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NZ Clean Energy: Darfield, Land Productivity Assessment.
Report Prepared For: NZ Clean Energy

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LANDVISION

LandVision

LandVision Ltd is an independent technical agricultural/land and resource management consultancy company with offices in Hawkes Bay, Nelson, Wanganui and Tauranga. It has a team of multi-skilled staff with extensive experience across farm planning and management, soil and LUC mapping, nutrient budgeting, environmental management, compliance, and policy.

LandVision is New Zealand's most experienced private soil /LUC mapping specialist with over 1million hectares mapped for various clients, including councils, farmers, and Iwi.

LandVision Ltd provide technical and strategic advice to clients throughout Aotearoa across multiple scales from small farms to large councils, industry groups, Iwi farming trusts and corporates. Its advice ranges from comprehensive farm plans and nutrient budgets, advice on development options and due diligence to full effects assessments to support resource consent applications.

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SUMMARY

Darfield Solar and Energy Storage Ltd propose to establish a Solar farm at 1352 Homebush Road, Darfield, Canterbury (the Site). The Site is mapped within the New Zealand Land Resource Inventory (NZLRI) as unit 3s5 when mapped at regional scale. The LUC is a basic system of land characteristics designed to describe suitability for a set of generic land uses.

Consideration of inappropriate use or development on highly productive land is relevant since the commencement of the National Policy Statement for Highly Productive land (NPS-HPL) in October 2022.

Currently, the site is used as an intensive pastoral operation specialising in the finishing of lambs. The site typically experiences significant soil moisture deficits between September and April. Site inspections found that the site has significant areas of shallow to very shallow soils not representative of unit 3s5.

The effect of solar panels on pasture production and therefore livestock performance is varied. The installation of solar panels induces secondary effects on soil moisture and plant physiology that changes the performance of shaded pasture relative to pasture in full sunlight. While the total amount of dry matter may be different under solar panels, this does not necessarily result in corresponding reductions in animal performance with changes in pasture quality and timing of pasture peak production to later in the season adding additional benefits to a pastoral system.

Overall, the basic elements of pasture production will continue on site. Grass will grow, soil moisture will fluctuate, soil nutrients will continue to flux and organic matter will continue to be added to the soil profile. Land based primary productivity will continue to occur.

The productive capacity of the Site will be maintained and will continue to be available for primary productivity within the bounds of the Site's recognised potential. The effect of the proposed development on the primary productivity will be less than minor over the long term.

1. INTRODUCTION

Darfield Solar and Energy Storage Ltd propose to establish a Solar farm at 1352 Homebush Road, Darfield, Canterbury (the Site). The Site is mapped with the New Zealand land Resource Inventory (NZLRI) as being within a single very large(>1000ha) unit of 3s5 (LUC3). The National Policy Statement for Highly Productive land (NPS-HPL) was introduced in September 2022 and commenced in October 2022. The single objective of the NPS-HPL is that "*Highly productive land is protected for use in land-based primary production, both now and for future generations*". There are 9 policies, with Policy 8 being particularly relevant to the establishment of the Solar Farm at the Site. Policy 8 provides highly productive land is protected from inappropriate use and development, while clause 3.9 addresses inappropriate use and development.

Highly productive land is land that is both LUC class 1-3 and zoned rural production.

LUC mapping occurred nationally through the late 1970s and early 1980s at regional scale (1:50000). This has produced maps that are useful for regional analysis but limited at smaller scale. To assist with an effective effects assessment under the NPS-HPL the site was visited to assess the actual physical characteristics as compared with the characteristics described in the NZLRI. It is noted that there are no areas of class 1 or 2 present on the Site.

Figure 1: The Sites boundaries outlined in blue

2. LUC SYSTEM

The LUC system is a basic system of land characteristics designed to describe suitability for a set of generic land uses. It is widely accepted that the catalyst for the LUC came out of the USA around 1930 in response to widespread erosion issues that were apparent at the time across the American and Canadian prairies (sometimes known as "the dust bowl''). Indeed, the first publication by soil erosion services within the USA of a "soil conservation survey handbook'' was August 1939[1]. The primary purpose of the soil conservation survey handbook was to develop a systematic method to describe and mitigate various soil erosion risks. Land was classified into broad categories based on physical characteristics of a site that contribute to erosion risk such as degree of erosion, land cover, slope class, and soil.

In New Zealand the need for soil conservation was recognised during the 1930s. The intense storm of April 1938 in which the Esk Valley suffered extensive soil loss and associated damage is widely credited as the catalyst for regional soil conservation service, and the Soil Conservation and Rivers Control Act 1941. LUC systems were first employed in New Zealand during the 1950s and a Land Use Capability Handbook was first published in 1969 to guide field mapping.

Initially the LUC system advocated for New Zealand was based on 6 classes, but after considered field testing such as that carried out in the Pohangina Valley, a new 8 class system was developed (as described in the original 1939 American publication). This is the system we continue to use.

The LUC system is composed of two key attributes. The first is a resource inventory that compiles physical factors in a consistent and methodical manner and secondly an LUC classification where land is categorised into classes based on its capability to sustain one or more productive uses[2].

LUC classification is based on pastoral, arable and forestry use.

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[1] Helms D. "The development of the Land Capability classification". Soil Conservation Service,1992,p60-73.

https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1043484.pdf

[2]Lynn I, Manderson A, Page M, Harmsworth G, Eyles G, Douglas G, Mackay A, Newsome P 2009. Land Use Capability Survey Handbook - a New Zealand handbook for the classification of land. 3rd ed. Hamilton, AgResearch; Lincoln, Landcare Research; Lower Hutt, GNS Science https://www.landcareresearch.co.nz/data/assets/pdf_file/0017/50048/luc_handbook. pdf

Increasing limitations to use ↓ / *Decreasing versatility of use* ↓

<table>
<tr><th>LUC Class</th><th>Arable cropping suitability†</th><th>Pastoral grazing suitability</th><th>Production forestry suitability</th><th>General suitability</th></tr>
<tr><td>1</td><td rowspan="4">High
↓
Low</td><td rowspan="7">High
↓
Low</td><td rowspan="7">High
↓
Low</td><td rowspan="4">Multiple use land</td></tr>
<tr><td>2</td></tr>
<tr><td>3</td></tr>
<tr><td>4</td></tr>
<tr><td>5</td><td rowspan="4">Unsuitable</td><td rowspan="3">Pastoral or forestry land</td></tr>
<tr><td>6</td></tr>
<tr><td>7</td></tr>
<tr><td>8</td><td>Unsuitable</td><td>Unsuitable</td><td>Conservation land</td></tr>
</table>

Figure 2: from LUC handbook - Increasing limitations to use and decreasing versatility of use from LUC Class 1 to LUC Class 8. Arable includes vegetable production.

Mapping of the initial LUC units across New Zealand was conducted primarily during the 1960s to 1970s. Often land was mapped as a desktop exercise using stereoscopes and aerial photography (a process producing 3 dimensional images). This resulted in low spatial resolution maps of around 1:50,000. Often units were mapped without a person physically walking the land. (Garth Eyles: Pers Com).

This has resulted in a mapping system that is useful for regional scale analysis but is generally regarded as having limited utility at sub catchment or farm scale.

An explanation of the various LUC units found on site is included below. A brief breakdown of the key LUC class (1-8) differences is provided in table 1 (derived from LUC handbook). As shown below the LUC classes identified in the NP HPL are class 1-3. These classes are generally good land with slight to moderate limitations. It should be noted that some units of class three are less versatile and productive than some units of class 5 and 6.

LUC mapping at larger scale does not usually recognise smaller areas of more severe limitation (in an HPL context) whereas paddock scale (1:6000) mapping will frequently map these areas separately from adjacent units because paddock scale mapping facilitates increased management options.

Table 1: Brief description of LUC classes.

Class	Description	Limitations (examples)
1 - HPL	Most versatile multiple use land. Flat to undulating. Deep soils.	Minimal physical limitations for arable use. High suitability for cultivated cropping with many possible crop types.
2- HPL	Very good land. Flat to undulating. Moderate soil depth.	Slight physical limitations. Occasional flood overflow.
3- HPL	Moderate physical limitations to arable use. Mostly undulating to rolling. Shallow (20-45cm) soils with higher incidence of unfavourable characteristics (clay, sand, stones).	Moderate susceptibility to erosion when cultivated. Wetness can remain after drainage. Low soil moisture holding capacity. Moderate structural impediments to cultivation.
4	Severe physical limitations to arable use. Substantial reduction in the range of potential crops. Flat to rolling. Very shallow (<20cm) soils often with stones to the surface. Flood frequently.	Very low soil moisture holding capacity. Moderate to high susceptibility to erosion when cultivated.
5	High producing land with physical limitations to arable cropping but negligible to slight limitations to pastoral. Limitations to arable use is frequently because of slope.	Slope. Erosion risk when cultivated. Rock outcrops. Wetness even after drainage. Flooding.

6	Not suitable for arable use. Slight to moderate physical limitations to pastoral use. Very stoney or shallow soils.	Moderate erosion under pasture. Low moisture holding capacity. Excessive wetness.
7	Unsuitable for arable and severe limitations for pastoral use.	Erosion severity. Steepness. Very Low moisture holding capacity. Frequent flooding. Extreme wetness.
8	Very severe extreme physical limitations making it unsuitable for arable pastoral or forestry. Suitable for retirement. Mainly mountainous or deep gullies or dunes.	Very steep. Severe – extreme erosion. Very shallow soils. Very rocky Climate

3. METHODS

The Site was visited by Ian Millner from LandVision May 2024 to collect basic data to compare to the inventory of landscape factors for the Site. This involved:

- General observations of vegetative ground cover and landform.
- Talking with farmer on site to ascertain the Site's history and areas of modification.
- Inspection of soil profiles at select points to ascertain soil characteristics (depth, texture, structure) and distribution.

This information was then combined with publicly available data sources (geology maps, S Map, etc) and Data developed by Landvision.

The entirety of this site had previously been mapped as class 3 in the NZLRI. The focus of this exercise was to collect more detailed information with which to more accurately assess potential effects under the NPS-HPL of the proposed solar farm. Typically, Landvision would remap sites where higher resolution LUC classifications are not available. However, since the recent Environment Court decision[3] that found more detailed mapping cannot prevail over that held in the NZLRI, Landvision focuses on the collection of base data to compare with NZLRI data to support analysis of a site's actual productive capacity.

4. RESULTS

Initial observations of The Site suggested that the area mapped as HPL within the NZLRI was more variable than expected for a unit of 3s5. Within the mapped Unit of 3s5 significant areas of shallow soils were observed. These soils would be mapped out as class four or higher if remapped due to severe or greater limitations to arable use. The two observed variants of Lismore type soils occur on high terraces in a complex (close association) where a complex microtopography of shallow braided channels and gentle ridges occurs[4].

Detailed mapping of the soils on site has revealed that the single HPL unit identified in the regional mapping actually has significantly variable characteristics, and some parts do not have the level of productive capability associated with LUC 3.

Of note are the variations illustrated below.

Wind reduction – where shelter from west- northwest wind is provided there is a noticeable greening of pasture	

[3] Decision No. [2024] NZEnvC 83. Blue grass Limited and Dunedin City Council.

[4] Soils and Agriculture of Part Paparua County, DSIR. Bulletin 34.1978

Lismore Soil 18-25 cm weak loam. Profile available water (300mm)=63mm	
Shallow and very shallow Lismore soil 15-22 cm weak stoney loam Profile available water (300mm)=49mm	

	
Pastures on shallow Lismore soil.	

Lambs grazing Lambs are introduced onto site January and leave approximately 250 days later having grown on average at 100grams/day	
Pasture in winter state. Low/no growth ready for next growing season	

Stock water race – runs North to South through the middle of the property.	

4.1 NZLRI AND SITE CHARACTERISTICS

Review of the NZLRI for the Site showed that of the 153.7-ha assessment area (shown figure 3), 100% was unit 3s5. 3s5 is shown as moderately shallow/stoney silt loam textured susceptible to wind erosion.

Table 2: Attributes of unit 3s5

3s5	Inventory Factor
Slope	A
Rock Type	Alluvium/Loess
Soil	Lismore
Erosion	Moderate wind when cultivated
Vegetation	High producing pasture, cereal and forage crops

Current Land Use	Pasture and forage crops
Potential Land Use	Pasture, forage crops

NZLRI units, respective areas and current use are shown below in table 4.

Table 3: NZLRI units, areas, and current use.

Unit	Area (ha)	Current use
3s5	100%	Improved pasture. Forage crops
Grand Total	**153.7**	

Figure 3: Map of NZLRI mapping and units across The Site. The entire site is LUC unit 3s5

Unit 3s5 is recorded in the NZLRI as having Lismore type soil, being flat to undulating, with slight to moderate wind erosion potential. Our inspection found that while these conditions (or very similar conditions) occur on site, they are not exclusively present. Clearly while the site is mapped as 3s5 conditions other than 3s5 exist. Notably areas of shallow to very shallow soil that would be mapped differently from 3s5. Across the site there is a recurring pattern of soil depths varying between 20+cm and <20cm. Typically the shallower soils would be mapped as class 4s where their extent justified mapping separately.

It is clear from observation and physical data collected that the Site is suitable for intensive/semi-intensive pastoral agriculture. The Site has been used for arable crops in the past with limited success due to low yields (which in turn are due to low summer rainfall and shallow soil). 3s5 is recorded in the South Island Land Use Capability extended legend as being potentially suitable for cropping, intensive grazing and production forestry.

4.2 LAND USE ON SITE

Currently, the Site is used as part of a lamb finishing operation. This involves approximately 4000 lambs being bought on through January and grazed until spring when they are around 55kg.

Pastures are a mixture of cocksfoot, sub and white clover. Forage crops for lambs are rotated around the site as a form of pasture renewal.

Lamb finishing has been utilized on this site because it is a flexible system that reduces exposure to dry summers. Arable (wheat) has been tried in the past but not continued with because it is inflexible land use in dry seasons. Yields in dry seasons are inconsistent.

5 DISCUSSION ON LUC

Multiple aspects of the remapped LUC distribution are discussed as below.

5.1 PROPORTION OF SITE THAT IS HPL

The site is recorded in the NZLRI as being LUC3 (3s5) in its entirety. There is no LUC class 1 or 2 land on this site.

Data contained on the Landcare research site 'OurEnvironment' shows that the Selwyn district has 140 492 ha of class 1-3 land of which 87 866ha is class 3. The subject site comprises 0.10% of the HPL in the Selwyn District (as mapped in the NZLRI).

5.2 RELEVANT CHARACTERISTICS OF HPL ON SITE

The LUC unit recorded on site is 3s5. As described above this unit occurs on flat older terraces where river gravels from braided rivers is covered in a layer of loess. Loess is deposited at variable depths due to gravel ridges – with loess deposits being deeper between ridges and shallower across ridges. This has produced soils of variable depth and therefore productive potential. On site observations confirm this pattern of shallow and deeper soils.

The NZLRI is mapped at regional scale. Regional scale mapping is suitable for regional scale analysis as it has a scale of approximately 1:50000. Paddock scale mapping typically has a scale of approximately 1:7000. The degree of confidence or certainty that can be drawn from regional scale information is proportional to the expected result. Obviously, the degree of confidence that can be attributed to paddock scale analysis that relies on regional scale data is lower than regional scale analysis using regional scale data. This means that a closer examination of physical characteristics of any site is very likely to identify characteristics not recorded in the NZLRI. In this case the incidence of shallow and very shallow soil is significant.

It is clear, that this site has lower primary production potential than that recorded in the NZLRI because the soils on site have characteristics in line with class 4 rather than 3. The LUC handbook states that soils where there is <20-45cm depth of light textured stoney soil with some stones present on the surface should be mapped as class 4.

Traditionally when planning further development within a land-based productivity context the limitations of various land types are considered, particularly, the known ability to overcome known limitations thereby achieving consistent and profitable results across multiple units. As an example, drainage is typically installed where the dominant limitation is wetness. This because on sites where drainage can be installed successfully productive potential and versatility will be improved. Significantly for this assessment is the fact that the HPL unit has a soil-based limitation.

Individual LUC units (where classes are further delineated into subclasses and units e.g., 3s2or 6e4) are developed based on the dominant limitation or where multiple limitations exist the following priority is observed: erodibility (e) > excessive wetness (w) > rooting zone limitations(s) > climate (c).

When allocating different units to blocks of land the following assumptions are made:

- The permanent physical limitations of the land remain.
- The rectifiable limitations may be removed.
- An above average level of land management is practiced.
- Appropriate soil conservation measures will be applied and maintained.

Physical limitations have three distinct categories:

- Permanent limitations that cannot be removed – examples of this type of limitation include climate, rock type, slope, and soil attributes where the ability to modify does not exist or is cost prohibitive.
- Removable limitations are those where the limitation can technically be removed but where it requires considerable effort and investment. E.g., soil wetness, flooding, gravel picking.
- Modifiable limitations are those that can be removed via ongoing investment and management. Examples include erosion, soil moisture deficits and nutrient deficiencies.

Therefore: Where LUC units have limitations that are considered removable or modifiable (e.g., wetness, nutrient deficiency, erosion) it is assumed that those limitations have already been removed when the unit is assessed. The exact wording from the LUC handbook is as follows[5]:

[5] Stone removal or stone picking is a method of removing stones from the surface and shallow subsurface to facilitate cultivation practices.

Where it is feasible to either remove or significantly reduce the physical limitation (e.g. installing drainage or permanent irrigation, improving soil fertility, removing surface gravel, stones or boulders, or minimising erosion), then the land is assessed as if the limitation has already been removed or managed. For example, stoney Kopua soils (Plate 79) may be classified as LUC 3s even before stone picking has taken place.

Clearly, the feasibility of removing limitations across every unit was not carried out for the entirety of each individual unit at the time of NZLRI mapping (approx. 1980). As time has progressed and land holdings have become further fragmented or additional infrastructure has been developed (e.g., residential housing) the opportunity for removal of limitations has also changed. Where current technical and financial feasibility has conclusively shown that the removal or modification of a limitation cannot be effectively or reliably implemented, then this need to be taken into account in determining the actual productive capability of the land (i.e. the kind of productive activity that could realistically occur), and therefore the actual effect on productive capability arising from another activity (such as a solar farm).

The handbook is clear that the "difficulty of removing or modifying limitations depends on their type and severity. The key words 'reasonable', 'feasible', and 'economic' are considered when deciding on the practicality of removing or modifying limitations.

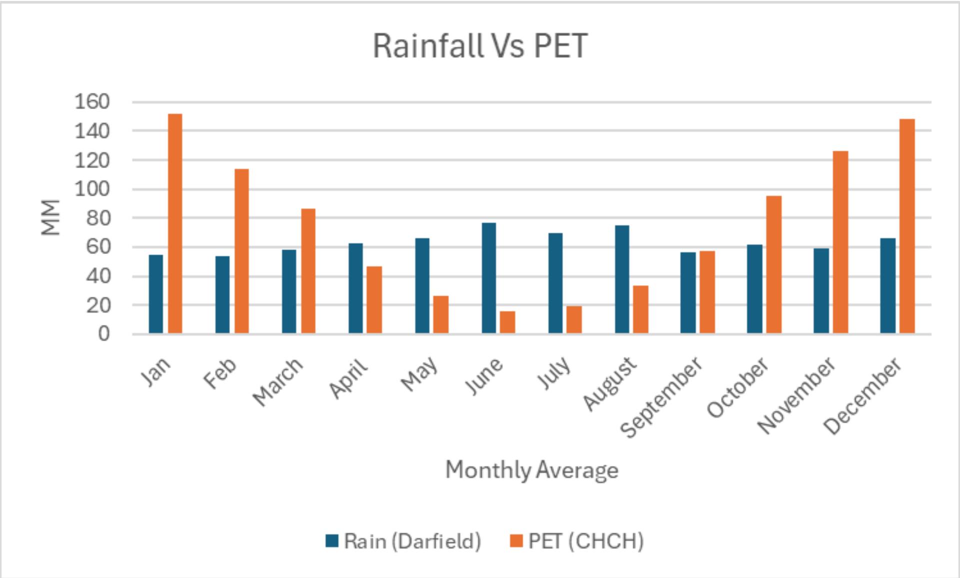
It should be noted that at regional scale (i.e., approx. 1:50 000) the smallest map unit is approximately the size of the old 1 cent piece (1cm2 or 20-25ha). This means that smaller areas within units may well have different degrees of limitation when compared to the unit as a whole and therefore different potentials/limitations when being assessed as highly productive land. Higher resolution mapping surveys (1:8000) may identify these areas and map them as separate (potentially different) units. At a scale of 1:8000 the smallest unit equates to approximately 0.7ha. On this site higher resolution mapping would identify areas of class 4 as well as 3s5..

In summary, the site is currently mapped as 3s5 within the NZLRI. The NZLRI is regional scale mapping. On site investigations found shallow and very shallow soils that would be classified as class 4s within higher resolution mapping. The key limitation for the units(s) on site is a soil limitation. Soil limitation is both permanent and unavoidable. The current use of this land for livestock production effectively manages the limitation into an effective unit through judicious stock management and timing. Land uses with more specific requirements and higher net investment are not well suited to this site due to the described variability and summer dry climate.

5.3 CLIMATIC LIMITATION

A key aspect of the overall site is the local climate. All the soils on site have been developed in a low to moderate rainfall climate. As shown below this means productivity on site is limited (on average) between the months of September and April by potential evapotranspiration (PET) exceeding rainfall resulting in dry soil conditions. In general, the most limiting factor will be the key limitation for land-based production, in this case, it is clear that soil moisture is most limiting.

Typically to overcome limitations of soil moisture in situations where cost benefit is beneficial irrigation is installed to supply additional water to overcome deficits in soil moisture. The feasibility of irrigation wasn't considered feasible within the current land use. Installation of irrigation on site would require the farm to convert to dairy. Conversion to dairy is no longer a permitted activity.



6 EFFECT OF AGRIVOLTAIC SYSTEM

Solar panels can be separated into two distinct designs , fixed tilt and single axis tracking. The proposed system on this site will be single axis tracking solar panels. As the names suggest they rotate on a single axis facing east in the morning and west in the afternoon. These are shown below.

Figure 4: Example of single axis tracking.

Figure 5: Example of fixed tilt.

Under both systems, pasture is maintained enabling the grazing of sheep. Obviously, any structure that restricts the amount of sunlight reaching the ground will produce a shadow. It is reasonable to expect that shadow will result in less potential grass growth. However, the shade under solar panels is variable to the extent that while some shade has consistent negative effects on pasture production not all the shade under solar panels has the same effect. This is illustrated below where it can clearly be seen that shade under the lowest point of the panel is greatest but reduces rapidly beyond that to levels consistent with cloudy days.

A range of studies on the effect of solar panels on pasture production are discussed below. A consistent theme within these studies is they separate effects into three areas.

- Full sun
- Full shade
- Partial shade

This clearly illustrates that the often-quoted shade ratio within solar farms does not equate directly with potential effects on pasture production. The actual affects are far more complex.

Relevant effects/Aspects of agrivoltaics systems are discussed below.

6.1 EFFECT OF SHADING FROM SOLAR PANELS

Figure 6: Image of solar panels in California being used by sheep for shade[6].

[6] Image from: Putting solar panels in grazing fields is good for sheep | New Scientist. 2023

Clearly, solar panels will change the amount of sunlight that reaches the ground and is available for plant photosynthesis. Therefore, to understand the full effect of solar panels we need to examine the potential effects of shade from solar panels on plant production.

Various studies have shown that the effects of solar panels are not detrimental to primary productivity. Andrew et al[7] have shown that dual use agrivoltaics systems (in Oregon, USA) can result in both energy production and viable sheep production systems. Specifically, they found that pastures under solar panels produced 38% less dry matter available for grazing, but the quality of that dry matter was higher (higher protein content) leading to very similar stock performance for solar and non-solar areas. Interestingly a partial reason for the reduced dry matter volume in this study was the effect of trampling – lambs that are returning to an area to be in the shade will trample growth in that area. Lambs were also observed to spend time ruminating in shade. Rumination is a significant source of body heat and therefore shade has a positive effect on animal performance. Overall, the net return from a two-year study found that lamb production from under solar panels was only 1.6% lower than open pasture. This reduction was more than offset by increased revenue from energy production.

A study in semi-arid Colorado[8] (Jacks Solar Garden) found interesting and dynamic interactions between light, soil moisture, temperature, and evaporative demand and concluded "o*ver relatively short spatial scales (_10 m), light availability varied by up to eightfold, SM by 30%, and aboveground plant productivity by approximately 40%".* Specifically, soil moisture was shown to exhibit seasonal patterns under tracking panels and increases in dry matter production where pasture received morning sun and afternoon shade.
Further studies[9] completed at the same site (Jacks Solar Garden) found "*Overall, our results indicate that grazing within a grassland AV array is unlikely to negatively impact forage production, and that forage quality in this semi-arid region may even be increased later into the growing season with grazing*."

[7] Andrew AC, Higgins CW, Smallman MA, Graham M and Ates S (2021) Herbage Yield, Lamb Growth and Foraging Behavior in Agrivoltaic Production System. Front. Sustain. Food Syst. 5:659175.doi: 10.3389/fsufs.2021.659175

[8] Sturchio, Matthew A., Jordan E. Macknick, Greg A. Barron-Gafford, Anping Chen, Cavin Alderfer, Kathleen Condon, Olivia L. Hajek, et al. 2022. "Grassland Productivity Responds Unexpectedly To Dynamic Light and Soil Water Environments Induced by Photovoltaic Arrays." Ecosphere 13(12): e4334.https://doi.org/10.1002/ecs2.4334

[9] Sturchio, M.A.; Kannenberg, S.A.; Knapp, A.K. Agrivoltaic Arrays Can Maintain Semi-Arid Grassland Productivity and Extend the Seasonality of Forage Quality. Appl. Energy 2024

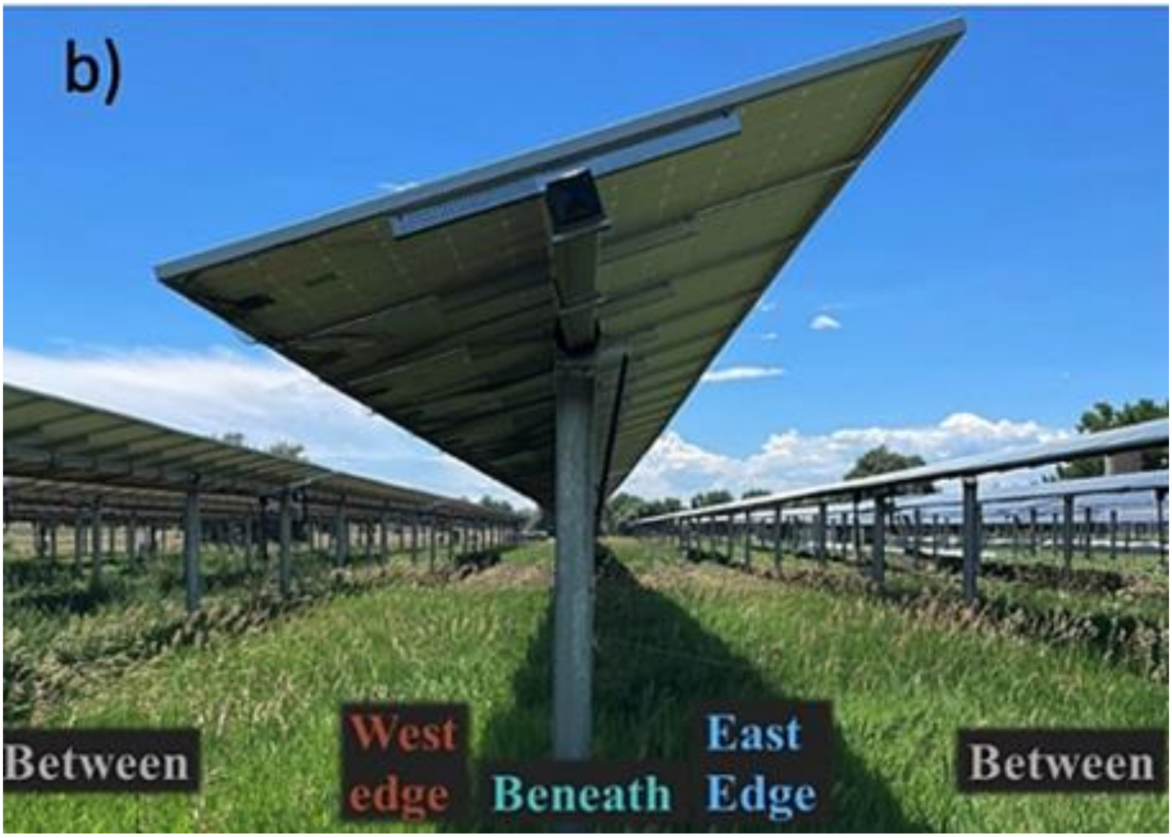


Figure 7: Study site at Jacks Solar Garden with microsites labelled

Specifically, this study found that above ground net primary productivity was significantly higher along the edges of the panels and lower beneath the panels. Consistent with similar studies forage quality was found to be higher later in the season for grass growth. Interestingly, pasture growth under the east edge was higher. Multiple studies have noted this effect and attribute its cause to the east edge receiving morning sun when temperature and vapour pressure deficit (a measure of moisture held in air versus potential saturation) is lower.

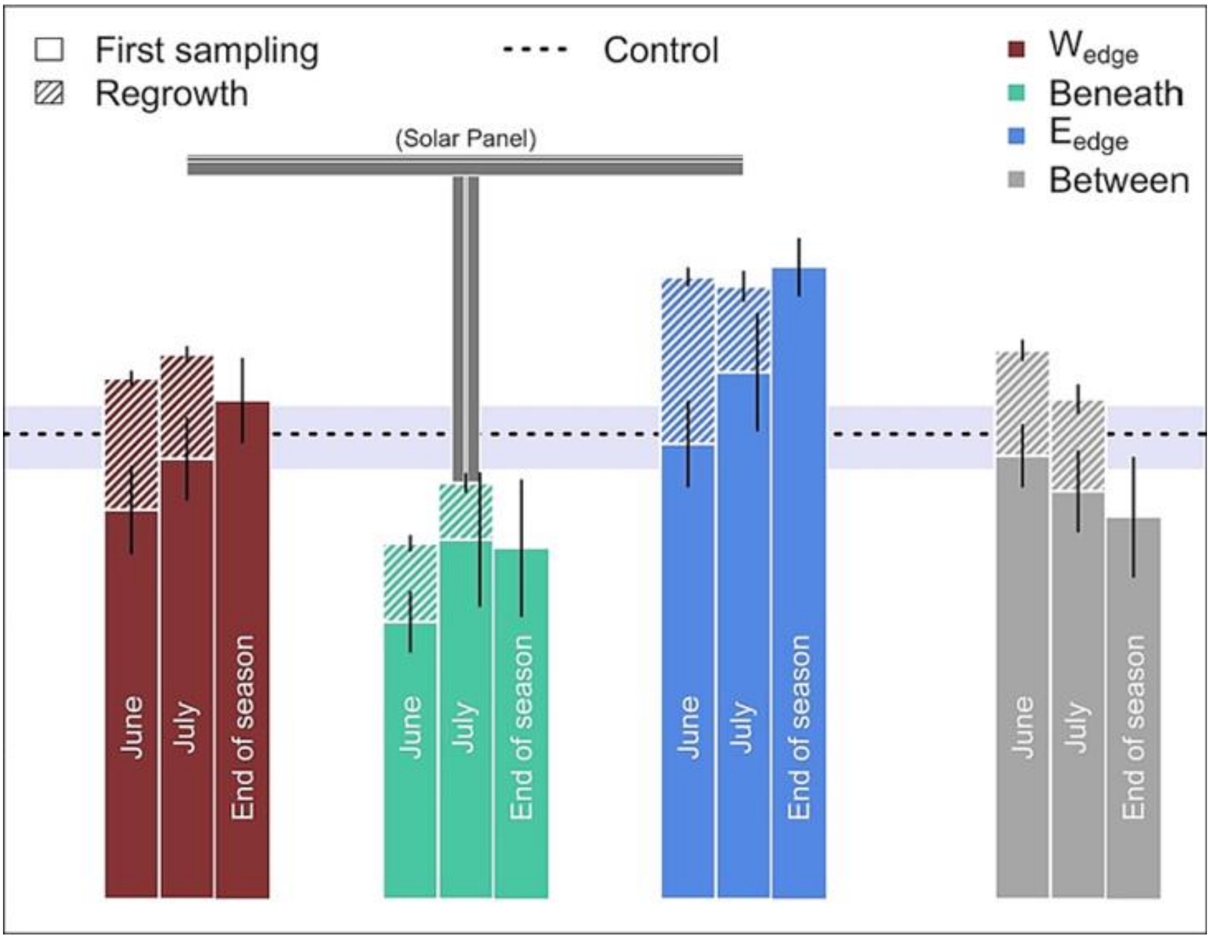


Figure 8: Graph of above ground net primary productivity under fixed tilt solar panels at Jacks Garden, clearly showing variance in productivity under, between and on the edge of panels. Loss of production directly underneath is compensated by extra growth at the edges and between.

Clearly solar panels change both light and soil moisture characteristic that can affect both total dry matter grown and the quality of that dry matter.

Another helpful study from Oregon[10] concludes that "*Water limited areas are most likely to benefit as solar management reduces PET and consequently the water demand".* This was because gains in productivity were observed due to increased water use efficiency from soil moisture under solar panels that continued into summer. This study surmises that semi-arid pastures with wet winters may be ideal candidates for agrivoltaics systems. In this study harvested dry mater was higher in shaded areas because of higher soil moisture.

More locally, Massey University has been studying the pasture production under solar panels in Taranaki. While this study has not been fully reported, the effect of solar panels on pasture production was shown to be a reduction under panels and an increase between the panels. An area

[10] https://doi.org/10.1371/journal.pone.0203256

weighted result showed net production was very similar to open pasture (Prof Danny Donaghy pers com).

The effect of solar panels on pasture production and therefore livestock performance is varied. The installation of solar panels induces secondary effects on soil moisture and plant physiology that changes the performance of shaded pasture relative to pasture in full sunlight. While the total amount of dry matter may be different under solar panels this does not necessarily result in corresponding reductions in animal performance with changes in pasture quality and timing of pasture peak production to later in the season adding additional benefits to a pastoral system.

6.2 POTENTIAL EFFECTS ON PRODUCTION

As described above the effect of solar panels on pasture production is varied. While there is no doubt the potential pasture production under solar panels will be affected when compared to open pastures, other dynamic interactions come into play and offer different opportunities. In the typical New Zealand pasture approximately 60% (or more) of total dry matter is produced in spring and early summer. This can lead to a large surge of pasture in the spring that can be difficult to control resulting in wasted feed and declines in feed quality that can endure over the summer. The introduction of solar panels while reducing total dry matter may also reduce the spring excess and increase summer production due to greater water use efficiency of stored soil moisture. Soil moisture is better conserved under solar panels due to lower evapotranspiration. This effect may be greatest in semi-arid pastural systems. The climate on site has a similar rainfall profile with wet winters and dry summers.

I would expect these potential effects to also vary with different soil types as soil moisture dynamics are driven by soil type (discussed further below).

6.3 SIMILARITIES WITH CURRENT FARMING PRINCIPLES

The concept of shade influencing pasture production is not novel. The effect of trees on total pasture production is well accepted as is the differences between north and south aspect slopes with later having slower spring and stronger summer growth than the former. Therefore, understanding the spatial and temporal variation in pasture production within an agrivoltaics system is well within standard practice for the industry. Silvo-pastural systems, where trees are integrated into a pastoral system are well understood for their pasture reducing characteristics, but this is balanced against the additional services trees offer to the pastural system (shade, shelter, diversified income, soil moisture conservation, soil conservation).

6.4 LONG TERM EFFECTS ON PRODUCTIVE CAPACITY

While it is helpful to understand any potential limitations to agricultural productivity from agrivoltaics the focus of this report is to assess the effect of the proposed solar farm on the HPL on site. In particular, effects on the productive capacity of the Site. While there may be changes in the production system employed on site to accommodate the installation of solar panels this doesn’t necessarily mean there will be a resulting change in productive output but does mean there will be a change in management system. These changes will reflect well known concepts relating to landscape heterogeneity.

Typically, in pastoral systems there is a significant increase in pasture growth during spring. This is because for a brief time both soil moisture and sunlight are equally abundant. As spring progresses temperatures increase, sunlight hours increase and sunlight intensity increases. Conversely, as spring progresses rainfall reduces. These factors combined produce the situation where in late spring and summer soil moisture becomes a limiting factor and pasture growth reduces or stops completely. As shown in 5.4 above the climate on site has low rainfall (by national standards) and a distinct summer dry pattern where PET exceeds rainfall by a significant margin. PET represents evaporation of moisture directly off the soil surface, in our experience this effect can dry out the top 50-60mm of a soil profile, and transpiration whereby plants draw moisture from the soil available soil profile.

Therefore, the introduction of additional shade into a pastoral system will have different effects if soil moisture is in surplus or in deficit. In the context of this site with the existence of a typical soil moisture deficit (in late spring and summer), the negative effects of shading are offset by also reducing PET. A reduction in PET will produce favourable (for growth) soil moisture dynamics. An increase in soil moisture through late spring and summer will result in a longer (albeit lower) pasture growth curve. As shown above improvements in pasture quality can also be expected resulting in comparable production outputs when compared to unshaded pasture. On heavier soils, it can be anticipated that this effect will be more pronounced as heavier soils holds more water to begin with.

Clearly, the installation of solar panels within a pastoral environment precludes cattle from the pastoral system (due to potential damage of solar panels by cattle). As cattle are not part of the current land use system on this farm, there is no opportunity cost from the lack of cattle on site.

The productive capacity of the Site will remain largely unchanged. This is because most aspects of the farm system will remain unchanged. The soil will remain, pasture will still be grown, stock will graze, and nutrients will still cycle through the system. Also, the use of land for solar production will be able to be completely reversed when the project reaches an endpoint. The solar panels can be removed, and this site will continue to grow grass and fatten livestock (its current use). The current productive capacity will remain. In many ways this is the same as the removal of an orchard. The trees and support structures are removed, and pasture or other crops are reinstated.

6.5 RELEVANT ASPECTS OF NPS-HPL

Within the NPS-HPL there are three relevant aspects to be discussed. These are addressed as below.

Objective/clause	**Analysis**
Objective 8: HPL is protected from inappropriate use and development	As described in 6.4 above. While some aspects of the productive system will change with the introduction of solar panels the overall productive output can be maintained at or near current outputs and within current recognised potential contained within the LUC for the HPL units on site. Overall, the productive capacity of the site will remain. The sites soils will still produce grass, exhibit seasonal changes in soil moisture and temperature and cycle nutrients as they do now.
Objective 9: Reverse sensitivity effects are managed so as not to constrain land-based primary production activities on highly productive land	The site is largely isolated (apart from a small area to the north) from other HP land by roads and a neighbouring industrial site. I do not consider it likely that the proposed development, once completed with appropriate screening, will create or cause any reverse sensitivity to or from this site.
Clause 3.9 (3): (a) minimises or mitigates any actual loss or potential cumulative loss of the availability and productive capacity of highly productive land in their district; and (b) avoids if possible, or otherwise mitigates, any actual or potential reverse sensitivity effects on	(a)As described above the proposed development will not reduce the area of HPL available in the district or reduce the productive capacity of the subject land. This is simply because the land will still be available to graze sheep as it does now, and the current productive capacity of the land will not alter. When compared against the sites recognised potentials, sheep grazing is considered highest and best use.

land-based primary production activities from the use or development.	(b) due to the sites isolation the proposed development will not create or cause any significant reverse sensitivity.

7 CONCLUSION

Several aspects of the Site as it relates to the NPS-HPL have been assessed by this report.

When assessed using the regional scale NZLRI it was shown that 100% of the development site was both LUC class 3 and rural production and therefore HPL. Recent Environment Court decisions have clarified that the LUC classification described in the NZLRI is the relevant LUC classification defining HPL.

The site has been shown to have attributes consistent with both LUC class3 and 4. There are not attributes consistent with class 1and 2 on site. The site is currently used for lamb finishing. The farm operation on site finishes around 4000 lambs annually. Arable crops have been grown on site previously with limited success. Intensive pasture operations based around seasonal soil moisture patterns are consistent with the site's long term potential.

Various international studies on the effects of solar panels of pasture production show that the effects are variable but not necessarily limiting. While solar panels unavoidably reduce sunlight, they also change soil moisture dynamics and pasture quality. The combined effect of a change in pasture quantity and quality is that lamb performance may be similar to unshaded pasture. A key driver of pasture performance under solar panels will be whether soil moisture or sunlight is the most limiting factor. On this site, PET exceeds rainfall significantly for most of spring and all of summer. It is expected that the effect of solar panels on this site will produce a longer but lower spring summer pasture curve with an increase in pasture quality. Variation in pasture growth curves due to differences in soil moisture and sunlight are not novel in New Zealand pastural agriculture, therefore management of variance will not be difficult.

Overall, the basic elements of pasture production will continue on site. Grass will grow, soil moisture will fluctuate, soil nutrients will continue to flux and organic matter will continue to be added to the soil profile. Land based primary productivity will continue to occur.

The proposed development will not produce significant effects within a NPS-HPL context on the availability or capacity of HPL, nor will the proposed development create significant reverse sensitivity.

The productive capacity of the Site will be maintained and will continue to be available for primary productivity within the bounds of the Sites recognised potential. The effect of the proposed development will be less than minor over the long term.