilience to the grid so energy can be stored and exported when it is needed (Thorn & Casey, 2024).

Since July 2020 (and as of 8 June 2024), Transpower has received 250 enquires related to solar (by planning region) which includes enquiries related to both the electricity and distribution network. The five regions with the highest enquiries are Central North

Island (49), Waikato (34), Canterbury (32), Northland (30), and Bay of Plenty (23) (Transpower New Zealand, 2024).

For the period between 2024-2027, uncommitted but actively pursued energy projects were largest for solar and totalled over 12,000 GWh (out of the 20,000 GWh that could potentially be completed over the next four years). It is understood that 63 percent of actively pursued projects (by output) that could be completed by 2027 are solar projects, a large proportion of which are in the hands of international developers (Concept Consulting Group, 2023).

As of May 2024, the Government has approved the sale or lease of 2900 hectares to foreign investors for the construction of solar farms since July 2022 through the Overseas Investment Act (**OIA**). Applications for the sale or lease of a further 680ha is currently being processed (Piddock, 2024). Further, this does not include developments occurring that do not need to go through the OIA process across NZ.

4.3.2 Social considerations

4.3.2.1 Farmer adoption

The adoption of solar farming or agrivoltaics by farmers has various factors at play. Decisions on the adoption of solar are largely driven by economic and environmental considerations, as well as the perceived 'usefulness' of bringing solar into farming operations (Brudermann et al., 2013, Wagner et al., 2024). Ethical or social considerations are relatively strong among farmers; however, they cannot be used as predictors in the decision-making process for the uptake of agrivoltaics (Wagner et al., 2024).

Solar farming has been identified by farmers as a way to protect the social license to farm in NZ. Many farmers appear open to the idea of agrivoltaics, provided that key concerns are addressed (such as capital costs, and the future value and ability to sell the land) and it is financially viable. The integration of solar with pastoral farming can result in reduced emissions, lower environmental impacts and better animal welfare. This therefore can have a positive public perception while improving animal production (Vaughan et al., 2023). However, there is an identified lack of skills in running an effective agrivoltaic system has been identified by NZ farmers as a potential barrier to the adoption of solar farming (Vaughan et al., 2023). There is an opportunity in this challenge to seek ways to reduce labour through harnessing synergies in innovative practice, and to make the integration and compatibility of solar with current production as streamlined as possible to increase farmer acceptance (Pascaris et al., 2020).

Sector perspectives on the adoption of agrivoltaics highlight barriers such as certainty of long-term land productivity, market potential and observability of benefits, just compensation, and system flexibility to accommodate different scales, types of operations, and changing farm practices (Pascaris et al., 2020). Alongside identified challenges, and opportunities include the development of agrivoltaic contracts which recognise the rights and duties of involved parties, which provide the opportunity to establish legitimate, mutually beneficial partnerships. Farmer willingness to adopt solar provides a unique opportunity to derive a revenue stream with the combination of solar and agricultural systems (Pascaris et al., 2020). Market unknowns also pose a potential barrier to farmer uptake of agrivoltaics (MacKenzie et al., 2022).

For farmers looking to diversify with solar with their own capital, finance has been identified as a barrier to uptake. The potential of low-cost finance provides an opportunity for farmers to de-risk upfront capital and unlock a new revenue stream for farms faster (Thorn & Casey, 2024).

4.3.2.2 Community perceptions

Generally, communities appear to be more accepting of solar farming if it is integrated with existing agricultural production (Pascaris et al., 2022, Torma & Aschemann-Witzel, 2023). The basis on which stakeholders judge and decide on innovations such as agrivoltaics is crucial to understanding perception and adoption, especially when the potential value of an innovation is not solely on an individual level but also on a societal level (Torma & Aschemann-Witzel, 2023).

In an Australian study, it was found that at the early stage of the renewable energy transition, people expressed level of support for local large-scale energy projects. This was primarily informed by more abstract attitudes and beliefs about the environment and the utility of renewable energy technology. Support for local solar projects is less dependent on local factors such trust, procedural fairness, and governance. However, it is likely that most people have not yet formed their beliefs about the social context in which solar farms operate. Support for local solar farms may start to change as residents gain more experience living near solar installations and associated infrastructure, or if negative feelings are invoked through bad experiences. It is possible that if a negative sentiment takes hold at local levels, broader public narratives about the energy transition may become negative (Scovell et al., 2024).

Known community perceptions around solar development includes themes such as uncertainty (in terms of impacts), optimism (positive attitude towards low impact renewable energy), and wider community benefits. For local communities, social impacts upon their way of life and personal rights will be minimally impacted during solar farm operation. However, local communities also experience little in the way of direct economic benefit from having a solar farm operating nearby, raising social equity concerns (Hinds et al., 2023).

Social acceptance of agrivoltaics can have challenges particularly during establishment. This can be due to concerns about visual changes in the agricultural landscape (Wagner et al., 2024). Minimising conflict through site selection and addressing agricultural communities concerns will be key in the deployment of agrivoltaics, as localised acceptance has been found to be a critical determinant of success (Pascaris et al., 2022).

It generally appears that communities prefer agrivoltaic and solar projects that (Pascaris et al., 2022, Hinds et al., 2023):

a) Are designed to provide economic opportunities for farmers and the local community.
b) Are not located on public property.
c) Do not threaten local and community interests, and.

d) Ensure fair distribution of economic benefits.

Local factors are important for determining the impacts and benefits of solar, however the narrative that surrounds the role for renewables such as solar also needs consideration, including people of influence and how they shape public perception (Scovell et al., 2024).

In the NZ context, installing solar on farms could create thousands of skilled jobs in regions including solar installation jobs, and additional demand for electricians and maintenance workers. An upscale in the solar industry would benefit regional economies (Thorn & Casey, 2024).

4.4 Environment and economic considerations

4.4.1 Regulatory considerations

Solar farms are a new development activity, and as a result an assessment of the current planning instruments which impact its potential expansion is required. The Resource Management Act (**RMA**) (1991) is one of the key documents that regulates the appropriate use and development of the environment. It provides regional and local councils with guidance on rules and requirements on a range of activities that relate to people, the environment, and needs of the country (Eastlake, 2022). Local governments (i.e., regional and district councils) are responsible for the management of the environment and are required to put in place policies, objectives, and rules that allow for assessment of the effects activities, and resource consent applications.

The National Policy Statement for Renewable Electricity Generation (**NPS-REG**) (2011) provides guidance on how renewable electricity should be dealt with through the planning system. Renewable electricity is a matter of national importance under the RMA, which means that direction provided through the NPS-REG ensures consistency across NZ in the way it is assessed in the planning framework (Eastlake, 2022).

Most solar farms in the NZ context will require some form of resource consent under the RMA, with most requiring a land use consent (Vaughan et al 2023). A resource consent process is assessed by outlining the importance of both the positive and negative effects of the activity proposed, and compliance with relevant regulatory requirements through an assessment of environmental effects, notification status, and a hearing (where applicable) (Eastlake, 2022). It is highlighted that a further element of understanding effects in the environmental context, is understanding the meaning of 'environment' set out in the RMA:

"environment includes –

(a) Ecosystems and their constituent parts, including people and communities; and
(b) All natural and physical resources; and
(c) Amenity values and
(d) The social, economic, aesthetic, and cultural conditions which affect the matters stated in paragraphs (a) to (c) or which

affected by those matters…." (Resource Management Act, 1991, Part 1, Section 2).

The Fast-track Consenting Act (**the Act**) as part of the Covid-19 recovery was introduced in 2023. The Act is an alternative consenting pathway to the RMA for projects that boost employment and economic recovery. Several large-scale solar projects have been processed through this avenue. However, the Act will no longer apply from 8 July 2026 (Vaughan et al., 2023).

Further to this, consultation closed in April 2024 on a Fast-Track Approvals Bill (**the Bill**). The Bill would enable fast track decision making process for infrastructure and development projects that are considered to have significant regional or national benefits. It is understood that solar projects, alongside projects like coal and gold mining as an example, could be fast tracked through this process once enacted (New Zealand Parliament Pāremata Aotearoa, 2024).

The National Policy Statement for Highly Productive Land (**NPS-HPL**) (2022) aims to protect highly productive land (versatile and productive land) so it can be used for land based primary production (Ministry for the Environment, 2023b). The NPS-HPL provides for the maintenance, operation, upgrade, or expansion of specified infrastructure (including renewable electricity generation) if there is a functional or operational need for it to be on highly productive land. The exclusion of the terms 'new' or 'establish' has led to issues in consenting solar farms. As a result, in 2023 consultation was undertaken looking at potential amendments to provide a potential consent pathway for specified infrastructure (i.e., solar farms) to be located on highly productive land (Ministry for the Environment, 2023b). However, as of 9 June 2024, there has been no further updates on progress on this process.

An analysis of the current regulatory framework in NZ for solar farming has found that updates are needed to the NPS-REG, as well as updates to local government plans. This is to ensure that the development of solar is being provided for to meet renewable electricity demands, while ensuring the environment and any effects are managed and mitigated appropriately (Eastlake, 2022). It is also acknowledged that NZ does not have any guidance documentation around the establishment of solar farms that cover performance standards such as glint and glare, road safety, infrastructure requirements, and mitigation strategies. Encouragement and support for dual land use, such as agrivoltaics provides a significant opportunity for NZ but it needs to be appropriately addressed through regulation (Eastlake, 2022).

A final consideration is that the Electricity Authority requires grid connected inverter systems to comply with regulations. Systems exporting more than 10 MW back into the grid also need to register as generator providers (Vaughan et al., 2023). The viability of a solar farm development will depend on its ability to connect to the grid (either directly with Transpower, or through a local distributor) and connection works and agreements in this respect play a critical role (Vaughan et al., 2023, Johnson et al, 2022).

4.4.2 Solar farming and the environment

The impact of solar panels on farmland is not well known or researched, particularly in the NZ context. It is acknowledged that solar farming may require vegetation clearance, and soil disturbance which can fragment ecosystems (Gasparatos et al., 2017). It is also noted that the presence of solar panels may impact the microclimate of a site, with shading effects of soil and airflow alterations due to the installation of infrastructure. Existing literature availability is minimal, and there is a need for further research and analysis (Gasparatos et al., 2017).

The installation of panels and the glint effects on bird life has been explored. Bird communities were found to largely be adaptable, depending on the species that are more likely to interact with an area. Natural features such as plantings, native trees which contribute to the habitat are good mitigators that can assist with any disorientation effects (Visser et al., 2019, Harrison, 2016).

The rural character and landscape from a visual perspective is a key consideration when looking at the impacts of a solar farm on the wider environment. Large scale solar sites can significantly change the rural landscape. Landscape assessments are linked to visual and sensory perceptions of the land impact perceived values, which are inherently linked to culture and society. (Tolli et al., 2016). For this reason, design approaches should be intertwined with the ecological aspects of the land within an inclusive approach while achieving desired energy capacity (Scognamiglio, 2016).

In the NZ context, solar power is an attractive opportunity to offset our current electricity generation that is not renewable (such as gas fired thermal generation, indirectly through initially offsetting hydro generation, which would then offset gas generation at a later time). The benefit of solar to reducing greenhouse gas emissions in NZ is still small, due to relatively low uptake, and wind and geothermal generation having potential to reduce greenhouse gas emissions more because they have better capacity factors (Schwartfeger and Miller, 2015).

4.4.3 Agricultural production and animal welfare

NZ is a pastoral based agricultural sector that relies heavily on animal grazing. A key consideration of solar farming and agrivoltaics for the sector, and specifically drystock farm diversification is the feasibility of solar farm system and any potential impacts on livestock and forage production, which effects overall productivity.

Solar panels shade the areas directly beneath them, which may provide a shade option for livestock to mitigate heat stress, as well as shelter against harsh weather conditions. This in turn may provide both welfare and productivity benefits (Vaughan et al., 2023). Sheep have been found to spend 38% of their time under PV panels when they are present (Maia et al., 2020). Shade provided by solar panels provides a more comfortable microclimate and reduces heat stress indicators of sheep, such as radiant heat on the body surface (Carvalho Fonsêca et al., 2023). In terms of lamb growth and pasture production, lambs grazing under solar panels can maintain higher carrying capacity towards summer, and land productivity could be increased up to 200% by combining grazing and energy production on the same land. Summer lambs consumed less water than those on open fields, while dry matter yield from fully shared sites was substantially lower than pasture in open or partially shaded areas (Andrew et al., 2021).

Looking at the effects of panels on unirrigated pasture in the United States (**US**), significant differences in mean air temperature, relative humidity, wind speed, wind direction, and soil moisture was found beneath the panels. Areas maintained higher soil moisture, with a 90 percent increase in late season biomass. Areas under PV panels were 328 percent more efficient (Hassanpour Adeh et al., 2018).

Conversely, here in NZ, preliminary results from a Massey University pilot study looking at pasture composition, growth and quality under fixed solar arrays found it could have both positive and negative impacts on pasture growth. In a period between July 2022 to January 2023, pasture growth was reduced by 84 percent directly under the panels but increased by 38 percent in the larger areas between panels. In the areas between the panels, the panels may have allowed a lower soil temperature and slowed down the loss of soil moisture when compared to an open paddock (Rural News, 2023). However, it is acknowledged that more data from across NZ and differing environments is needed to understand the impact of panels on pasture in our climate (Rural News, 2023, Vaughan et al., 2023).

In terms of cattle grazing, solar panels would need to be located higher off the ground to allow cows to graze underneath which increases the capital costs (Vaughan et al., 2023). A US study found that agrivoltaics incorporated into pasture dairy systems may reduce the intensity of heat stress, increase the well-being of cows, and the efficiency of land use (Sharpe, 2021). Further, the impact of integrating agrivoltaics into a farming system is dependent on the site, characteristics of plants being grown, and the configuration and design of the PV panels (Vaughan et al., 2023). Improved production and water use efficiency are potential benefits to be realised by a successful agrivoltaic system.

It is acknowledged that further research is needed on the impact of solar panels on production of meat (Carvalho Fonsêca et al., 2023), and to understand potential financial impacts for farming systems (Vaughan et al., 2023).

4.4.4 Feasibility of solar for diversification

Ultimately, the feasibility of solar as a diversification strategy is a key consideration for farmers. The emerging discourse around energy development includes diversifying and benefiting from a secondary income source (Delfanti et al., 2016). The potential for integration of the innovation into current farming practices, reducing complications in the farming business, and finding ways to reduce labour through harnessing the synergies of innovative practices to compliment current farming practices are important considerations for feasibility (Pascaris et al., 2020). It is also noted that the costs of some solar technology and batteries is declining at a fast rate, which adds to the case for feasibility (Thorn & Casey, 2024).

Feasibility largely looks at the cost, both the initial investment and ongoing expense. The initial investment in a utility-scale solar system requires land purchase or lease, acquiring and constructing the solar generating plant, and building transmission or distribution to the electricity transmission or distribution network. Ongoing costs include operation and maintenance of the solar generating plant, operation and maintenance of the transmission or distribution connection assets, and tax costs (Miller, 2020). It has been forecasted that the costs for developing solar panels on high producing exotic grassland is $40,000 per hectare, $30,000 per hectare for low producing grassland; and $10,000 per hectare for depleted grassland (Miller, 2020).

Capital investment has been identified as a barrier to solar farming. However, to manage the capital cost while maintaining ownership of the land, farmers identified potential ownership models such as partnerships, leasehold, or owner/operator arrangements (Vaughan et al., 2023). Revenue would depend on the time of production and the spot market prices (Fitzgerald et al., n.d.). However, in the NZ context, under a solar leasing agreement, a farmer could be looking at between $2000 to $5,500 per hectare, adjusted annually. This is dependent on the individual developer, and how much the development costs including the connection to the grid (Dickey, n.d.).

Analysis of a case study sheep and beef farm in NZ (1,100 hectares effective, wintering 7,500 stock units in Canterbury) found that agrivoltaics presented a significant diversification opportunity to increase profitability. Comparing the 'status quo' (i.e., a sheep paddock) with a 100% agrivoltaics stocking rate reduction, adding solar panels to a 5.8-hectare site could increase income by $955,142, with net profit (after debt servicing and depreciation) increased to $419,450. The solar panels were assumed to be funded through borrowing, which increased the farms term loan by $5.625 million, with a depreciation of the solar panels over the 30-year lifespan. It was concluded that agrivoltaics in the Canterbury region is technically and economically feasible and is likely to be of particular interest for sheep and beef farmers, given current reduced farm gate product prices, compliance costs, and increased working expenses (Vaughan et al., 2023).

Agrivoltaic success and ultimately feasibility based on a research study in the US has been summed up as the 5'Cs (Macknick et al., 2022), as detailed below:

1. Climate: soil and environmental conditions
2. Configurations: solar technologies and designs
3. Crop selection and cultivation: methods, seed and vegetation selections, and management approaches.
4. Compatibility and flexibility: the needs of design and configuration with the competing needs of researchers, solar owners, agricultural practitioners, etc.
5. Collaboration and partnership: understandings and agreements made across stakeholders to support agrivoltaic installations.

For NZ farmers, the need for accessible and easily understood resources to inform decision making and provide confidence to engage in conversations, and form partnerships with solar companies was identified as a key requirement moving forward (Vaughan et al., 2023).

5. Findings and discussion

The following section discusses the key findings from semi-structured interviews. Interview responses were analysed as described in the methodology section (Section 3). High level themes of the findings, and the relationship between them is outlined in the thematic map (Figure 3) below.

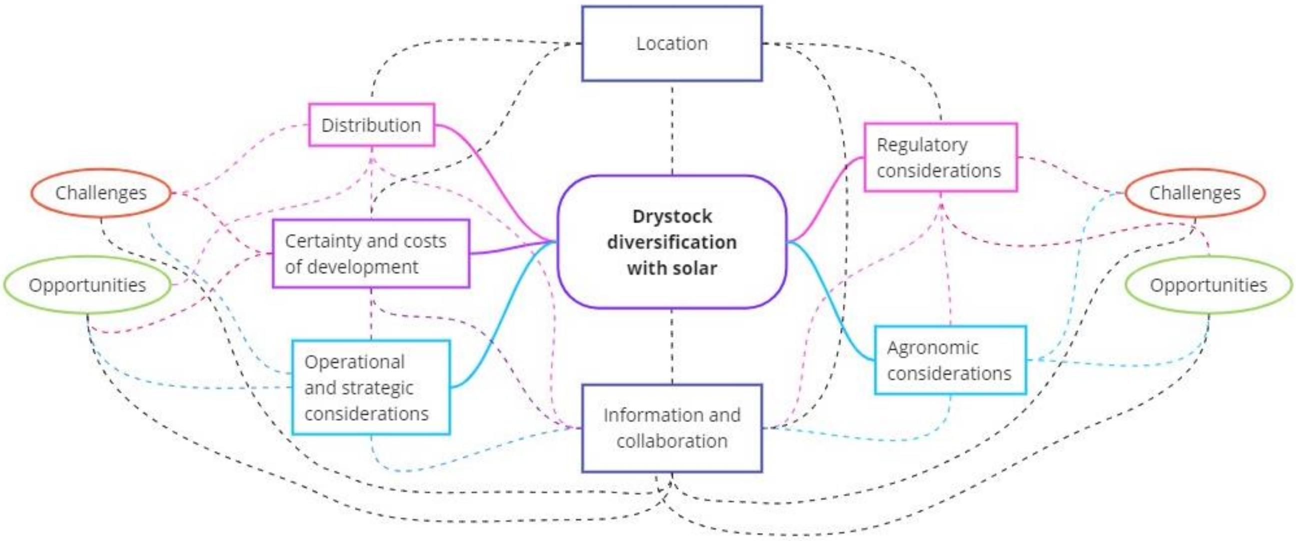

***Figure 3** – High level themes of research findings developed using Miro.*

5.1 Solar trends in Aotearoa New Zealand

Participants were asked about their experiences and awareness of locations of solar in NZ to date. Participants generally noted that there has not been significant investment in energy for a long time, but the need for greater national electricity supply has gained momentum particularly in the last few years. Participants also highlighted that was recently spotlighted in May 2024 where Transpower asked for the country to reduce power usage where possible due to potential shortages in generation.

Solar poses a potential solution to some of these energy challenges. There are many opportunities due to increasing energy demands, global policy settings requiring reductions in emissions, and improvements in the affordability of solar technology. The reduced Levelised Cost of Energy (**LCOE**) make solar projects economically viable in the NZ generation market. Participants noted that there is a lack of subsidies and incentives in NZ for solar, but the declining costs of solar technology help mitigate this.

Participants also acknowledged that NZ already generates most of its electricity from renewable sources. However, the integration of solar into our energy system will help meet future energy needs, diversify energy sources, as well as minimising reliance on coal, oil and gas. Some participants discussed NZ and the current and potential for data centres, which will also increase power demand. Further, participants acknowledged that there are limitations on other renewable resources, noting the lengthy and complicated nature of applications for projects such as hydroelectricity, and wind energy as examples. Solar projects can be rolled out much faster compared to these types of projects.

It was observed that regions with flat land and high GHI are generally prioritised for potential solar development, which aligns with literature (Miller, 2020). NZ is narrow, with mountainous geography and lower GHI compared to other countries means that often, suitable areas overlap with productive agricultural land, which can pose challenges. Project locations are often chosen based on the available solar resource, grid connection availability, and nodal prices.

Many participants noted that many suitable farmland areas will have already been identified by solar development companies. However, one participant noted that there is a huge amount of land suitable for solar, and thought it was unlikely that more than an eighth of these landowners would have been contacted yet. Many participants referred to the global solar atlas maps which show PV power potential and GHI for countries, including NZ.

Participants commented that many large-scale projects are in the planning stage, with the potential for hundreds of megawatts of solar power being developed in the future. By 2030, participants anticipate a substantial increase in solar generation capacity. Despite significant interest and the potential for projects, the number of operational solar farms at present is small, despite many perceptions that solar is 'taking over' agricultural land. One participant estimated that agricultural land used for solar farming currently is approximately 0.2 percent.

Participants generally agreed that the North Island of NZ, particularly Northland, Waikato, Bay of Plenty, and Wairarapa is seeing more solar development due to higher electricity demand and better GHI. Participants observed that there is a trend towards more solar projects in the North Island compared to the South Island. While less emphasis is placed on the South Island, areas like Central Otago and Canterbury are being considered and seeing development. It was also noted that mid-Canterbury and the Ashburton District has higher transmission capacity due to irrigation demands during summer. Observations made by participants generally aligns with existing literature and in particular the AgriPV suitability maps (Mackenzie et al., 2022) and Transpower solar enquiries (Transpower New Zealand, 2024).

5.2 Location

Ultimately, participants noted that the location of drystock farms is a key determinant in whether solar is a viable diversification strategy. Proximity to substations and main grid lines significantly influences the viability of solar farm locations. Some participants noted that developers may compromise GHI of a site for an easy grid connection. Solar project locations either need to be close to the national grid for large scale projects, or close to a substation for smaller scale projects and ideally flat. Proximity to electricity infrastructure (ideally within 5 kilometres of a substation, but one participant noted that one solar farm is 20km from a substation) and minimal slope (ideally less than 5 degrees) were common themes from participants, and this was found to be consistent with literature (MacKenzie et al., 2022). If they are not, this increases the connection costs and therefore economies of scale are needed in terms of the size of the development.

Smaller scale projects can typically connect to the low voltage local distribution system, while larger projects require connection to the higher voltage systems. The capacity of local networks (measured in kilovolts – **kV**) varies by region and current network inputs, which influences the potential size of solar projects that can be supported in different areas.

These findings align with existing literature whereby the viability of a solar farm development will depend on its ability to connect to the grid (either directly with Transpower, or through a local distributor) and connection works and agreements in this respect play a critical role (Vaughan et al., 2023, Johnson et al., 2022). Ultimately, this means that solar as a diversification strategy may be suitable for some, but it will not be viable for all drystock farmers across NZ. However, as one participant coined it, it may be a 'tool in the toolbox' for some drystock farmers.

5.3 Drystock diversification with solar

5.3.1 Distribution

Challenges

Participants acknowledged that existing grid infrastructure is not fully optimised for widespread solar. Investment in battery storage in the short term was considered crucial to balance supply and demand, especially when solar generation is high during the middle parts of the day (and therefore prices are lower). This is also important for when solar is generating low power (early morning and at night). Battery storage was highlighted in literature as an option for medium scale projects (Thorn & Casey, 2024), however battery storage appears to only be part of the solution to a longer-term problem for NZ energy infrastructure. Distribution capacity will likely need to be upgraded to meet demands towards 2050 and into the future.

Opportunities

For drystock farmers that have proximity to the national grid for large scale projects or are close to a substation for smaller scale, then solar presents an opportunity for diversification. Flat land and access to electricity distribution lines was highlighted by most participants as the two key determinants of viability for solar development. Capacity for distribution may be limited in the short term in some areas, but in the future, there may become more opportunity for drystock farmers to install solar.

5.3.2 Certainty and costs of development

Challenges

Investment (particularly overseas investment through the OIA) and Council approval plays a critical role in the success and progression of solar projects. Solar farming has the potential for rapid growth, however the extent of development versus speculative interest is subject to regulatory and market influences. This is consistent with literature, where it was highlighted that market unknowns pose a large barrier to farmer uptake of agrivoltaics (MacKenzie et al., 2022).

Participants noted that while interest in solar is high at the moment, many projects will not end up being taken through to construction phase. One participant noted that some developers basically lock up land to enable them to 'cherry pick' the best ones for development from a feasibility point of view. Many proposed projects are still in the early stages, and realistically may never reach the construction phase. Selecting feasible sites for solar can lead to land being secured, but not necessarily developed. These significant costs are also a consideration if a farmer decides to put in solar themselves, with a process to go through in terms of bank approvals, discussions with the local EDB, to construction phase.

Participants noted that initial set up costs for solar farms can range from $600,000 to $1.5 million per hectare, or $2-3 million per MW. As an example, one participant noted that building a solar farm of 100 MW could cost between $150 million to $400 million. This differs to findings in literature, where it was forecasted that the costs for developing solar panels on high producing exotic grassland is $40,000 per hectare, low producing grassland is $30,000 per hectare; and depleted grassland is $10,000 per hectare (Miller, 2020). Participants also commented that it also depends on how many MW are being installed per hectare, with a comment from one participant that 1 MW on one hectare would be 'quite squeezed', and another noting that 2.5-3 hectares per megawatt would be standard.

Participants noted that panels, inverters, transformers, and other hardware and infrastructure significantly contribute to the initial capital expenditure. Further, connecting to the national grid is an expensive exercise, with estimates at $25 million for a national grid connection, and even higher for the High Voltage Direct Current system, which can reach a billion dollars. This makes it essential for solar farms to be strategically located near existing infrastructure, where possible.

Due to high connection costs, only very large projects i.e., hundreds of hectare are likely to be connected directly to the 110kV or 220kV national grid lines. Smaller projects may find it challenging to justify the connection costs, unless they are located in very close proximity to the main grid. One participant noted that unlike wind farms that can justify the cost of long transmission lines due to high wind resource areas, solar farms typically do not tolerate such high build costs. This limits the development of solar farms to areas relatively close to existing transmission infrastructure.

For local grid connections, an application starts at $20,000. For 33kV lines, participants estimate the cost is approximately 1 million dollars a kilometre to build a line and prices increase as the line voltage increases.

Farmer participants noted for those entering lease agreements, there is no certainty of the project until the panels start being installed. This can be years from when an agreement is signed. This is a challenge and a risk that a drystock farmer must take on to viably consider solar as a diversification strategy. This is captured by the observability adopter category under Rogers diffusion of innovation theory (Rogers, 1983), whereby the adoption or rejection of solar as an innovation depends on the extent to which it will provide tangible results for the farming operation (Pascaris et al., 2020).

Opportunities

Solar farming leases can offer significantly higher returns compared to drystock farming, and for less profitable agricultural uses at present such as sheep farming. The fixed income from lease agreement can provide financial stability for farmers. It can also enable farmers to invest in additional land or on farm improvements. Developers often cover additional costs like fencing, rates, and land improvement which ultimately reduces the financial burden on drystock farmers. There is significant opportunity to achieve an arrangement and agreement that works best for the drystock farmer.

Participants highlighted the benefit of lease agreements with solar developers is the fact that there are no capital or ongoing costs for the installation and maintenance of solar panels. For those not entering lease agreements and for solar projects more generally, the return on investment is typically around 10-12 percent. Payback periods can range from six to 12 years, depending on electricity prices. While capital expenditure can be high, operational costs are generally low, with ongoing maintenance costs around 0.35 percent of the initial capital expenditure (depending on the project size). Low-cost finance has been identified in literature as an opportunity to de-risk upfront capital and unlock a new revenue stream for farms faster (Thorn & Casey, 2024).

Regular maintenance includes cleaning panels and occasional hardware replacements. In NZ, panel cleaning is infrequent compared to other countries where dust can be an issue. One participant provided an example of long-term employment for a 100 MW solar project, which may require four full-time roles.

Lease agreements typically include clauses for Consumer Price Index (**CPI**) adjustments, and potential revenue sharing based on electricity prices. Ensuring that the costs for decommissioning and recycling panels, and liability for this is agreed between parties is also important. Participants anticipated recycling markets to develop over the next 30 years for PV panels in NZ. Some participants stated that the main materials are silicone, aluminium, steel and glass which should have recyclable value.

Many participants noted that engaging legal and financial advisors to review agreements and ensure all aspects are covered is critical. This includes understanding the developer's credibility and their financial backers. Though many lease agreements are between 30-35 years (aligning with maximum consent terms under the RMA), at 30 years solar panels are producing at 88 percent of what they produced on day one. Therefore, many developer cash flow models build this out to 50 to 70 years.

5.3.3 Operational and strategic considerations

Challenges

Participants highlighted that farmers who are considering solar as a diversification strategy must thoroughly understand the arrangements they are entering into. This includes lease terms, duration, financial terms, and obligations. Participants advised that clauses to protect the farmer’s interests, such as decommissioning responsibilities and inflation adjustments should also be considered. Farmer participants did highlight the capital needed to ensure that lease agreements and associated documentation are suitable. One participant stated they will likely spend more than $25k in legal costs for their situation and highlighted that this is something that farmers should be prepared to pay to get things right.

Some participants highlighted that on an area of land where panels are being installed, drystock farming is a secondary consideration to the primary goal of solar energy development and production. Therefore, drystock farmers need to weigh up the environmental and economic benefits of solar against any potential production losses, or changes to farm management. This includes the 'usefulness' of bringing solar into their farming systems, and longer-term goals for their farming operations. This is similar to findings in research (Brudermann et al., 2013, Wagner et al., 2024). This will require a change in mindset for many farmers and their families. This is also captured by Rogers diffusion of innovation theory (Rogers, 1983) whereby the adoption depends on the relative advantage of solar, and the degree to which is viewed as better than what it replaces (i.e., conventional drystock farming). Some drystock farmers may view the integration of solar as an advantage, or a disadvantage to their current operation.

Opportunities

Solar farming was viewed by many participants, including farmer participants, as a way to secure their land for future generations and enable succession planning. It was also viewed as an option for farmers to reduce risk and explore alternative revenue streams. Declining profitability from sheep and beef farming was highlighted as a key consideration for diversifying income streams. It was viewed by some participants as more favourable than other diversification or land use change options, such as carbon farming, conversion to dairy farming, or leasing land, for example. Looking at this perspective through Rogers diffusion of innovation theory (Rogers, 1983), farmer participants interviewed who are either diversifying with solar, or considering it, can be thought of as innovators. They are interested in new ideas, and willing to take risks, and are at the start of the bell curve for the diffusion of solar as an innovation in NZ.

The long-term financial stability offered by a solar lease and potential returns was viewed favourably by farmer participants, with some referring to it as 'like winning the lotto'. For farmer participants, some were approached by a solar developer about a project on their farm based on location, while others approached developers because they thought their farm may be suitable. Another participant is looking into solar on their own merit and has initiated discussion with their local EDB.

Many participants highlighted the need for farmers to work with a developer that aligns with individual values, and the vision for the future of the farming operation. The decision to diversify into solar farming should align with their overall strategic goals and future plans for the farm. This ties into the succession planning discussion which was a key theme for why farm owners are considering diversification with solar. Farmers need to consider the long-term impact on their families and communities, and how the land can be used both during and after the solar farm's life span should be part of the decision making process. This is captured by Rogers diffusion of innovation theory (Rogers, 1983) whereby the adoption of solar depends on the compatibility. This includes how consistent solar is found to be with the values, experiences and needs of potential adopters (i.e., drystock farmers).

Participants agreed that there is an opportunity to work with developers during the design phase, to manage ongoing operational needs. This is to ensure that it works for the farming operation while meeting requirements for solar development access, and maintenance. This includes discussions around regrassing, cropping, grazing, machinery access or other farm operational needs. Developers interviewed stated that solar designs can be easily customised – they just need to be facing the sun.

Many participants also discussed the potential for multiple farm opportunities, where a few landowners may choose to each diversify part of their farm with solar. This increases the economies of scale in terms of infrastructure to connect to the electricity network and provides benefits to multiple farmers.

5.3.4 Regulatory considerations

5.3.4.1 Challenges

Participants agreed both farming communities and the public have a perception that solar will result in the loss of agricultural land, which will impact food production. Despite legislation that supports renewable electricity (such as the NPS-REG), there can be conflicts with policies aimed at preserving highly productive land. The NPS-HPL was a common theme in responses from participants, which aims to protect highly productive land from inappropriate use and development. This policy often covers the land most suitable for solar farms (i.e., flat and often near urban areas) leading to a conflict between land use for agriculture and electricity generation. However, dual land use through agrivoltaics may present a solution to these issues, with the right policy settings and considerations, which was also highlighted in literature (Eastlake, 2022, Vaughan et al., 2023).

Some participants commented that local and regional plans often do not anticipate solar, leading to gaps in regulations and planning frameworks. Councils also have a role to play in ensuring sustainable use and development in their district or region and have a responsibility to ensure that solar farms are not having an adverse effect on rural landscapes.

5.3.4.2 Opportunities

Many participants highlighted that consent processes under the RMA have been relatively straight forward to date, depending on the location of the solar development (i.e., the relevant district or regional council plans and policies).

There is strong policy direction for enabling renewable electricity generation through the NPS-REG. Participants acknowledged the need to balance renewable electricity, and any potential loss of productive agricultural land. However, many participants highlighted that because livestock grazing can continue under the panels, there is no real loss of agricultural land.

Participants acknowledged that the government has a role to play in facilitating the development of solar. There was also acknowledgement that the regulatory framework has not adapted quick enough to support solar development, which is leading calls for more proactive government intervention particularly from participants involved in solar development. Many participants highlighted hopes for a better pathway for solar through the potential fruition of the Fast-Track Approvals Bill.

It was also acknowledged by some participants that NZ has limited guidance documentation around the establishment of solar farms. Findings align with literature where encouragement and support for dual land use, such as agrivoltaics provides a significant opportunity for NZ but it needs to be appropriately addressed through regulation. Further, NZ also does not have solar performance standards such as glint and glare, road safety, infrastructure requirements, and mitigation strategies. (Eastlake, 2022).

5.3.4.3 Environmental, economic and social effects

5.3.4.3.1 Challenges

A key challenge raised by participants was the potential visual impacts and changes to the character of the rural landscape because of solar. This was expressed by some participants as a reason for some consent processes being slower than others.

Participants agreed that the visual impacts on the rural landscape as a result of the presence of solar panels is a common concern. Visual impacts were considered relevant both to rural communities where projects are located, and also for the wider public who may be travelling on rural roads or locations where they may see solar developments. One participant compared solar to kiwifruit canopies. There was likely to have been some issues around visual impacts at the time, but now it is an accepted part of the rural landscape.

Participants had mixed views on biodiversity impacts, with some concerns about local wildlife and vegetation changes due to solar farms. Panels can provide shelter for animals but may confuse birds and potentially insects due to reflectivity. Literature in this space highlighted that bird communities were largely adaptable around solar installations, depending on the species that are more likely to interact with an area. Natural features such as plantings, native trees which contribute to the habitat are good mitigators that can assist with any disorientation effects (Visser et al. 2019, Harrison, 2016). Participants emphasised the need for NZ based data for determining any environmental and social effects as a result of diversification with solar, and how they can be mitigated.

It was evident from participants answers that the public perception of solar varies significantly across different regions. This is likely influenced by local community values, and the scale of proposed solar projects. Participants agreed that the suitability of land for solar is a key consideration, with some areas being better suited than others (for example, more marginal or less productive areas of farmland). Participants also highlighted that there is some concern that solar will remove jobs from rural communities in the long term (i.e., after the construction period which may for a time create temporary jobs).

Many participants stated that NIMBYism (**Not In My Back Yard**) is common in discussions around solar. This is where people support solar energy projects, but they do not want it near their homes, farms, or in their communities. The theme of property rights was also common, which ties into 'NIMBYism'. This is particularly relevant for some communities located near potential solar development, and neighbouring properties of a solar development. This can lead to opposition, especially when solar farms are perceived to benefit a drystock farmer at the expense of others, or communities. For the farming community, some participants noted that there can be a generational difference of opinion as well. Some participants noted that generally, older generations can be more resistant to the potential of solar for diversification, wanting to maintain traditional drystock farming operations and maintain the rural landscape. On the other hand, younger farmers can be more open to innovation and diversification opportunities such as solar.

Scovell et al (2024) identified that support for local solar projects is less dependent on local factors such trust, procedural fairness, and governance. It is possible that if a negative sentiment takes hold at local levels, broader public narratives about the energy transition may become negative (Scovell et al., 2024). This appears the case in some instances of solar projects to date based on participant experience. Literature also indicates that minimising conflict through site selection and addressing agricultural community concerns will be key in the deployment of agrivoltaics. Localised acceptance has been found to be a critical determinant of success (Pascaris et al., 2022). This may add further limitation to site selection, coupled with the NZ landscape and electricity network.

It is evident that updates are needed to the NPS-REG, as well as updates to local government plans. This is to ensure that the development of solar is being provided for to meet renewable electricity demands, while ensuring the environment and any potential effects are managed and mitigated appropriately (Eastlake, 2022).

5.3.4.3.2 Opportunities

In terms of environmental effects, participants generally agree that properly designed solar farms avoid creating heat sinks, with adequate spacing and planting to manage temperature effects. One participant noted that that solar panels operate efficiently below 30 degrees, and above this temperature the efficiency can start to decrease. Further, solar installations are screened with plantings which assists with visual impacts on the landscape.

One participant in a resource consent process has been asked about stormwater management. However, they noted that tracking panels help distribute rainfall more evenly which reduces concentrated runoff issues. Participants agreed that modern solar panels have minimal leaching of heavy metals and are generally constructed with safe materials. Many participants stated that concerns about leaching and environmental contamination are generally unfounded with current technology.

Solar farming can provide a stable income stream for drystock farmers. This can either supplement (i.e., solar revenue and grazing stock under the panels) or replace (just have solar) the normal revenue generated from that piece of land. In terms of economic effects, lease terms are generally around 35 years. Participants indicated that returns for leasing drystock farmland for solar farming can yield between $2,000 to $6,000 per hectare annually, with some higher rates in specific cases. This is an annual payment on top of any profit made from continuing farming under the panels if the farmer decides to pursue a grazing license. This appears relatively consistent with existing literature which estimated lease returns between $2,000 to $5,500 per hectare (Dickey, n.d.).

Many participants emphasised the need for effective engagement and education in addressing misconceptions and gaining public support. Involving local communities in processes, and demonstrating benefits, such as improved power reliability and local employment opportunities, has been found by participants to enhance acceptance. Despite some resistance depending on the person, there appears to be a general support for renewable energy. This is likely driven by the need for a sustainable power supply and security. Recent power shortages and the push for greener energy have increased some public awareness and support for solar energy projects. Visual impacts and changes to the character of the rural landscape appear to be a common challenge, and the opportunity for mitigation involves vegetation planting and setbacks to minimise effects. This will also help bird communities and assist with any disorientation effects (Visser et al. 2019, Harrison, 2016).

Addressing community concerns was found to be key in the deployment of agrivoltaics, as localised acceptance is a critical determinant of success (Pascaris et al., 2022). Many participants viewed solar projects as an opportunity to engage with and provide benefits to the local community, support educational initiatives, create wider awareness of the integration of agriculture, and potentially create employment opportunities. One participant provided an example where they are working to provide learning opportunities on the solar farm with local school groups. Other examples may include the provision of jobs during construction and ongoing operation, and increased power security. This appears consistent with literature that indicates that an upscale in the solar industry would benefit regional economies (Thorn & Casey, 2024).

Any community power security benefits would be due to infrastructure connections and associated upgrades that come with solar development. This was viewed favourably by farmer participants as a way to provide wider social benefits to rural communities, such as fewer power cuts. This was an interesting observation as literature found that for local communities, social impacts upon their way of life and personal rights will be minimally impacted during solar farm operation. However, local communities also experience little in the way of direct economic benefit from having a solar farm operating nearby, raising social equity concerns. (Hinds et al., 2023).

Some participants also discussed the potential for collaboration between large manufacturing facilities and nearby farmers to access solar energy, to reduce reliance on non-renewable energy sources like coal. Some participants provided of integrating solar generation with nearby factories and other commercial and industrial businesses. This has potential for multiple positive environmental, economic and social effects.

5.3.5 Agricultural considerations

5.3.5.1 Challenges

Participants highlighted that site preparation and planning for the next 30 years (i.e., lifetime of the panels) is crucial if farmers are going to continue grazing areas with solar panels present. Participants noted that there can be some restriction on regrassing and cropping areas with panels present. However, this depends on the arrangement between the farmer and developer.

Pasture growth generally depends on panel design (i.e., fixed or titling panels, and spacing between rows). Shading from panels can result in more dead material and less grass growth, particularly affecting clover which does not tolerate shading. One participant noted that in some preliminary research, there was no significant difference in the nutritive value of pasture under panels, but the presence of weeds can be more pronounced. Change in pasture management can lead to weed growth which can present a challenge. Broadleaf species like thistles, docks, and dandelions, which thrive in the shade, can proliferate in this situation. These weeds often lack the fibre content beneficial for animals, making them undesirable for grazing. Some participants acknowledged there may be some compaction which may reduce soil carbon. This may require remediation if the land use is reverted at the end of solar panel life.

Farm landowner participants also highlighted a challenge in managing pests under solar panels, such as rabbits. Restrictions on the use of firearms near the panels poses a challenge to pest management. Many potential agricultural challenges can be managed and mitigated through conversations between developers and farmers, and further research in the NZ context to understand PV panel and pasture relationships. Some challenges will also require innovative solutions.

In terms of livestock, participants agreed that sheep were the most suitable animal for grazing beneath panels. Many participants believed it would be impractical to graze cattle. Cattle are generally not favoured due to their size and their scratching behaviours which can cause damage. Solar panels would need to be located higher off the ground to allow cows to graze underneath which increases the capital costs (Vaughan et al., 2023). Other drystock, such as deer are also not able to be grazed due to their jumping tendencies.

5.3.5.2 Opportunities

Farmers may need to adjust their farming operations with the integration of solar, but there is an opportunity of dual benefits with grazing and solar-generated revenue. Site preparation and planning should include selecting suitable grass or crop species that can thrive under the specific conditions created by solar panels.

Participants placed emphasis on early discussions and agreement on planting choices that suits both parties. Further, participants interviewed that are involved in developments were open to discussions around design in terms of spacing and other considerations to allow for tractor access and other farm equipment. Participants agree that having discussions early should allow for continued drystock farming with minimal changes, alongside solar energy production. Many participants expressed a willingness to work with drystock farmers to meet their needs, such as adjusting the angle of panels to allow for access or stock movements. Panels can be positioned to maximize sun exposure while allowing space for farm equipment and operations.

There is significant opportunity for collaboration between parties on regrassing and cropping arrangements with agrivoltaics. Periodic crop planting and harvesting every 2-5 years can provide an additional revenue stream if well-coordinated between parties. Despite a potential reduction in pasture growth by 10-20 percent due to the presence of panels, panels have been found to potentially have a protective effect on pasture with temperature and moisture regulation and less evapotranspiration, but once again, more research in a NZ context is needed. If pasture gets equal share of sunlight with titling panels, this can have positive effects both under panels, and in the rows between panels.

This is captured by Rogers diffusion of innovation theory (Rogers, 1983) whereby compatibility (i.e., how consistent solar is with the values and needs of potential adopters) provides an opportunity to increase farmer acceptance and willingness. This also is consistent with literature, where climate, configuration, crop selection, and compatibility and flexibility were identified as being key determinants of agrivoltaics success (Macknick et al., 2022).

Weed management is required to ensure the solar panels maintain their efficiency, and it reduces fire risks. Sheep grazing through agrivoltaics can help control weeds naturally, which reduces the need for mechanical or chemical interventions. Participants were generally in agreement that sheep are the most compatible type of livestock for grazing with solar panel installations. In some instances, it may be possible to also graze cattle depending on design considerations, with one participant noting that grazing rising one year olds is possible. Many participants noted that grazing arrangements are a win-win for both farmers and developers as essentially the grass gets mown (meaning the panels operate efficiently), and farmers get a revenue stream from the livestock.

Solar panels can break up wind effects, provide shade and reduce heat stress and water consumption. Shelter benefits are provided both winter and summer, and these benefits have been found overseas to potentially increase lamb weight gains and reduce stress (Carvalho Fonsêca et al., 2023, Andrew et al., 2021). Shading benefits were acknowledged by participants to be particularly beneficial for regions such as Canterbury. Further, two participants noted that in an NZ based study, facial eczema spores between and under the panels were less than open paddock areas which may provide a solution to this animal welfare issue.

Installation of solar on a drystock farm often included improvements to existing farm infrastructure, such as roads and tracks, and power supply. Participants noted that solar panels only cover approximately 30-35 percent of a total land area. The supports which panels attach to do not cover the same area as they are pile driven into the ground. Participants confirmed that there is no concreting or foundations laid as part of the installation process. Some participants stated that the presence of solar panels has minimal impact on soil properties, as there is only some cabling that goes underground, and structures are piled into the ground.

Soil quality can be improved with the presence of panels, as animals tend to disperse over a land area more as opposed to camping in certain areas which creates nutrient dispersion. Further, many participants acknowledged that only small quantities of fertiliser are required to maintain soil quality over the life of the panels.

5.4 Information and collaboration

An overall key theme highlighted by participants is that overseas data and experience is really the best information we have at present in terms of what challenges and opportunities solar may have for drystock farm diversification in NZ. However, this information may not be fully applicable or relevant to our unique environment, society, and climate.

Many participants acknowledged the need for NZ specific data to inform solar farming knowledge and regulation. Further, many acknowledged that there is a need and a want for data, but there is a lack of willingness to invest in this information. Getting NZ specific data will require significant investment, and where this investment will come from remains a challenge that needs a solution in the short term. It is also important to have a wider range of information available to drystock farmers about solar, not just information from developers.

Participants expressed that there are concerns in the community about the potential impacts of solar on agricultural land and food production. One participant compared solar as being similar to genetic engineering debates, which can also be polarising. At a grassroots level there is some support for solar solutions, however there are many misconceptions about the integration of solar and agriculture. Local education and evidence is needed to provide community level solutions to concerns. There is a significant opportunity to educate the community and demonstrate the potential value and benefits of integrating solar with drystock farming in NZ.

Participants also expressed a need for greater collaboration between solar development companies, communities, government, and research organisations to further determine and address the challenges and opportunities of integrating solar with agriculture. This is captured by Rogers diffusion of innovation theory (Rogers, 1983) whereby complexity (i.e., how difficult solar is to understand and/or implement) can create challenges to adoption both for drystock farmers, and for wider communities.

Given agrivoltaics and solar farming in NZ is relatively new, there is an opportunity for research to inform potential adoption. This is captured by Rogers diffusion of innovation theory (Rogers, 1983) whereby triability (i.e., the extent to which solar can be tested or experimented with before a commitment to adopt is made) can have multiple benefits. This will provide crucial information for both drystock farmers, and rural communities where solar farms may operate alongside drystock farming. This has also been identified in literature as a need, to provide confidence to engage in conversations and form partnerships (Vaughan et al., 2023). Further, collaboration and partnership has been found to be a key determinant of agrivoltaic success (Macknick et al., 2022).

5.5 Review of methodology

While this research project has provided some valuable insights, it is important to reflect upon the methodology used. It became evident while completing interviews that some of my interview questions were in fact asking for the same information and therefore overlapped. Further refinement of these questions would have avoided unnecessary duplication.

Interviews were an insightful way to gauge the perceived challenges and opportunities of solar for drystock farm diversification. However, another option could have been to do NZ based case studies as opposed to focus on just interviews.

In the future, it would be beneficial to create a map that shows GHI potential on suitable drystock land, overlayed with suitable distribution lines to quantitatively determine the areas of land that may be suitable for diversification with solar. This research project intended to use geographic information systems to develop a map of drystock land and distribution lines, however due to time and resource constraints it was not able to be completed.

6. Conclusions

Ultimately, solar has potential to be a viable diversification strategy for drystock farmers. However, based on location and network considerations, unfortunately it will not be a silver bullet solution for every drystock farmer. This is because of current electricity infrastructure limitations, and land requirements.

Solar projects may be a viable diversification strategy, but proximity to electricity infrastructure is crucial. Dual land use through agrivoltaics is a potential solution to meet both the increased demand for power and reduce potential risk from drystock markets. Solar farming can provide a stable income stream for farmers, which may either supplement or replace drystock farm revenue.

For those that can viably consider solar or agrivoltaics, it can provide financial stability for farmers, with lease terms providing significant returns compared to traditional drystock farming. The benefit of 'harnessing the sun twice' by capturing sunlight on the solar panels, and grazing beneath them, provides dual land use and dual income opportunity. Farmers entering into solar agreements (whether with a developer or on their own merit) need to do their due diligence, have discussions around farm operation and design, terms, where investment funding is coming from, decommissioning, costs, and inflation adjustments as examples.

It is apparent that while there is awareness of the increased need for power, electricity infrastructure is not fully optimised at this stage for widespread solar adoption. This likely means investment in battery storage and distribution capacity upgrades will be needed in the short to medium term.

Public perception of solar varies depending on the area, with some concerns about visual impacts and potential loss of agricultural land. Generally, there is support for renewable energy driven by the need for sustainable power supply, and more of it. Encouragement and support agrivoltaics provide a significant opportunity for NZ. It also provides an opportunity to work through potential environmental, economic and social effects associated with solar development, but it needs to be appropriately addressed and managed through regulation.

In terms of Rogers diffusion of innovations theory, it is apparent that given agrivoltaics and solar farming in NZ is relatively new, there is an opportunity for research to inform potential adoption. While there are some drystock farmers leading the way with adoption ('innovators'), wider diffusion will depend on observability, compatibility and relative advantage to the farming operations.

There is a significant opportunity for collaboration between industry including drystock farmers, solar developers, government, and research organisations to address challenges and optimise solar integration with agriculture. More NZ specific research and data is needed as soon as possible to inform solar farming knowledge and regulation.

7. Recommendations and next steps

Recommended steps for industry (i.e., energy and electricity industry, research institutes and universities, and the drystock industry including Beef + Lamb New Zealand, Deer Industry New Zealand, and Federated Farmers) and the Government (Ministry for the Environment, Ministry for Business, Innovation and Employment, and Ministry for Primary Industries) include:

Undertake NZ based research:

(a) To inform policy development and refinement around how to manage solar farming and agrivoltaics in terms of social, environmental and economic effects.

(b) To understand how solar panels and the NZ climate and geography interact with each other.

(c) To understand agricultural challenges and opportunities for NZ based pastoral systems.

Invest in research and development:

(a) While some NZ based research is in progress or has been completed, there is a significant knowledge gap that is not keeping pace with potential development.

(b) Where investment for research will come from requires serious consideration by industry and Government.

(c) Investment in electricity infrastructure upgrades will likely be required to meet projected increases in demand for electricity.

Develop publicly available resources:

(a) Currently, there is limited industry resources for farmers to understand agrivoltaics, solar farming, and the potential opportunities and challenges for diversification. Development of resources for drystock farmers will help address confusion and determine whether solar is viable for their farming operation. This should include a guide to solar and agrivoltaics for farmers, which should share learnings of solar and agrivoltaics to date in NZ and international findings.

(b) Currently, there is also limited information available for communities to understand the need for more energy, and how solar, and agrivoltaics in the NZ context can help meet this need. This material will help with collaboration, understanding, and to address misinformation. It will also educate the community and demonstrate the potential value and benefits of integrating solar with drystock farming in NZ.

(c) Guidance documentation around the establishment of solar farms that cover performance standards such as glint and glare, road safety, infrastructure requirements, and mitigation strategies needs to evolve with development. There is an opportunity for NZ based research to inform any updates to such documentation.

For drystock farmers looking at solar as a potential diversification strategy, recommendations include:

Have clear, long-term aspirations:

(a) Being clear on long-term aspirations for your farming operation, family, and wider community.

(b) Think about how diversification with solar may change your management practices and farming operation moving forward.

Initiate discussions:

(a) Discussing your situation with a developer, or for those doing it themselves – engaging in conversations with your local EDB. This will allow you to discover if your farm can viably consider diversification with solar and if so, how many hectares.

(b) Talk to other farmers who have diversified with solar to understand the practicalities of going down this path.

Do your due diligence:

(a) Find a developer that aligns with your long-term aspirations for your farming operation.

(b) Choose a developer that has a good track record.

(c) Understand where a developer's investment is coming from, and.

(d) Seek financial and legal advice where appropriate.

8. Limitations of this study

Some of the limitations of this research project are outlined below:

- This report has only examined challenges and opportunities of drystock farms installing large collections of panels (beyond just self-sufficiency for powering

their homes or farm energy demands) by diversifying part of their farming operations to have mixed land use with solar.
- This project has not considered cultural effects as a result of any development or diversification.
- This report has not considered solar system designs, infrastructure, or lifecycle considerations associated with the manufacture, end of life disposal or recycling of solar panels in detail.
- This report has not considered energy efficiency in terms of end users or the electricity distribution and transmission network.
- This project has only looked at PV solar.

9. References

Andrew, A. C., Higgins, C. W., Smallman, M. A., Graham, M., & Ates, S. (2021). Herbage Yield, Lamb Growth and Foraging Behaviour in Agrivoltaic Production System. *Frontiers in Sustainable Food Systems*, *5*. https://doi.org/10.3389/fsufs.2021.659175

Ara Ake Future Energy Development. (2023). *Understanding the electricity ecosystem in Aotearoa New Zealand* [Community Energy Guide]. https://www.araake.co.nz/assets/Community-Energy-Guides/Community-Energy-How-to-Guide_Chapter-5.pdf

Bayne, K., & Renwick, A. (2021). Beyond Sustainable Intensification: Transitioning Primary Sectors through Reconfiguring Land-Use. *Sustainability*, *13*(6), 3225-. https://doi.org/10.3390/su13063225

Beef + Lamb New Zealand. (n.d.). *Benchmarking tool.* Retrieved May 7, 2024, from https://tools.beeflambnz.com/benchmarking-tool

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3, 77-101. SpringerLink. https://link.springer.com/article/10.1007/s12571-021- 01182-8

Brudermann, T., Reinsberger, K., Orthofer, A., Kislinger, M., & Posch, A. (2013). Photovoltaics in agriculture: A case study on decision making of farmers. Energy Policy, 61, 96–103. https://doi.org/10.1016/j.enpol.2013.06.081

Burtt, A., Davison, R., Haddrell, M., & Fisher, A. (2024). *Mid-season update 2023-24* [ISSN 2230-5777]. Beef + Lamb New Zealand. https://beeflambnz.com/knowledge-hub/PDF/mid-season-update-2023-2024.pdf

Carvalho Fonsêca, V. de F., de Andrade Culhari, E., Moura, G. A. B., Nascimento, S. T., Milan, H. M., Neto, M. C., & Maia, A. S. C. (2023). Shade of solar panels relieves heat load of sheep. *Applied Animal Behaviour Science*, *265*, 105998-. https://doi.org/10.1016/j.applanim.2023.105998

Concept Consulting Group Ltd. (2023). *Generation investment survey 2023 update* [Report prepared for the Electricity Authority]. Electricity Authority Te Mana Hiko. https://www.ea.govt.nz/documents/4414/Generation_Investment_Survey_-_2023_update.pdf

Deer Industry New Zealand. (n.d.). *Statistics*. Retrieved May 7, 2024, from https://deernz.org/home/deer-industry-new-zealand/statistics/

Delfanti, L., Colantoni, A., Recanatesi, F., Bencardino, M., Sateriano, A., Zambon, I., & Salvati, L. (2016). Solar plants, environmental degradation and local socioeconomic contexts: A case study in a Mediterranean country. Environmental Impact Assessment Review, 61, 88–93. https://doi.org/10.1016/j.eiar.2016.07.003

Dickey, D. (n.d.). *Solar leasing: Making money while the sun shines*. Retrieved March 27, 2024, from https://dairyexporter.co.nz/solar-leasing-making-money-while-the-sun-shines/

Eastlake, B. (2022). *Powered by the Sun: Implications of Grid-Scale Solar Farming under the Aotearoa NZ Planning System* [Graduate Thesis/Dissertation, University of Otago]. Our Archive. https://hdl.handle.net/10523/15452

Electricity Authority Te Mana Hiko. (n.d.). *Powering the future*. Retrieved May 14, 2024, from https://www.ea.govt.nz/about-us/what-we-do/powering-the-future/

Energy Efficiency & Conservation Authority Te Tari Tiaki Pūngao. (n.d.). *Solar*. Retrieved May 7, 2024, from https://www.eeca.govt.nz/insights/energys-role-in-climate-change/renewable-energy/solar/

Fitzgerald, W., Norton, S., & Stephenson, J. (n.d.). *Future-proofing Aotearoa NZ's Agricultural Food System – Energy-related risks and opportunities* [Scoping paper]. https://www.otago.ac.nz/__data/assets/pdf_file/0013/281110/agriculture-and-energy-623147.pdf

Gasparatos, A., Doll, C. N. H., Esteban, M., Ahmed, A., & Olang, T. A. (2017). Renewable energy and biodiversity: Implications for transitioning to a Green Economy. Renewable & Sustainable Energy Reviews, 70, 161–184. https://doi.org/10.1016/j.rser.2016.08.030

Hall, R. (2023). *New Zealand Deer Production and Trends* [Report number NZ2022-0019]. United States Department of Agriculture Foreign Agricultural Service. https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=New%20Zealand%20Deer%20Production%20and%20Trends_Wellington_New%20Zealand_NZ2022-0019.pdf

Harrison, C., Lloyd, H., & Field, C. (2016). Evidence review of the impact of solar farms on birds, bats and general ecology. Manchester Metropolitan University. https://publications.naturalengland.org.uk/file/6000213410447360

Hassanpour Adeh, E., Selker, J. S., & Higgins, C. W. (2018). Remarkable agrivoltaic influence on soil moisture, micrometeorology and water-use efficiency. *PloS One*, *13*(11), e0203256–e0203256. https://doi.org/10.1371/journal.pone.0203256

Hillhorst, S. (2024, February 16). *Venison returns buck up deer outlook.* Farmers Weekly. Retrieved May 8, 2024, from https://www.farmersweekly.co.nz/markets/venison-returns-buck-up-deer-outlook/

Hinds, L., Kuparinen, E., Millar, C., Thompson-Fawcett, D., & Walker-Smith, E. (2023). *Planning for grid-scale solar developments in Central Otago: Investigating potential impacts and community perceptions* [research report submitted in fulfilment of the requirements for PLAN435/535]. University of Otago. https://www.codc.govt.nz/repository/libraries/id:2apsqkk8g1cxbyoqohn0/hierarchy/sitecollectiondocuments/reports/other-reports/MPlan_Solar_Developments.pdf

Johnson, M.F., Minhinnick, D., Butler, D., Callus, P., & Worthington, G. (2022). Retrieved May 19, 2023, from: https://www.russellmcveagh.com/insights/october-2022/investing-in-utility-scalesolar-in-new-zealand-top-4-legal-consideration

MacKenzie, D., Brent, A., Hinkley, J., & Burmester, D. (2022). AgriPV Systems: Potential Opportunities for Aotearoa–Aotearoa NZ: A GIS Suitability Analysis. *AgriVoltaics Conference Proceedings 1*. https://doi.org/10.52825/agripv.v1i.600

Maia, A., Culhari, E., Carvalho Fonsêca, V., Milan, H., & Gebremedhin, K. (2020). Photovoltaic panels as shading resources for livestock. Journal of Cleaner Production, 258, 1-9. doi:10.1016/j.jclepro.2020.1205510959-6526/

Macknick, J., Hartmann, H., Barron-Gafford, G., Beatty, B., Burton, B., Choi, C.S., David M., Davis, R., Figueroa, J., Garrett, A., Hain, L., Herbert, S., Jansi, J., Kinzer, A., Knapp, A., Lehan, M., Losey, J., Marley, J., MacDonald, J., . . .Walston, L. (2022). *The 5 Cs of Agrivoltaic Success Factors in the United States: Lessons from the InSPIRE Research Study* [Technical Report]. National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy22osti/83566.pdf

Manawa Energy. (n.d.). *Developing a solar farm.* Retrieved April 18, 2024, from https://www.manawaenergy.co.nz/solar

Miller, A. (2020). *Economics of Utility-Scale Solar in Aotearoa New Zealand* [Paper prepared for Ministry of Business. Innovation and Employment]. https://www.mbie.govt.nz/assets/utility-scale-solar-forecast-in-aotearoa-new-zealand-v3.pdf

Ministry for the Environment. (2023a). *New Zealand's projected greenhouse gas emissions to 2050.* Retrieved March 2, 2024, from https://environment.govt.nz/facts-and-science/climate-change/new-zealands-projected-greenhouse-gas-emissions-to-2050/

Ministry for the Environment. (2023b). *Te whakahaere i te whakamahinga me to whanaketanga o ngā whenua whai hua Managing the use and development of highly productive land – potential amendments to the NPS-HPL: Discussion* *document* [Publication number: ME 1802]. https://environment.govt.nz/assets/publications/land/Potential-amendments-to-the-NPS-HPL-discussion-document.pdf

Ministry of Business, Innovation & Employment Hīkina Whakatutuki. (2023a). *Energy in New Zealand 23 – comprehensive information on and analysis of New Zealand's energy supply and demand* [ISSN 2324-5913]. https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-publications-and-technical-papers/energy-in-new-zealand/

Ministry of Business, Innovation & Employment Hīkina Whakatutuki. (2023b). *Briefing for the incoming Minister for Energy*. https://www.mbie.govt.nz/dmsdocument/27988-briefing-for-the-incoming-minister-for-energy-proactiverelease-pdf

Ministry of Business, Innovation & Employment Hīkina Whakatutuki. (2024). *Electricity Statistics*. Retrieved March 28, 2024 from https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/electricity-statistics

New Zealand Parliament Pāremata Aotearoa. (2024, March 14). *Fast-track Approvals Bill*. Retrieved June 9, 2024 from https://www.parliament.nz/en/pb/sc/make-a-submission/document/54SCENV_SCF_083F0A7B-F182-41D5-0897-08DC3E31559C/fast-track-approvals-bill

Pascaris, A. S., Schelly, C., & Pearce, J. M. (2020). A First Investigation of Agriculture Sector Perspectives on the Opportunities and Barriers for Agrivoltaics. *Agronomy (Basel)*, *10*(12), 1885-. https://doi.org/10.3390/agronomy10121885

Pascaris, A. S., Schelly, C., Rouleau, M., & Pearce, J. M. (2022). Do agrivoltaics improve public support for solar? A survey on perceptions, preferences, and priorities. Green Technology, Resilience, and Sustainability, 2(1), 8.

Piddock, G. (2024, May 15). *Securing a place in the sun*. Farmers Weekly. Retrieved June 8, 2024, from https://www.farmersweekly.co.nz/opinion/securing-a-place-in-the-sun/

Rogers, E. M. (1983). *Diffusion of innovations* (3rd ed.). Free Press. https://teddykw2.wordpress.com/wp-content/uploads/2012/07/everett-m-rogers-diffusion-of-innovations.pdf

Rural News. (2023). *Research could inform future design of on-farm solar panels*. Rural News Group. Retrieved 3 May 2024 from https://www.ruralnewsgroup.co.nz/rural-news/rural-management/research-could-inform-future-design-of-on-farm-solar-panels

Schwartfeger, L., & Miller, A. (2015, June). *Environmental Aspects of Photovoltaic Solar Power – The New Zealand Context* [Research Paper]. EEA Conference & Exhibition, Wellington Aotearoa NZ. https://ir.canterbury.ac.nz/server/api/core/bitstreams/df28af2a-240e-40e3-b339-bb6df5f188e6/content

Scognamiglio, A. (2016). 'Photovoltaic landscapes': Design and assessment. A critical review for a new transdisciplinary design vision. *Renewable & Sustainable Energy Reviews*, *55*, 629–661. https://doi.org/10.1016/j.rser.2015.10.072

Scovell, M., McCrea, R., Walton, A., & Poruschi, L. (2024). Local acceptance of solar farms: The impact of energy narratives. *Renewable & Sustainable Energy Reviews*, *189*, 114029-. https://doi.org/10.1016/j.rser.2023.114029

Sharpe, K. T., Heins, B. J., Buchanan, E. S., & Reese, M. H. (2021). Evaluation of solar photovoltaic systems to shade cows in a pasture-based dairy herd. Journal of Dairy Science, 104(3), 2794–2806. https://doi.org/10.3168/jds.2020-18821

Thorn, D., & Casey, M. (2024). *Electric Farms – the role of farms as future power stations.* Rewiring Aotearoa. https://www.rewiring.nz/electric-farms

Tolli, M., Recanatesi, F., Piccinno, M., & Leone, A. (2016). The assessment of aesthetic and perceptual aspects within environmental impact assessment of renewable energy projects in Italy. Environmental Impact Assessment Review, 57, 10–17. https://doi.org/10.1016/j.eiar.2015.10.005

Torma, G., & Aschemann-Witzel, J. (2023). Social acceptance of dual land use approaches: Stakeholders' perceptions of the drivers and barriers confronting agrivoltaics diffusion. *Journal of Rural Studies*, *97*, 610–625. https://doi.org/10.1016/j.jrurstud.2023.01.014

Transpower New Zealand. (2021). *NZGP1 Scenarios Update – NZGP1 Scenarios and modelling results for an unconstrained transmission grid.* https://tpow-corp-production.s3.ap-southeast-2.amazonaws.com/public/uncontrolled_docs/Transpower_NZGP_Scenarios%20Update_Dec2021.pdf?VersionId=TYXBFEkibX0ZjlGg5Rt59NPTl4sSIR5y

Transpower New Zealand. (2024). *New Connection Enquiries*. Retrieved June 8, 2024, from https://experience.arcgis.com/experience/97d4604079b545448280423f9269b9ea/page/Dashboard/

Vaughan, A., Brent., A., Fitzgerald, M., & Kueppers, J. (2023). *Agrivoltaics: Integrating Solar Energy Generation with Livestock Farming in Canterbury*. https://ourlandandwater.nz/wpcontent/uploads/2023/08/Agrivoltaics_Report_OLW-RPF23.pdf

Visser, E., Perold, V., Ralston-Paton, S., Cardenal, A. C., & Ryan, P. G. (2019). Assessing the impacts of a utility-scale photovoltaic solar energy facility on birds in the Northern Cape, South Africa. Renewable energy, 133, 1285-1294

Wagner, J., Bühner, C., Gölz, S., Trommsdorff, M., & Jürkenbeck, K. (2024). Factors influencing the willingness to use agrivoltaics: A quantitative study among German farmers. *Applied Energy*, *361*. https://doi.org/10.1016/j.apenergy.2024.122934

Appendix 1

Types of interviewees

List of interviewees (total of 13 interviews undertaken with 17 people total):

- Two farmers who are currently diversifying their farming system with solar farming.
- Two farmers considering diversifying their farming system with solar.
- One lawyer involved in the solar industry.
- Three academic researchers (one interview conducted with two people, the other with one person) researching the integration of solar and pastoral farming systems in Aotearoa New Zealand.
- One agri-consultant who is involved in the agrivoltaics space.
- Two central government representatives (conducted as one interview), and.
- Four solar farming development companies (one of these interviews was conducted with a group of three people).

Information provided to interviewees

Cultivating the sun: The challenges and opportunities of solar farming for drystock farm diversification in Aotearoa, NZ

Kellogg research project

Aotearoa NZ in recent years has attracted significant interest as a location for solar farming opportunities. Solar farming (in the context of this research) refers to a large collection of photovoltaic solar panels located on land, that absorb energy from the sun. The absorbed energy is converted into electricity and is fed into the national power grid which distributes electricity across the Country.

We are starting to see some farms install in large collections of panels (beyond just self-sufficiency for powering their homes, or farm energy demands) by leasing or diversifying part of their farming operations to have mixed land use with solar.

The aim of this research is to investigate the challenges and opportunities of solar farming as a potential farm diversification strategy for drystock farms (i.e., sheep, beef and deer farming operations). Interviews aim to examine some of the known challenges, and opportunities associated with it. Information obtained through interviews will allow for an analysis of factors influencing the adoption of solar farming to date, and to assess the wider potential for adoption (in terms of viability for farming operations).

This research project forms part of the Kellogg Rural Leadership Programme which I am currently undertaking. I am doing this project as part of the Kellogg Programme, and as a Lincoln University student completing a Post Graduate Certificate in Commerce.

The interview questions below have been developed to extract your perspective on the topic through a range of semi- structured interview questions. The interview should take approximately 1 – 1.5 hours. The questions have been provided for your information below. Should you be interested in participating, further information will be provided with a consent form.

Please do not hesitate to contact me should you wish to discuss this project further – my contact details are below.

Thank you for your time – and I look forward to hearing from you.

Jesse Brennan
Current student

KELLOGG
RURAL LEADERSHIP PROGRAMME

Kellogg project – Semi-structured interview questions

General/context questions

1. What sparked your interest or consideration of solar farming? (for interviews with landowners only)
    a) Why did you decide to diversify with solar? / Why did you decide to not diversify with solar?
    b) What were the key factors that made you come to that decision?

2. Based on your experience, how extensive is solar farming in Aotearoa NZ at present?
    a) Are you seeing any trends, i.e., certain areas or regions having more potential development than others?

3. Why do you think Aotearoa NZ (or your farm – for landowners) is a good location for solar farming?
    a) How does proximity to the national grid impact the ability for a farm to become a solar farm?

4. How does the current regulatory environment for solar farming in Aotearoa NZ impact solar as a diversification strategy?

5. What do you think the current perception of the farming community is towards solar as a diversification strategy?

6. What do you think the current perception of the public is towards solar farms in Aotearoa NZ?

Environmental and farming system questions

1. What does the presence of solar panels do to a land area?

2. How does the presence of solar panels affect agricultural production and animal welfare?

Social questions

1. What do you think the key decision making considerations are for farmers when it comes to solar as a diversification strategy?

2. How do you think solar farming could be developed by a farmer as part of a diversification strategy?

Economic questions

1. How does solar farming impact the productive capacity of a farming operation?

2. Are you aware of the returns that can be made from leasing land for solar farming, and if so, can you provide an indication of these?

3. Did you go through a company or do it yourself for solar panel installation and operation? (for farmer interviews - adapt for those that haven't gone through with it)

4. What factors need to be considered for a farm to viably consider diversification with solar?

5. What are the capital and ongoing costs associated with solar farming?

Other questions

1. Is there anything else that we haven't covered that you would like to?

Thank you for your time!

Note: this information was provided alongside the standardised Kellogg research project consent form for participants (dated 2024).