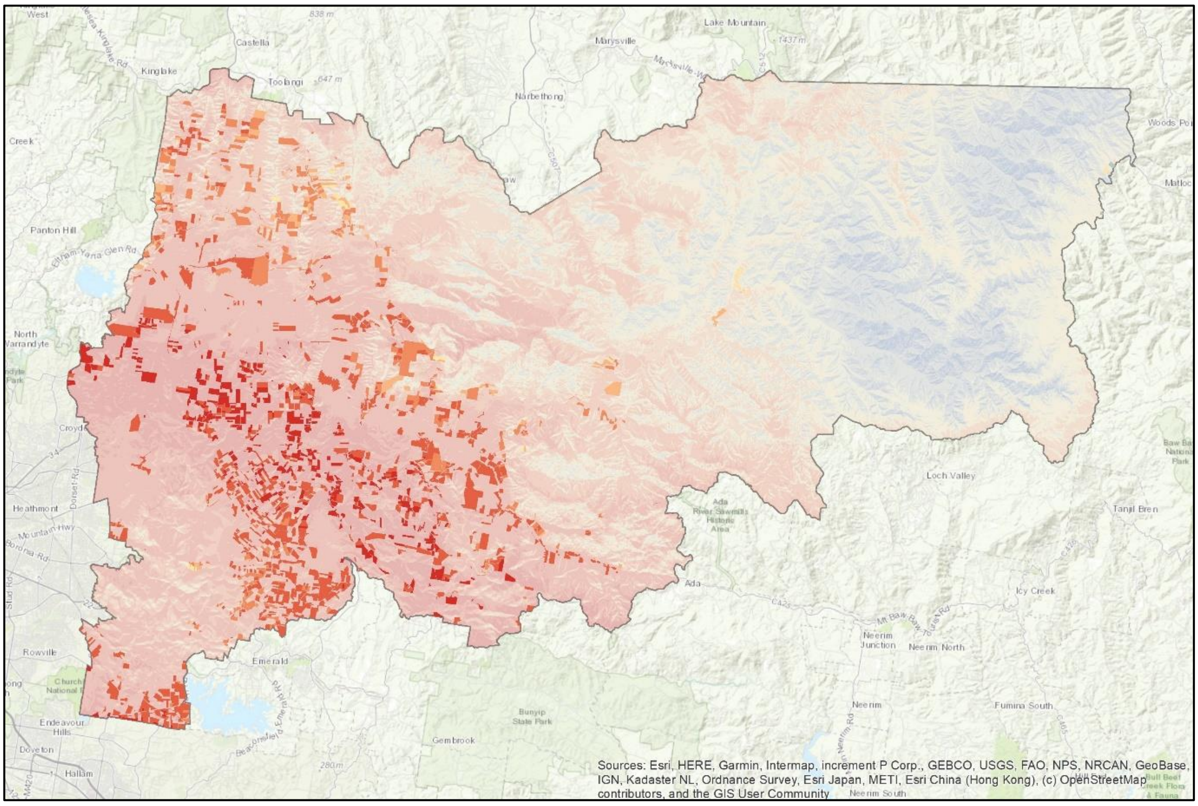

Assessing the suitability for photovoltaic solar farms in Yarra Ranges

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1. Table of Contents

2. Executive Summary

The aim of this report was to analyse the suitability of land parcels in the Yarra Valley Shire for the development of a photovoltaic (PV) solar farm. Using a geographic information system (GIS), a multiple criteria analysis was conducted to identify parcels of land which best suited to a number of variables contributing to PV suitability. Overall, the results suggest that there are many land parcels which are suitable candidates for a PV power plant and that solar power in the Yarra Valley is a viable option. However, this report concludes that fine-tuning of the methodology is required before this model can be used to reliably identify the most favourable land parcels.

3. Introduction and Aim

This study has been commissioned by the Yarra Ranges City Council and the Victorian Department of Environment, Land, Water and Planning (DELWP), to develop a method to establish the appropriateness for the investment of photovoltaic (PV) renewable energy in the region while mitigating the conflict of land competition with the agriculture industry.

3.1 Investing in solar power

The need for governments and industries to turn to cleaner, renewable practices is at an all time high, as the global climate emergency requires global carbon emissions to be reduced by 7.6% every year between now and 2030 to prevent irreversible damage to the planet (UN Environment Programme, 2020).

The demand for renewable energy sources is therefore set to rise, as Victoria's Renewable Energy Targets are that by 2030, 50% of Victoria's energy will come from renewable sources, up from 25% in 2020 (Energy Victoria, 2020). Unfortunately, as this demand increases, the competition for land will become a significant issue. A PV power plant typically requires 2 - 3 hectares of land to produce 1MW of electricity (Solar Choice, n.d.), which means that large parcels of land, typically in a rural setting are required. Nonhebel (2005) foresaw that these requirements for land for PV power and the competing industry of agriculture would be an issue as the population grows.

3.2 Meeting the overlapping demands for land

It is therefore important that analysis and consideration is exercised when planning a major development such as a solar farm. Controversies have already arisen, where poor planning has raised tempers of other stakeholders. Tuffield and Long (2019) reported community opposition to three solar farms near Shepparton, Victoria, where local farmed held "concerns the project will make the land unusable for agriculture".

While it is not realistic that all factions of the ongoing land use debate can be pleased, stakeholders should be encouraged to assess multiple factors when making decisions regarding solar power development.

Others have devised solutions for this, including *'agrivoltaics'*, which is the concept of co-developing land for solar power production as well as the farming of shade tolerant crops or livestock (Harshavardhan & Pearce, 2016). However, the possibility of finding parcels of land that are suitable for solar power while excluding farms from the search should be assessed.

3.3 Study area

The Yarra Ranges Shire is a local government authority in Victoria, Australia. It is situated directly to the east of the Melbourne metropolitan area, with an area of 246,800 km^2 and a population of nearly 160,000 (Yarra Ranges Demographic Profile, n.d.).

It is a unique location to perform this study, as it contains a varying landscape. It has large, urban towns of Healesville, Lilydale and Belgrave, the rural, agricultural Yarra Valley, which is known for its wine production, as well as the remote forests of the Great Dividing Range and Yarra Ranges National Park.

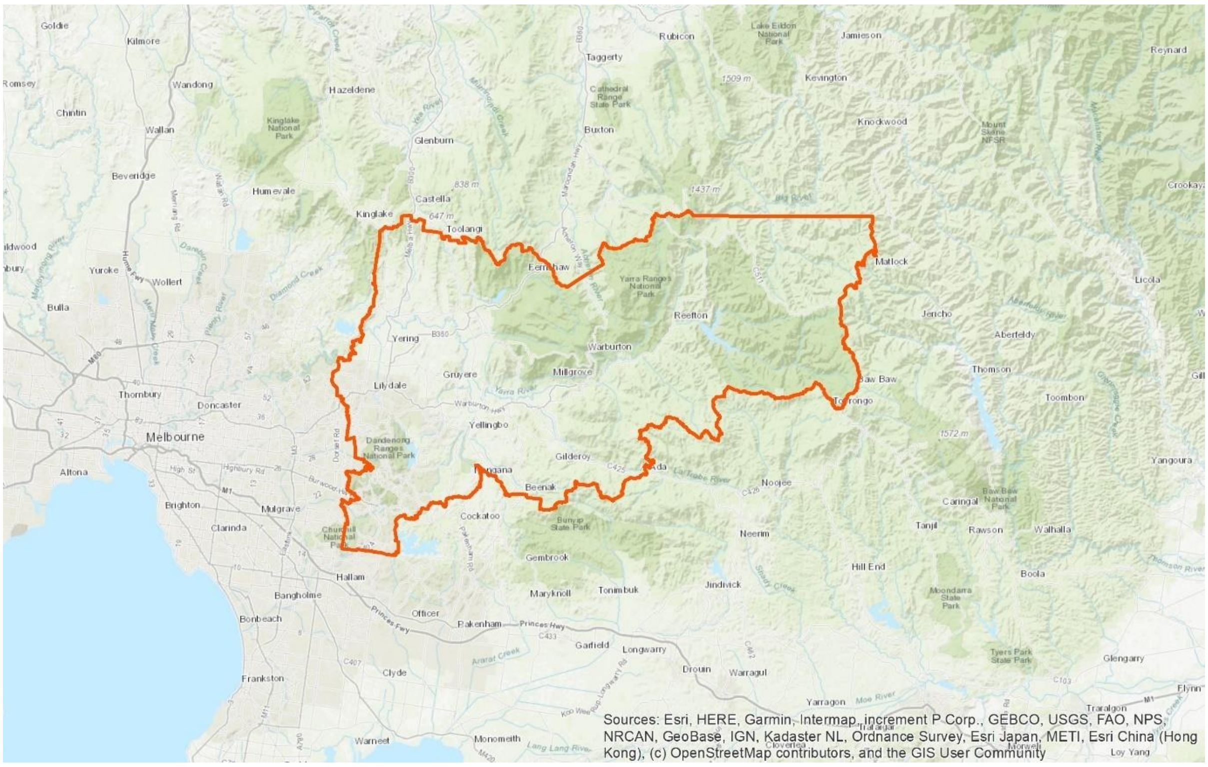

Figure 1: *Map showing the extent of the Yarra Ranges Shire, Victoria, Australia.*

Yarra Ranges is cooler, more densely populated, and less flat than many other rural regions of Australia. While these may seem like unideal conditions for a solar farm, its proximity to Melbourne may allow any potential sites to power a greater population with less cost and infrastructure required to transport energy. The city council of Yarra Ranges has declared a climate emergency (Yarra Ranges Council, 2019), and are amenable to the potential of renewable energy in the region. The resolution of such an issue in this region may also be able to demonstrate the feasibility of renewable energy in other areas around the country or the world that seem too difficult to develop.

3.4 *Study objectives*

The research question has been defined as: "If highly valued farmland is excluded, to reduce land competition, where are the areas that are most suitable for solar power production?"

This question will be addressed by using a Geographic Information System (GIS) to conduct a multi-criteria analysis of the Yarra Valley Shire, using a number of variables that influence any given locations suitability for solar power production.

The aim will be to rule out areas that are totally unsuitable, using a binary model analysis, and to produce a list of land parcels than might be suitable with an accompanying overall suitability value, using an index model analysis.

Solar farm GIS suitability analysis has been conducted in the past, including studies in England (Watson & Hudson, 2015), Poland (Mierzwiak & Calka, 2017) and Spain (Sanchez-Lozano et al., 2013). In Australia, there have been numerous papers assessing the suitability of different renewable energies from different angles, including PV energy. A study was done analysing the potential for Concentrated Solar Power (CSP), a different method of generating electricity to PV, in rural Western Australia (Clifton & Boruff, 2017).

4. Methodology

4.1 Suitability criteria

The criteria by which land would be evaluated was decided upon, based on research of the papers cited above. These criteria were separated into two analysis models: binary and index. The binary model assigns land to one of two categories, 0 or 1 – or unsuitable and suitable. This rules out all land that would not be acceptable. The binary criteria are stated in Table 1.

Table 1: *List of binary criteria used in this project.*

Criteria	Description
Built Up Areas	Built up areas should be excluded, as a solar power plant cannot be built here, due to availability of large land parcels, and nearby structures that may interfere with solar exposure.
Residential Areas	A buffer of 500m from any residential areas should be excluded, in order to reduce impact on quality of living for nearby residents.
Protected Areas	National Parks, State Forests and other such public land should be excluded, as these areas of nature that should be preserved and are protected from development of this nature.
Agricultural Land	For the purposes of this study, farmland will be excluded, in order to minimise land competition.
Water	Hydrological areas should be excluded.

The index model was analysed in a raster format, assigning a value between zero and 1, depending on an area's degree of suitability. The index criteria are stated in Table 2.

Table 2: *List of index criteria used in this project.*

Criteria	Description
Solar Radiation	More favourable land should have a higher average solar radiation, as this will improve the output of a PV power plant
Slope	Many past studies have used slope as a binary criterion, some citing 10° gradient as the maximum, however given the nature of this study, the majority of flat land will by occupied by agriculture in this reason, and therefore it will be considered an index criteria, where more favourable land will have a lower average slope.
Distance from Residential Areas	In addition to the 500m buffer, land that is furthest away from any residences will be considered more favourable, to further minimise local disturbances
Proximity to Road Network	Land which is closer to a road (sealed local or higher) will be considered more favourable, as this will reduce construction, infrastructure and maintenance cost and interference.
Proximity to Power Network	More favourable land should be closer to a transmission or sub-transmission powerline, as this will minimise infrastructure costs in connecting a PV power plant to the electricity grid.

4.2 Data sources

Table 3 describes the data sources that were used, and the corresponding derived layer, which is referred to in the rest of the methodology. The references for these layers can be found in the appended to this report. Refer to section *8. Appendices*.

Table 3: *Outline of the data sources used in the GIS.*

Data Source	Description	Derived Layer
Vicmap Elevation DTM 10m	A digital terrain model which is used to calculate solar radiation and slope.	yr_Elevation
Victoria Mesh Blocks ASGS	Mesh blocks are the smallest geographical area defined by the Australian Bureau of Statistics (ABS) and are used to identify residential areas.	yr_residential
Public Land Management	Used to identify protected areas.	yr_protected
Vicmap Features of Interest	Contains a series of datasets, including those used to identify built up areas and powerlines	yr_builtareas yr_PowerNetwork
Vicmap Transport	Used to identify road network. Only features with a hierarchy above 5 (local roads) was extracted.	yr_RoadNetwork
Vicmap Hydro	Used to identify water features.	yr_hydro
Victorian Land Use Information System	Dataset which describes land cover, land use and land tenure at a parcel level. Used to identify farmland, according to the Australian Land Use and Management Code.	yr_farmland
Vicmap Property	Used to identify land parcels.	yr_parcels

4.3 Binary model workflow

The Buffer tool was used to create a 500m buffer of *yr_residential*. Using this, and the other four binary criteria, an overall binary layer was created with a Union of all criteria and assigning the relevant binary values. Features with a value of 1 (suitable) and an area of over 5000 square metres was extracted. The area parameter was used as some source layers were found to not align exactly, resulting in small outlier features that were not to be considered. Due to the overlapping of features causing a larger number of features to be part of the final extracted layer, the Select by Location tool was used on the *yr_parcels* dataset, to extract all land parcels which contained land that was not constrained by the binary criteria. A full workflow diagram can be found appended to the report. Refer to section *8. Appendices*.

4.4 Index model workflow

A pairwise comparison was performed to assign the weight, or importance, to each of the criteria. The authors judgement was used, based on the research that was done. Table 4 shows the resultant weights, and the full pairwise comparison matrix can be found appended to this report. Refer to section *8. Appendices*.

Table 4: *Weights of the index criteria as a result of the pairwise comparison.*

Criteria	Weight
Solar Radiation	0.413
Slope	0.153
Distance from Residential Areas	0.062
Proximity to Road Network	0.107
Proximity to Power Network	0.265

The variable rasters were calculated using a series of functions. The Solar Radiation tool was used to create a solar radiation raster. This uses a Digital Elevation Model (DEM) to calculate insolate across the landscape, based on the viewshed of the sun over a desired period (ArcGIS Help, 2019). For this exercise, it was calculated for a whole year (2020) at monthly intervals.

The Slope tool was used to create the yr_slope raster, and the Euclidean Distance Tool was used to create rasters describing the shortest linear distance from residential areas, roads, and powerlines.

These rasters were then clipped to the extent of the area of interest, the Yarra Ranges Shire, to remove any outlier values. These values were then standardised using a simple linear standardisation, where the smallest value in the raster was transformed to 0, the largest value in the raster was transformed to 1, and all values in between were proportionally transformed. It must be noted that in the case of the Slope, Road Network and Power Network grids, these values were inversed, as a smaller value is more desirable and therefore should be closer to 1.

The Raster Calculator tool was then used to reduce these values to a single overall index value, using the weights ascribed in the pairwise comparison. A full workflow diagram is appended to this report, refer to section *8. Appendices*.

4.5 Final workflow

The values of the Index raster were applied to each binary parcel by using the Zonal Statistics as Table tool. This calculates statistics such as minimum, maximum, mean, and standard deviation, for all cells whose midpoints lie within each respective polygon. This table could then be joined to the parcel layer, representing the overall fit of each parcel.

5. Results

5.1 Binary results

Land parcels which met binary criteria were able to be identified and are shown in Figure 2. The Binary analysis produced a viable area of 3,191 parcels and 187 km^2, as outlined in Table 5.

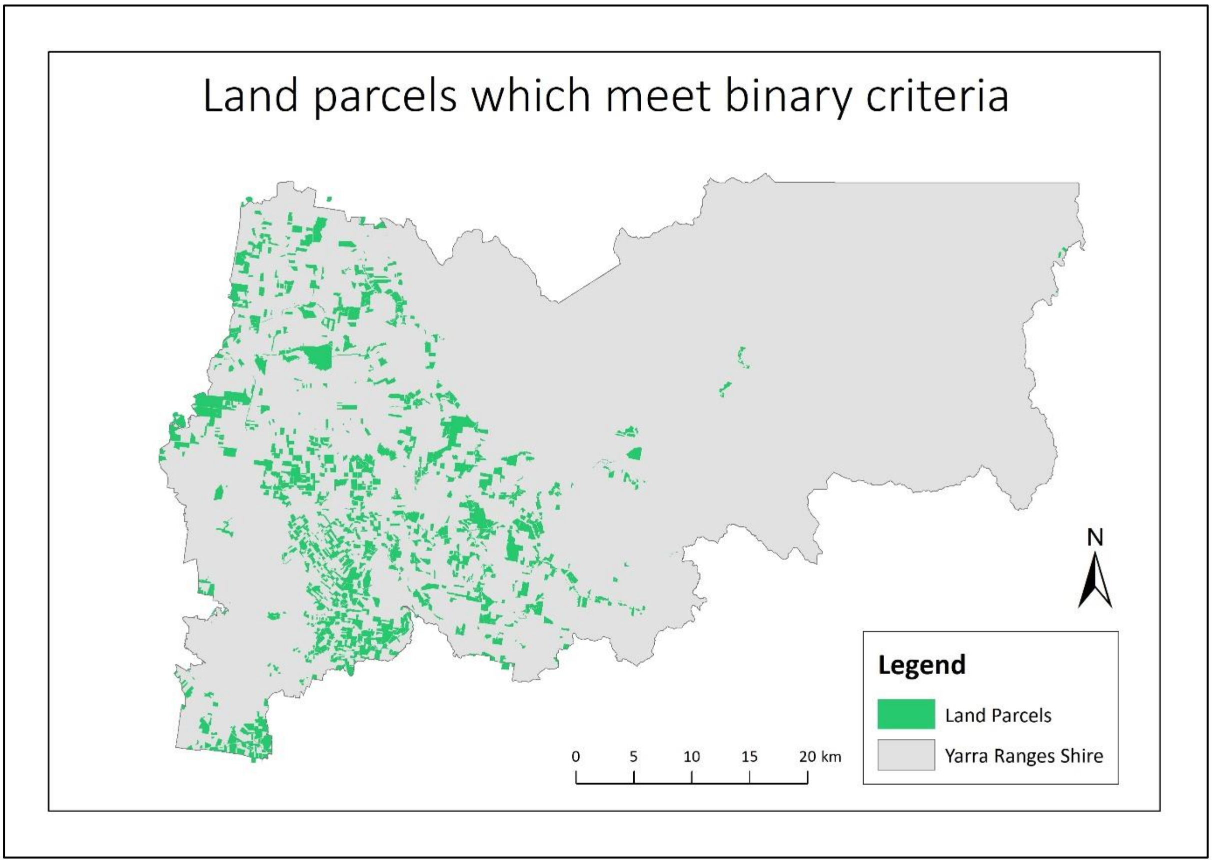

Figure 2: *Map showing the results of the binary model analysis.*

Table 5: *Summary table of the land which meets the binary criteria.*

Number of Potentially Suitable Parcels	3,191
Average Parcel Area	5.9 ha
Total Parcel Area	187.1 km^2
Areal Percentage of Yarra Ranges Shire	7.6%

5.2 Index results

The index raster that was created was used to assess the parcels of land outlined in the binary analysis. The Zonal Statistics as Table tool was used to summarise the index values that were located in each parcel. The values of the Index raster were applied to each binary parcel by using the Zonal Statistics as Table tool. These parcel values are shown under section *5.3 Summary Results* in Figure 5 and Table 6.

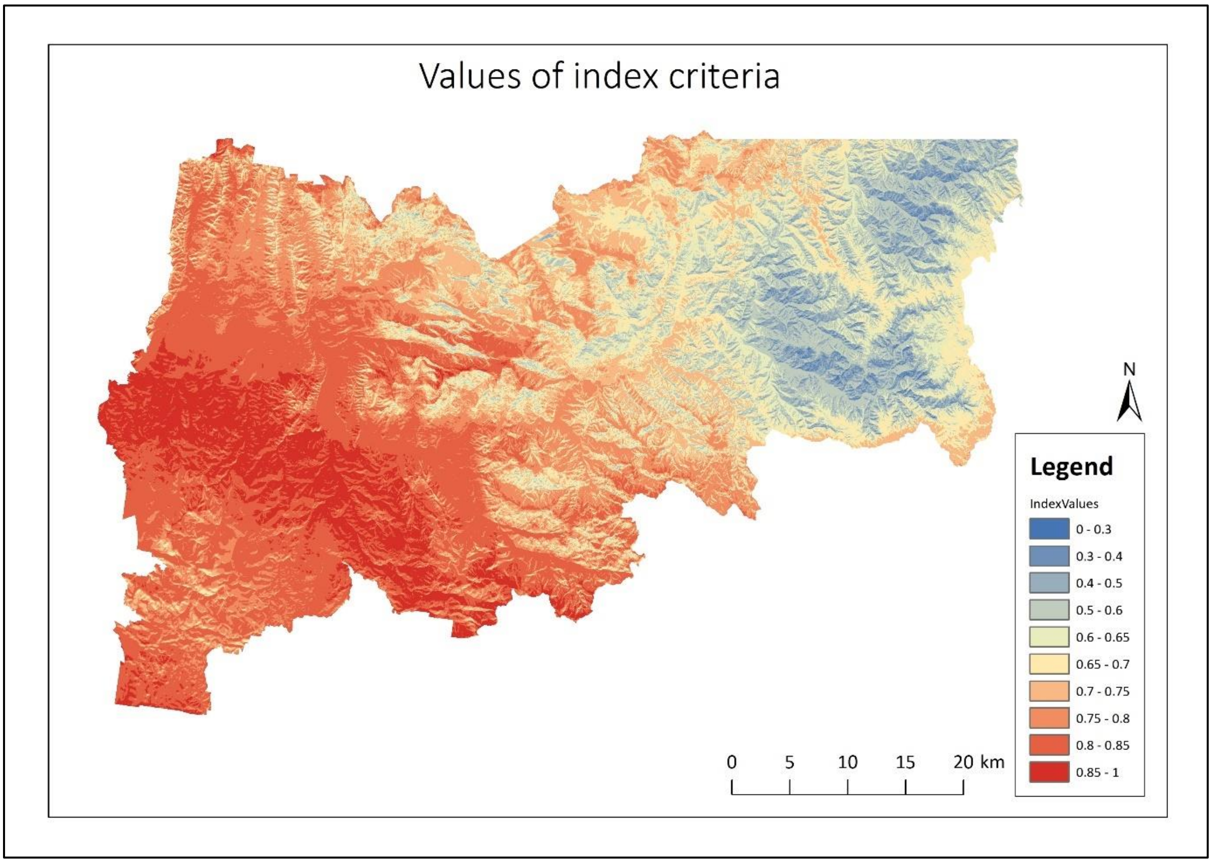

Figure 3: *Map showing the results of the index model analysis.*

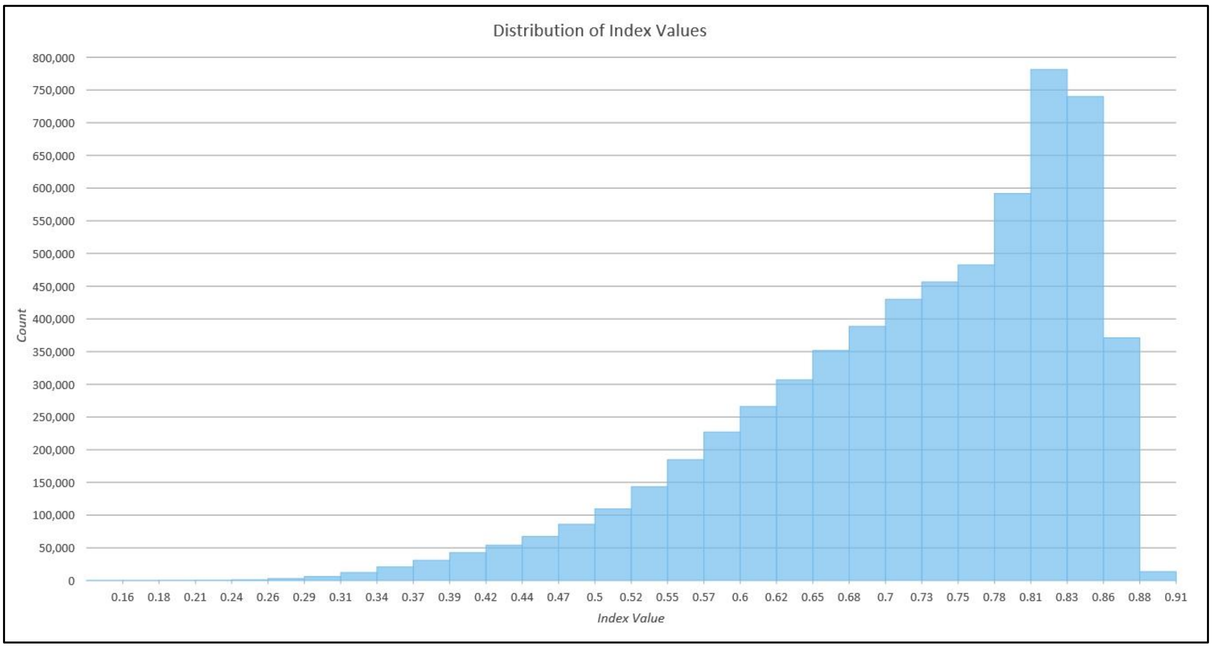

Figure 4: *Histogram of the distribution of suitability values in the IndexValues raster.*

5.3 Summary results

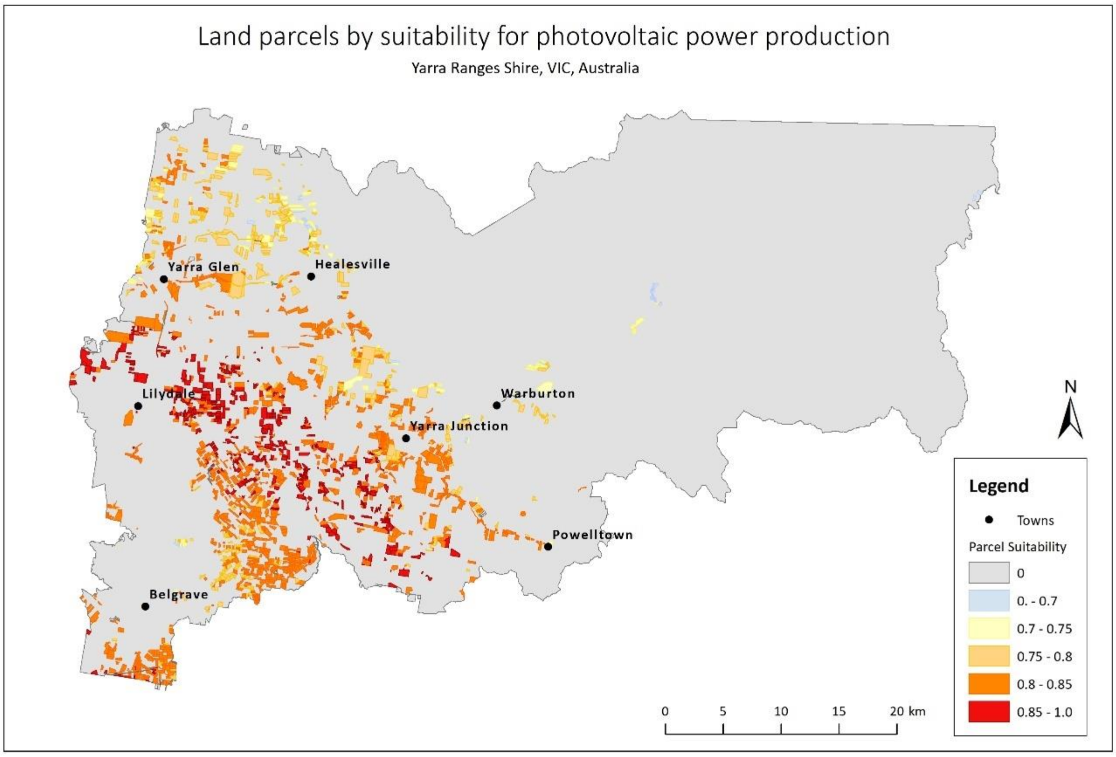

Figure 5: *Map showing the final results of the analysis.*

Table 6: *Summary table of the viable land parcels and their index criteria.*

Statistic	Mean	Min	Max
Overall Suitability	0.82	0.62	0.89
Average Solar Radiation	1269 kWh/m^2	1021 kWh/m^2	1475 kWh/m^2
Average Slope	13.3%	0.3%	47.1%
Minimum Distance from Power Network	6.8 km	0 km	46.9 km
Minimum Distance from Road Network	0.08 km	0 km	2.7 km
Minimum Distance from Residential Areas	5.5 km	0km	3.1 km

6. Discussion and recommendations

6.1 Significance of results

It has been demonstrated that there are a number of suitable locations for the development of a solar farm, as based on the parameters of this study, the 3,191 viable parcels had a mean suitability of 0.82 out of 1.

This suggests that investment in renewable energies, specifically PV power, is appropriate. Through this study, a workflow has been devised that is easily applicable to any region of Victoria. All data has either come from state or federal government sources, meaning that the same structure of layers applies to the whole state. Further work could include using the ArcGIS Model Builder to create a tool which could automatically carry out this task.

6.2 Limitations of the project

There are limitations to this study, however. An area of improvement would be the task weighting the criteria. This was done at the author's discretion, however, given the time and resources, it would be ideal to consult a number of experts in the field of solar power development, in order to get a more accurate and reliable weighting of criteria. There are also limitations to the method of pairwise comparison. It requires the user to rank each variable on its relative importance in comparison to each other variable, which leaves room for subjectivity as to which is more important, as well as the degree to which it is more important.

The other major limitation of this study is the linear standardisation of variables. As it uses the local minimum and maximum values of the raster, it accurately reflects suitability of a point in relation to other points in the raster, however this does not provide any insight on the overall suitability in the Yarra Ranges region compared to other regions. Further research should ideally be done to determine standardisation functions which truly represent a criterion's effect on overall suitability.

For example, there may be a certain threshold for solar radiation below which a PV panel cannot generate electricity. In this case, that value should be set as 0. Increases of solar radiation may also have a logarithmic relationship if increasing levels of solar radiation have diminishing returns on electricity output. While this is a hypothetical scenario, it highlights the need for further research, as it could significantly affect the results of the study.

Some slight inconsistencies in the resultant data were experienced. This was highlighted in Table 6, where the minimum value for Distance from Residential Areas was zero, when it was intended that there be a 500m buffer from any residential areas.

This is most likely a result of the process of extracting parcels using the Select by Location tool. It was intended that this step would simplify the binary dataset, however there were likely some instances where only a small portion of the parcel was suitable, and it was selected regardless. Some fine tuning of this part of the methodology is required.

6.3 Areas of further study

In addition to using research and more advanced techniques to improve the parameters, a significant area for further projects to explore is the inclusion of more variables. Possible criteria could include land cover, as land that has significant tree cover or is close to tall trees or structures would have a lower suitability. Humanitarian factors could also be considered, such as nearby populations that a given parcel of land could supply power to.

Similar studies should also be done on other forms of renewable energy, such as wind, or CSP instead of PV solar power. The results of these analyses could be compared, in order to make an informed decision about the best from of renewable energy to invest in.

7. Conclusion

This project has successfully developed a method to identify land parcels which may be candidates for a new PV solar power plant. However, improvements need to be made to refine the results, before this method can be implemented in Yarra Ranges Shire and the rest of Victoria.

Other factors must of course be considered when deciding on developing new infrastructure, such as ownership of land, and cultural value that may not be captured by the GIS. While this project cannot provide a definite answer, analysis such as this is an important part of the process to identify the most favourable locations to create renewable energy.

8. Appendices

When referring to the ArcMap Documents, SolarProject.mxd is the final combination of Binary and Index results.

Appended documents can be found in the project folder labelled Appendices:

Appendix 1. Spatial Data Sources: 1_DataSources.xlsx

Appendix 2. Pairwise Comparison: 2_PairwiseComp.xlsx

Appendix 3. Binary Model Workflow: 3_BinaryWorkflow.pdf

Appendix 4. Index Model Workflow: 4_IndexWorkflow.pdf

Appendix 5. Full Scale Binary Map: 5_BinaryMap.pdf

Appendix 6. Full Scale Index Map: 6_IndexMap.pdf

Appendix 7. Full Scale Final Map: 7_FinalMap.pdf

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