A GIS based site suitability assessment for solar and wind farms to facilitate green hydrogen production and export within Australia

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1. Abstract

Recently there has been significant interest and investment in developing a sustainable Australian hydrogen export industry. This is largely due to a global effort to enact environmentally sustainable practices and minimise carbon emissions. Australia's experience in exporting natural resources and unique geographical qualities result in Australia being well positioned to become a market leader in green hydrogen production and export.

This project was developed as a response to the national interest in green hydrogen with an overarching aim of finding efficiencies in the renewables site selection process required for green hydrogen production and export. This has been achieved by applying geospatial information systems (GIS) methods of analysis and mapping techniques to perform a regional scale suitability assessment of potential solar and windfarm sites within regions of Australia that have been identified for their high potential for green hydrogen production.

The GIS model has been constructed from public spatial datasets to refine pre-existing national scale analyses to a Regional scale. The suitability assessment considers solar power sites within the Gladstone Region of Queensland and wind power sites within mainland Tasmania. The results of the model are presented in suitability assessment maps weighted for the following scenarios: grid connected, dedicated renewables or ease of constructability. The site suitability assessment maps categorise areas as raster cells ranging from unsuitable to very high suitability based on various spatial parameters relevant to the development of a green hydrogen renewable energy site.

Generally, green hydrogen production sites should be located close to the coast for access to seawater for desalination and hydrogen production through electrolysis. For solar farm sites, proximity to the coast must be balanced with solar energy production that is maximised in large flat areas with high solar irradiance generally found inland. For wind farm site selection, proximity to the coast must be balanced with higher wind speeds as well as large areas of undeveloped land generally found inland. While the comparison of solar power sites within the Gladstone Region and wind power sites within Tasmania is limited based on the results of the assessment, it has been considered that of the search areas considered, solar power sites within the region bounded by Gladstone, Rockhampton, Duaringa and Biloela hold the greatest potential for development to facilitate green hydrogen production and export. In addition to providing a user-friendly map of the assessment results, this project provides a simple and reproduceable method for applying multicriteria decision making (MCDM) and analytical hierarchy process (AHP) to the site selection process, enabling industry to apply the method to other regions of interest.

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2. Introduction

2.1 Significance

Hydrogen, when produced from electrolysis of desalinated ocean water with electricity supplied from renewables, is classified as green hydrogen. Green hydrogen is particularly beneficial to industry and governments that are looking to decarbonise. Hydrogen when used as an alternative for diesel and petrol, can reduce a domestic and international reliance on non-renewable oil supplies. Hydrogen fuel is well suited to assist in a transition to renewables by filling the gaps in energy intermittency – a common detractor from renewable energy sources such as wind and solar.

Australia has a well-developed experience in exporting natural resources. This experience, combined with Australia's unique geographical context of large undeveloped areas with high solar irradiance and vast coastlines, means Australia is well positioned to become a market leader for green hydrogen production. Australia's experience in liquid natural gas (LNG) exportation could also assist in developing an exportation industry.

Optimising the site selection process is critical for minimising the cost of infrastructure as well as for maximising the ongoing efficiency of hydrogen production. *Prospective hydrogen production regions of Australia,* (Geoscience Australia, 2019) presents a national scale spatial analysis of potential sites for green hydrogen production. This analysis is one of five national scale hydrogen production scenarios including grey and blue hydrogen production. This project has been developed in response to the findings of the study conducted by Geoscience Australia (2019). While the study is important in highlighting regions of high potential for hydrogen production across Australia, it does not provide detailed, regional scale data that can be used by industry during for more advanced stage of site selection.

Based on the review of the Geoscience Australia (2019) the regions based around the port of Gladstone, Queensland and Hobart Tasmania and have been selected for spatial analysis. The regions have been considered to have a high potential for green hydrogen production, with access to an existing port infrastructure. As Gladstone lies within a region of high solar irradiance and Hobart within a region of high wind, each region will be comparatively assessed for their respectively suited renewables.

The focus of green hydrogen research is primarily centred on improving production, storage and export processes to improve efficiency and reduce associated costs. While this is critical to the development of a green hydrogen industry within Australia, there is a need to target the subsidiary components of green hydrogen production and export. Namely, the large quantity of renewable energy required for green hydrogen production. By considering the requirements for green hydrogen production, such as access to the ocean for seawater desalination and access to ports for efficient product exportation, a set of geographic constraints emerge for the issue of site selection. While these constraints reduce the total number of sites that would be appropriate for site selection it does provide an opportunity for the application of geospatial information systems (GIS) software to improve the site selection process. *The National Hydrogen Roadmap Report* published by Commonwealth Scientific and Industrial Research Organisation (CSIRO et al., 2018) describes the key barriers to the development of the hydrogen industry as a lack of infrastructure and cost of hydrogen supply. A site suitability model has been developed by applying GIS to efficiently process and visualise the spatial parameters and constraints for green hydrogen energy supply. The suitability assessment model can be used by industry improve the site selection process by ensuring the optimal sites are considered for development. This aims to reduce the cost of site selection and the risk of selecting a sub-optimal renewables site.

2.2 Problem Statement

Renewable energy site selection is a key step in the development of a green hydrogen production plant. Selecting an optimal renewable energy site requires consideration of multiple factors that effect the performance, constructability and economic viability of the site. To optimise site selection, multicriteria decision making analysis methods can be applied to quantify the most important considerations producing a weighted spatial overlay map. MCDM can only be applied to one area with one unique set of spatial parameters at a time. This provides an opportunity for GIS software to apply MCDM as an iterative process to multiple areas through efficient computational methods. While the application of GIS to MCDM suitability assessments is well established, the application of GIS to MCDM suitability assessments for renewables facilitating green hydrogen plants is a relatively novel area.

P*rospective hydrogen production regions of Australia* published by Geoscience Australia (2019) provides a national scale spatial analysis of Australia's hydrogen production potential. However, this analysis does not provide the level of detail to effectively optimise the site selection process on a regional scale. It is a regional scale suitability assessment that can bridge the gap between industry and truly optimised site selection.

2.3 Aim

- To conduct a regional scale assessment for the Gladstone region on the suitability of potential solar farm sites for supplying electricity for green hydrogen production and export through the existing port of Gladstone.
- To conduct a regional scale assessment for the mainland of Tasmania on the suitability of potential wind farm sites for supplying electricity for green hydrogen production and export through the existing ports of Tasmania.

2.4 Hypothesis

For both wind and solar farm suitability assessment models, there is a need for balance between energy production potential, constructability and constraints specific to green hydrogen production and export. For dedicated renewables models, the distribution of areas classified as highly suitable will be concentrated in areas close to the coast where hydrogen production sites are likely to be located. For grid connected models, the distribution of areas classified as highly suitable will be concentrated in areas between 50-100km of the coast within close proximity to existing power infrastructure. For constructability models, areas classified as highly suitable will be concentrated within close proximity to the coast within close proximity to main roads and existing power infrastructure.

As dedicated renewables models are not reliant on existing power infrastructure, it is expected that dedicated renewables models will hold a higher mean suitability score relative to grid connected and constructability models and will also have a higher proportion of area found to be highly suitable.

2.5 Objectives

- To address the primary barriers for hydrogen industry market activation in Australia established within the National Hydrogen Roadmap (CSIRO et al., 2018).
- To research and develop a set of baseline parameters such as energy and land area requirements
- To develop a suitability assessment model in GIS software that considers key spatial parameters relevant to green hydrogen production and export, improving the efficiency of renewable energy site selection.
- To refine the scale of pre-existing spatial models that have mapped hydrogen production potential from a national scale to a regional scale scale, looking specifically at the potential for solar energy and wind energy production.
- To establish a method for regional scale suitability assessment that can be further developed by industry to assess other regions of interest. To produce a series of suitability assessment maps for wind and solar models displaying categorised raster data representing suitability for development.

2.6 Scope

2.6.1 In Scope

The following elements formed the scope of works for the project.

- Set of spatial parameters relevant to green hydrogen renewable sites. The complete list of spatial parameters is shown in Section 4. The set of spatial parameters has been designed to consider the overall site performance, ease and cost of construction and ability to contribute to a larger hydrogen export business.
- Data collection of the spatial parameters considered relevant to green hydrogen renewable sites.
- Selection of suitability model weighting factors for spatial parameters.
- Verification of data accuracy and quality. All data has been verified to '*ISO9001 quality management system'* standards for data sources.
- Baseline energy requirements for green hydrogen production
- While land area requirements have not been incorporated in to the spatial model, estimates have been included to provide context to the results of the spatial model and assist in the discussion of the results.
- Application of multicriteria decision making (MCDM) to geospatial suitability assessment
- Application of analytical hierarchy process (AHP) to geospatial suitability assessment
- GIS processing and analysis methods. All methods of spatial processing analysis were carried out within ArcGIS.
- Application of GIS tools to provide further recommendations regarding renewable site development outside of the suitability model

2.6.2 Out of Scope

The following elements have been excluded from the scope of the project.

- The set of parameters considered for development is relatively limited and has been formed with a consideration for the capabilities of GIS methods of analysis. Parameters that were considered too difficult to obtain or manage within GIS software have been omitted from the suitability model. The most important omitted parameter was land value. This was difficult to determine for the scale of the model; however, it would likely hold significant influence over the results of the suitability assessment. This is discussed further in Section 7.2 Limitations.
- Elements such as site development and construction constraints, and export infrastructure have been described within the literature review of this report. This has been carried out to facilitate the results of the suitability assessment. Recommendations on the above issues are not stipulated within this report and would require consideration for the context of each unique site.
- While the model aims to perform a techno-economic assessment, the economic characteristics of an area are limited by proxy parameters accounting for land use and construction issues rather than true economic parameters such as land value.
- Offshore wind farms or floating solar farms
- PV and Wind turbine types and layouts. While PV types are examined in the literature review. This has been carried out for the estimation of baseline energy and land area requirements. PV and Wind turbine types and layouts should be considered within the context of the proposed site.

3. Literature Review

3.1 Previous Research

The research required for this project has been summarised in to the following categories:

- Green hydrogen production and exportation in Australia
- Criteria for renewable energy sites facilitating green hydrogen production and export
- Search area establishment
- Energy requirements
- Application of Multicriteria Decision Making (MCDM) and Analytical Hierarchy Process (AHP) to geospatial suitability assessments

3.1.1 Green Hydrogen Production and Exportation in Australia

3.1.1.1 Electrolysis

Green hydrogen can be produced through the electrolysis of water within an electrolyser unit or stack. Electrolysis causes the decomposition of water in to base elements hydrogen and oxygen. In the electrolyser unit positively charged hydrogen ions are attracted to the negatively charged cathode while negatively charged oxygen ions are attracted to the positively charged anode. Balance of plant (BOP) including compressors, heat exchangers, pumps, control systems and valves are required as subsidiary components of the hydrogen production system.

At current, the two primary electrolysers available are alkaline electrolysers (AE) and proton exchange membrane (PEM).

AE used a potassium hydroxide electrolyte to conduct traditional decomposition of water. AE have been more widely used in recent years and have a lower capital cost and LCOH compared to PEM electrolysers. PEM uses a catalyst to split water into protons that flow through a membrane from the anode to the cathode. Protons are bonded with neutral hydrogen atoms at the anode to produce hydrogen gas. The advantages of PEM is by and large a more efficiency process that produces higher purity hydrogen with a lower footprint.

Table 1 shows the comparative LCOH (2018 prices) of each AE and PEM

Table 1 Comparative LCOH for AE and PEM (CSIRO, 2019)

Electrolyser	AE	PEM
LCOH ($/kg)	4.78-5.84	6.08-7.43

Recommendations for electrolyser units and other elements of production are not included in the scope of this report. Due to the level of investment in hydrogen production research and development in recent years, it is expected that efficiencies will be found to reduce the LCOH of existing technologies whilst also developing new methods of production.

3.1.1.2 Energy Supply

Cost of electricity is the most important element in the levelized cost of hydrogen (LCOH) production. Another key element in reducing LCOH is maximising the capacity factor. The capacity factor refers to the degree utilisation of the electrolysers. Increased electrolyser utilisation results in a greater potential to produce revenue and cover capital investment. There are three different electricity supply options, each with a different LCOH (CSIRO, 2019).

Grid Dedicated Renewables

Off grid renewable energy sources are constructed for the sole purpose of supplying electricity to green hydrogen production plants. The dedicated renewables model is the primary method of energy generation for green hydrogen production and can be considered as the baseline model for the study. Dedicated renewables are constructed either on site with production plants or using dedicated transmission lines. Dedicated renewables have a higher capacity factor when constructed on site as there are no less energy losses due to transmission.

Grid Connected

Electricity to supply electrolysers is sourced directly from the power grid. Power purchase agreements (PPAs) can be established with utilities companies to ensure low emission electricity is used however unless the source for grid power can be guaranteed as emissions free, the hydrogen produced by grid connected energy cannot be considered green hydrogen. As summarised in Table X, grid connected scenarios offer the lowest average electricity cost and LCOH.

Curtailed Renewable Energy

Electricity is to supply electrolysers is sourced directly from the power grid when there is a surplus of renewable energy available from the grid. Curtailed renewable energy can also be sourced directly from renewable energy sites that have normally feed electricity to the grid when conditions are more favourable. Table 2 compares the above electricity supply options for PEM in 2018

Table 2 Electricity Input Scenario Comparison PEM (2018 Costs) (CSIRO, 2018)

Input Scenario	Grid Connected	Dedicated Renewables	Curtailed Renewable Energy
Average Electricity Cost (c/kWh)	6	6	2
Average Capacity Factor (%)	85	35 (Co-located PV and wind)	10
LCOH ($/kg)	~6.60	~11	~26

Curtailed renewable energy carries a significantly lower cost when compared to grid connected and dedicated renewables at a third of the cost. However, curtailed renewable energy supplies are inconsistent and result in a lower degree of plant utilisation and average capacity factor. This in turn results in a higher LCOH compared to grid connected and dedicated renewables. Opportunities may exist for curtailed renewables with above average supply rates for hydrogen production. In these instances, electrolysers could be utilised more improving reducing the LCOH.

The cost of electricity and dedicated renewables is comparable however the average capacity factor of dedicated renewables is significantly lower due to issues of energy intermittency from periods of low sunlight for PV and low wind speeds for WTs. In order to increase the capacity factor of dedicated renewables, the renewable energy supply needs to include energy storage in the form or batteries or alternative methods such as pump hydro. While this will increase the start-up capital required, the improved capacity factor will allow for start-up capital to be regained quicker.

3.1.1.3 Storage

The considerations for hydrogen storage and export are centred around maximising the volumetric density. In its natural gaseous state (30-35 bar and 25C˚), hydrogen has a volumetric density of 2.77kg/m^3. High pressure gaseous hydrogen stored at 350 bar and 25C˚ has a volumetric density of 23kg/m^3. While there are costs associated with increasing the storage pressures of hydrogen, it enables more efficient storage and transport. Liquefaction can be carried out to produce liquid hydrogen capable of being stored at 1 bar and -253C˚ with a volumetric density of 121kg/m^3. While liquefaction offers the best volumetric density for hydrogen storage, the energy required is significantly greater. Alternative methods such as storing hydrogen as liquid ammonia and underground storage also hold potential.

Table 3 produced by CSIRO (2019) presents a comparison of hydrogen volumetric densities and energy usage of different storage methods.

Table 3 Comparison of Hydrogen Density and Energy Usage of Available Storage Methods (CSIRO, 2019)

Storage Method	Hydrogen Density (kg/m^3)	Energy Required (kWh/kgH_2)
No pressure (30-35 bar and 25C˚)	2.77	Standard output pressure for hydrogen produce. No extra energy required.
Low Pressure (50-150 bar and 25C˚)	3.95 – 10.9	0.2-0.8
High Pressure (350 bar and 25C˚)	23	4.4
Liquid Hydrogen (liquefaction) (1 bar and -253C˚)	70.8	10-13
Stored as liquid ammonia (1 bar and -33C˚)	121	10-13
Stored as liquid ammonia (10 bar and 25C˚)	107	10-13

Recommendations for storage and export procedure have not been included in the scope of this report. The balance between storage costs and volumetric density should be considered on a case by case basis. By reducing the cost of electricity supply, more energy intensive storage methods such as liquefaction can be seen as more preferable.

3.1.1.4 Transport and Export

Hydrogen can be transported by truck, rail, pipeline and ship. The storage method, and preferred method of transport is largely dependent on the distance that must be covered by transport. For shorter distances, less than 1000km, truck and rail are economical options and can transport hydrogen that us undergone compression, liquefaction or conversion to ammonia. Pipelines are more economical at distances between 1000-4000km but are limited to the transport of compressed hydrogen.

For international export or distances greater than 4000km, shipping will be required. Compression storage is uneconomical at this distance due to the limited volumetric density of storage. Table 4 produced by CSIRO (2019) summarises the costs of hydrogen transport.

Table 4 Hydrogen Transport Costs

Method	Compression ($/Tkm H_2) 430 bar	Liquefaction ($/Tkm H_2)	Ammonia ($/Tkm H_2)
Truck	2.33	0.92	0.33
Rail	0.55	0.28	0.04
Shipping	0.52	0.09	0.03

For the context of this study, it has been assumed that export will be carried out by shipping. The transport method from production site to export port has not been considered within the scope of this study.

3.1.2 Criteria for renewable energy sites facilitating green hydrogen production and export

3.1.2.1 Performance Criteria

3.1.2.1.1 Solar Irradiance

An assessment of PV systems and performance conducted by (Usman, Tah, Abanda & Nche, 2020), outlines the critical parameters to consider as solar irradiance and temperature.

Solar irradiance refers to the quantity of power per unit area obtained from electromagnetic radiation omitted from the Sun. This is the primary determinant for solar energy production and heavily influences the suitability assessment for the Gladstone solar model.

Solar irradiance is primarily measured as a global horizontal irradiance (GHI). GHI is the total solar irradiance on a horizontal surface of the Earth. It is the sum of direct normal irradiance and diffuse horizontal irradiance. Where direct normal irradiance is the direct radiation measured at a surface of the earth perpendicular to the sun, minus the losses due to radiation scattered or reflected by the atmosphere. Diffuse horizontal irradiance is the radiation that is captured on the Earth's surface after the effects of scattering.

$$GHI = DHI + DNI \times \cos(z) \tag{1}$$

Where z is the solar zenith angle of the sun

3.1.2.1.2 Wind Speed

Where winds are not consistent throughout the day, wind farms can still be effective if the windy periods of the day coincide times of high energy demand in the local power grid. A similar MCDM GIS suitability assessment for wind farms conducted by Noorooahi et al., (2016) requires a minimum useable wind speed of 5m/s.

To capture wind energy as a renewable energy source, wind energy is produced through the conversion of kinetic energy in the form of moving air in to a rotational force via the rotor. The rotor then turns a generator to produce electrical energy.

The total energy flowing through a turbine blade with area A is determined by equation 2.

$$E = \frac{1}{2}mv^2 = \frac{1}{2}(Avt\rho)v^2 = \frac{1}{2}At\rho v^3 \tag{2}$$

$$where\ \rho\ is\ the\ density\ of\ air$$

$$v\ is\ \ wind\ speed$$

$$t\ is\ time$$

$$Avt\ is\ volume\ of\ air\ passing\ through\ area\ A$$

The power imposed on the turbine of blade is then determined by equation 3.

$$P = \frac{E}{t} = \frac{1}{2}A\rho v^3 \tag{3}$$

Wind speeds and thereby the power derived from wind flow is inherently variable. While wind speeds are generally consistent from year to year, there is significant variability over short term periods. This is due to the complex and varied mechanisms that cause wind. While there is no single indicator for an area that produces consistent and ideal winds for wind energy capture, Geosciences Australia (2019) suggests the following features are typical of such areas.

- Typically, coastal regions with mid to high latitudes in either the northern or southern hemisphere, or mountainous areas
- Smooth landscapes. Smooth landscapes result in higher speeds but also less turbulent winds that have the potential to cause damage to infrastructure.

3.1.2.2 Economic Criteria

3.1.2.2.1 Slope

Flat sites were found to be preferable within a most reference suitability assessment studies by Uyan (2013), Watson and Hudson (2015), Baseer (2017), Jensen and Pedersen (2017), Ali et al., (2018) Anwarzai and Nagasaka (2017). Sites with slopes of greater than 15% for wind farms and 5% for solar farms were considered unsuitable for development by studies from Baseer (2017) and Anwarzai and Nagasaka (2017). Sloping sites are more difficult and expensive to develop as they require extra earthworks and may cause access issues for plant. Mountainous terrain can disrupt wind flow resulting in reduced wind speeds or turbulent winds that have the potential to damage WTs. Heaving sloped terrain also causes issues for PV due to the restricted aspect of the land and shadowing effects of hills and mountains.

3.1.2.2.2 Land Use

Land use is a primary concern for any site any development. Studies by Ali et al., (2018), Bera et al., (2016) and Uyan (2013) recommend sites considered to be barren land or similar. Land use is primarily indicator of land use and cost of redevelopment. Sites that have been undergone previous development require additional works in deconstruction and preparation. From an environmental perspective, existing land use should not be of considerable environmental value such as wetlands, rainforests and native vegetation. For land that has been previously developed a preference was established for grazing pastures and light cropping areas. Generally, these areas are cheaper per unit area and due to their flatness and minimal tree cover will offer better performance for PV arrays and WTs.

3.1.2.2.3 Proximity to Roads

To develop the site, plant and equipment must be delivered to site. By positioning the site as close as possible to existing roads, this reduces the level of investment required to construct new roads for site access. This criteria is included in similar studies by Uyan (2013), Watson and Hudson (2015), Baseer (2017), Jensen and Pedersen (2017), Ali et al., (2018) Anwarzai and Nagasaka (2017).

3.1.2.2.4 Proximity to Existing Power Grid

To transport electricity from solar and wind farms to production plants requires the construction of transmission lines. Long transmission distances result in an increase to cost of the overall development as well as electricity losses. For this reason, solar and wind farms should be positioned as close as possible to existing power grid infrastructure. When solar and wind farms are positioned on site with hydrogen production plants and the system operates outside of the power grid, the power grid is of little importance.

3.1.2.2.5 Proximity to Coast

When produced via electrolysis, the principal raw material for hydrogen production is water. To produce hydrogen on a large enough scale to support an export business, it is recommended that water sourced for electrolysis is obtained from desalinated ocean water which can be considered as an unlimited resource as opposed to constrained inland water sources. While inland waters are often fresh water sources that require less treatment, the total cost of water including desalination in hydrogen production is less than 2%. The relatively low cost for desalination is considered more important using a restricted water source. Production plants should be located as close as possible to the coast to minimise the cost of pipeline infrastructure required to extract the water.

3.1.2.2.6 Proximity to Ports

This study has been developed to support an Australian hydrogen export industry. Shipping hydrogen is the only feasible transport method for international transport and will thus require the use of ports. Using existing ports is preferable to the construction of a new dedicated port and has this has been incorporated in to the suitability assessment through the proximity to port criteria.

3.1.3 Search Area Establishment

3.1.3.1 Gladstone Region

Queensland was recognised by CSIRO (2018) studies for its high solar potential and available land. The topography of the area is generally flat and land is primarily used for grazing, cropping and heavy industry – land uses that are well suited to redevelopment for solar farm sites. Gladstone is characterised by long dry seasons with a short wet season. The tropical savanna climate contributes to the high annual solar irradiance within the region where global horizontal irradiance (GHI) ranges from 4.4-5.5kWh/m^2. While the GHI for the Gladstone region is slightly below the mean GHI across Australia, as shown in Figure 3.1, the GHI is above average for a coastal area close to a large export port.

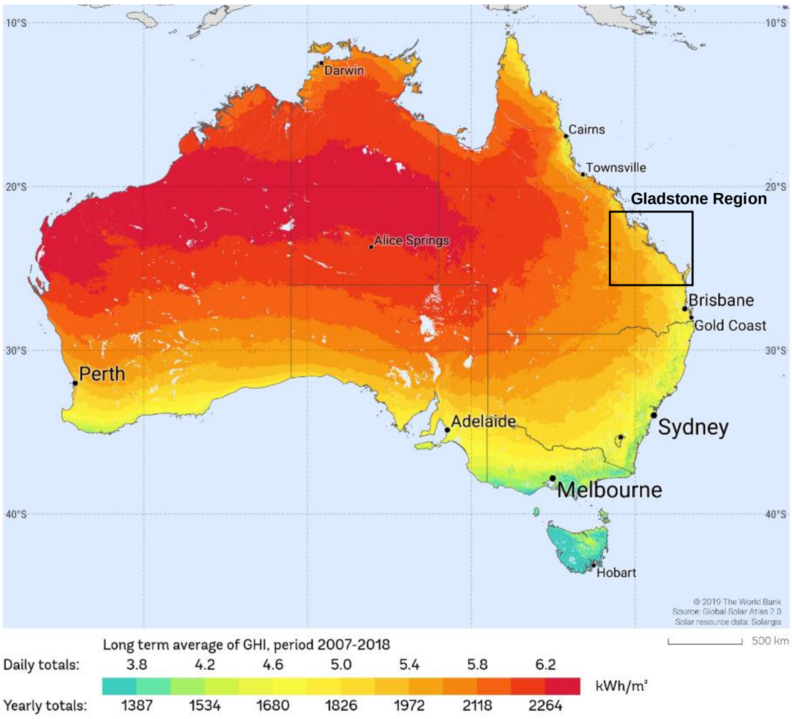


Figure 3.1 Average Annual Solar GHI (kWh/m^2) for Australia 2008-2018 (SolarGIS, 2019)

There is only one port located within the Gladstone region, in the town of Gladstone itself. Gladstone Port is Queensland's largest multicommodity shipping port. The region has a well-developed history in the resources industry which provides an opportunity to transition workers from existing resources-based jobs to hydrogen production.

Recently, Fortescue Future Industries announced a planned billion-dollar hydrogen equipment manufacturing plant which would be the largest of its kind in the world. The plant will be located approximately 20 kilometres west of Gladstone is expected to start producing 2GW worth of electrolyser per annum from 2023 (Australia New Zealand Pipeline Infrastructure, 2021). This development reinforces Gladstone as a hub for hydrogen production and the renewable energies required to support it. Currently Queensland produces only 27.7% of its energy from renewable sources (Clean Energy Council, 2021). To facilitate a green hydrogen industry within the state there will need to be significant investment in the development of renewables.

3.1.3.2 Tasmania

Studies by CSIRO (2018) and Geoscience Australia (2019) recognise Tasmania as region of Australia with a unique set of characteristics suited to green hydrogen production. Tasmania offers high wind speeds with consistent grades and directions making it well suited for wind farms. 100m wind speeds for Tasmania range from 3.2 – 17.2m/s while values for mainland Australia ranged from 1.8 – 15m/s, shown in Figure 3.2 and 3.3.

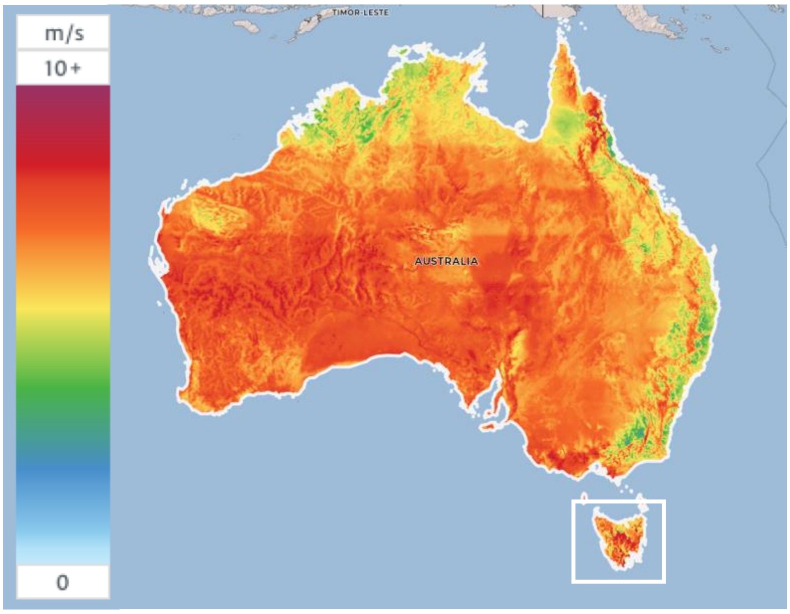


Figure 3.2 Australia mean wind speed at 100m elevation above ground level (Global Wind Atlas, 2019)

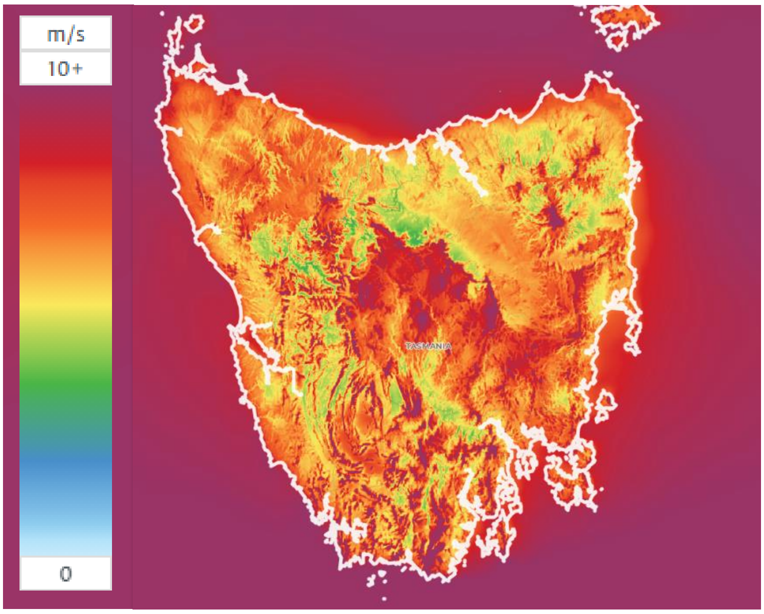


Figure 3.3 Tasmania mean wind speed at 100m elevation above ground level (Global Wind Atlas, 2019)

Additionally, Tasmania has several water resources suited for hydroelectric power generation that can assist in meeting power demands during periods of low wind speeds, increasing the total energy capacity of the system.

Tasmania has consistently lead Australia in renewable energies over the past ten years. As of 2014, Tasmania generated 93% electricity from renewables. This was significantly higher than any other state or territory of Australia with South Australia generating 36% (Clean Energy Council, 2014). Since 2014, renewable energy generation has risen in Tasmania from 10420GWh to 10866GWh in 2021. This rise has resulted in Tasmania producing for renewable energy than what is consumed by the state. This means there are opportunities for hydrogen production plants to utilise the existing power grid without sacrificing the capacity factor of production.

A report published by Australia New Zealand Pipeline Infrastructure (2021), details a proposed 250MW green hydrogen plant at Bell Bay, Tasmania. The proposed plant will use existing port infrastructure at Bell Bay to transport 250 000 tonnes of green ammonia per year for domestic use and international export.

This industry interest combined with Tasmania's multiple export ports and ideal conditions for wind farm development lead to the decision to include Tasmania as a study search area for wind farms sites. The search area has been restricted to the mainland Tasmania with an area of approximately 64 000km^2 prior to reduction for heavily developed land and conservation areas.

3.1.3.3 Restricted Land

Land areas classified as highly developed urban and commercial areas were removed from the search area due to the difficulty and cost required to redevelop. Land areas classified as conservation areas were considered unsuitable for development. For this classification, reference was made to the Collaborative Australian Protective Area Database (CAPAD). CAPAD is a national scale database updated every two years to conserve biodiversity of environmentally valuable areas.

Table 5 shows the area of CAPAD protect areas within the search areas of the Gladstone region and Tasmania

Table 5 CAPAD Areas for Gladstone Region and Tasmania (Geological Society of Australia, 2021)

Search Area	Gladstone Region	Tasmania
CAPAD Area (km^2)	1,410	15,212

3.1.4 Energy Requirements

This model has not been carried out with respect to the energy requirements of a specific hydrogen production plants. Baseline energy and area estimates have been determined to provide context to the results of the model and to assist in the interrogation of data.

To support a small-scale hydrogen plant with a production rate of 100,00kgH_2/day. Based on the findings of (Dincer, 2012) and (Sigal et al. 2014), the following

approximate assumptions have been used:

Hydrogen output = 100 000kg/day

Energy required = 50 kWh/kg/day

Power required = 208MW

3.1.4.1 PV Efficiency and Land Area Estimates

Table 6 summarises the Photovoltaic (PV) efficiency estimates from the review conducted by (Usman, Tah, Abanda & Nche, 2020).

Table 6 Types of PV Systems

PV Module	Efficiency Estimate	Advantages	Disadvantages
Monocrystalline	20-25%	Efficiency, power output,	Expensive

PV Module	Efficiency Estimate	Advantages	Disadvantages
		less affected by high temperatures	
Polycrystalline	15-20%	Low cost	Inefficiency under high temperatures, shorter lifespan
Thin Film	7-10%	Significantly lower cost, less affected by high temperatures	Inefficient, shorter lifespan
Concentrated PV cells	15-40%	High efficiency under DNI, require is less space, less affected by high temperatures	Less common, power output effected by variance in DNI

A 2018 Queensland Government report on Solar Farm Guidelines (Queensland Government, 2018) estimates that approximately two to three hectares of land is required per one megawatt of power generation within typical Queensland conditions. Using this estimate, an approximate solar farm land area would require between $4km^2$ and $6km^2$ to supply the 208MW required for a small production plant with an output of 100,000kgH_2/day.

3.1.4.2 Wind Turbine Efficiency and Land Area Estimates

Wind turbine (WT) efficiency is dependent on WT classes and selecting the correct WT class to match the wind conditions for a given site. Turbines designed for higher wind classes are constructed with larger blades are unable to operate at higher winds without risking damage but are able to operate at a higher efficiency in low and medium winds. (Katsigiannis and Stavrakakis, 2014).

In order for an estimate of WT efficiency to be determined, the average annual and extreme 50-year gust speed must be used to select the optimal WT blade size. Table 7 shows the wind class specifications published from ‘Estimation of wind energy production in various sites in Australia for different wind turbine classes: A comparative technical and economic assessment.’ (Katsigiannis and Stavrakakis, 2014).

Table 7 Wind Class Speeds

Wind Class	Annual Average Wind Speed	50-year Extreme Gust (0.02 AEP) (m/s)
IEC high wind	10	70
IEC II medium wind	8.5	59.5
IEC III low wind	7.5	52.5

Notes:

AEP: Annual Exceedance Probability

In the assessment conducted by (Katsigiannis and Stavrakakis, 2014), annual produced energy was tabulated across three sites categorised as low wind potential, low/medium wind potential and medium/high wind potential over 33 different models of wind turbine. These results have been tabulated to determine the average power production (MW) within Table 8.

Table 8 Wind Turbine Efficiency

Wind Potential	Annual Average Wind Speed (m/s) at Anemometer	Annual Average Wind Speed at Typical Hub Height (90m)	Average Annual Produced Energy (MWh)	Average Power Production (MW)
Low	4.21	5.76	6100	0.696
Low to Medium	4.77	6.52	7042	0.804
Medium to High	5.45	7.46	7566	0.864

For WTs to operate efficiently, smooth flowing, turbulent free wind is required. Subsequently, turbines require an approximate distance of 550m between rotors to operate efficiently. For a hydrogen production plant producing 100,000kgH_2/day, requiring 200MW of energy, the approximate wind farm land area requirements have been provided in Table 9.

Table 9 Wind Farm Specifications

Wind Potential	Average Power Production	Number of Wind Turbines Required to Supply 208MW	Approximate Area Required (km^2)
Low	0.696	299	73
Low to medium	0.804	259	63
Medium to High	0.864	241	59

3.1.5 Application of Multicriteria Decision Making and Analytical Hierarchy Process to geospatial suitability assessments

Multicriteria Decision Making (MCDM) or Multicriteria Decision Analysis (MCDA) is a systematic approach to solving complex multicriteria problem. It is uses a method of weighted summation (Choi et al,, 2019) to quantify the suitability of an outcome according to a varied set of criteria. A review of MCDM methods by Mardani et al., 2017, p. 285), suggests that multicriteria analysis has become increasingly common due to the added complexity of problems faced by industry and the ability to cross analyse multiple datasets.

In order to locate potential green hydrogen renewable energy sites, weighting factors can be distributed to spatial parameters or selection criteria by the degree of importance that criteria carries to problem of green hydrogen solar and wind farm site selection. This reduces the reduces risk of oversights in site selection whilst streamlining the overall process.

The challenge in MCDA is in determining the distribution of weights that are applied to these parameters. According to a review of GIS based MCDM/MCDA by Choi et al., (2019), Analytical Hierarchy Process (AHP) is the most common method of determining criteria weights. The AHP method developed by Saaty (1990) requires pairs of decision criterion to be compared without consideration for the remaining criteria.

To complete the pair-wise matrix comparison, Saaty (1990) developed the fundamental scale that quantifies the "intensity of importance on an absolute scale." The scale is included as Table 10 below and has been referred to in the methodology of this report.

Table 10 *The fundamental scale for AHP criteria weighting as defined by Saaty (1990) adapted to site suitability assessment*

Intensity of Importance	Definition	Explanation
1	Equal importance	Two criteria contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favour one criterion over another
5	Essential or strong importance	Experience and judgement strong favour one criterion over another
7	Very strong importance	A criterion is strongly favoured and its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one criterion over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	Applicable when compromise is need
Reciprocals	If criterion *a* has one of the above numbers assigned to it when compared with criterion *j*, then *j* has the reciprocal value when compared with *b*	

AHP requires the following pair-wise matrix to be completed using the above scale to compare pairs of criteria (Saaty, 1990). For a matrix element $C_{ab,}$ it can be said that the criterion C_a is being compared to criterion C_b to determine its relative intensity of importance. From this, a set of matrices $M_{x,}$ (size *n* x *n)* can be formed as shown in equation 4.

$$M_x = \begin{bmatrix} C_{11} & C_{12} & \dots & C_{1n} \\ C_{21} & C_{22} & \dots & C_{2n} \\ \dots & \dots & \dots & \dots \\ C_{n1} & C_{n2} & \dots & C_{nn} \end{bmatrix} \qquad (4)$$

The relative weights for each criterion are then determined by normalising each criterion eigenvector by the eigenvector of the reciprocal ratio matrix.

This can be done by computing the sum of each column, dividing each matrix element by its column sum and finding the mean across each matrix row to calculate relative weights.

A weight or priority vector is determined for each individual matrix by normalising each criterion eigenvector

While this is the most widely used method, it is not entirely objective as it still requires the opinion of individuals. To manage the influence of potentially mislead opinions, Saaty (1990) developed the consistency ratio (CR) to measure the deviation of consistency of the pair-wise comparison matrix. Generally, the pair-wise comparison matrix is completed by multiple subject matte experts before being scrutinised by the consistency ratio method.

The consistency ratio method has been used in in similar studies carrying out GIS based site suitability assessments by Uyan (2013), Watson and Hudson (2015), Baseer (2017), Jensen and Pedersen (2017) and Ali et al., (2018). Saaty (2019) requires the CR values below 0.1 for an acceptable level of inconsistency. A CR greater than 0.1 suggests there is a significant inconsistency between the pair-wise hierarchy of the individuals surveyed.

The formula for CR is shown in equation 5.

$$CR = \frac{CI}{RI} \qquad (5)$$

$$Where\ CR = Consistency\ Ratio$$

$$CI = Consistency\ Index$$

$$RI = Random\ Consistency\ Index$$

The formula for CI is shown as equation 6.

$$CI = \frac{(\lambda \max - n)}{(n-1)} \qquad (6)$$

$$Where\ \lambda max = is\ the\ maximum\ eigenvalue\ of\ the\ pair - wise\ comparison\ matrix$$
$$n\ = matrix\ size\ (n \times n)$$
$$RI = Random\ Consistency\ Index$$

RI values are dependent on the size of the pair-wise comparison matrix and have been included below in Table 11.

Table 11 Random index values for pair-wise comparison matrix size (n x *n)* (Saaty, 1990)

n	*1*	*2*	*3*	*4*	*5*	6	7	8	9	10
RI	0.00	0.00	0.58	0.09	1.12	1.12	1.32	1.41	1.45	1.49

Provided each individual matrix satisfies the consistency requirements developed by Saaty (1990), an average of the weight or priority vector can be taken to calculate the final suitability criteria. Once the suitability criteria are developed, each raster cell of the search area can be assessed against the suitability criteria. The total suitability score for each raster cell is determined by the weighted sum of the cell's properties.

The above computation is carried out for every unique raster cell of the geospatial suitability assessment model. Given there are over 10,000 raster cells for both the Gladstone and Tasmania search areas, an appreciation can be developed for the level of computation required, and furthermore the efficiencies that can be found through the application of MCDM, AHP and GIS to a spatial suitability assessment.

3.1.6 Review of Criteria Weights from previous Multicriteria Decision Making and Analytical Hierarchy Process Studies

The application of MCDM and AHP is a relatively novel method for assessing renewable sites to facilitate green hydrogen production and export. The context of green hydrogen production and export brings unique criteria and constraints that have not been considered in the literature available for the application AHP to renewable site selection. To reduce the risk of assigning arbitrary weights for criteria under false assumptions, an AHP pair-wise comparison matrix has been formed with reference to similar studies that have applied MCDM and AHP to geospatial suitability assessments for solar and wind farm sites such as Uyan (2013), Watson and Hudson (2015), Baseer (2017), Jensen and Pedersen (2017) and Ali et al., (2018).

The primary disadvantage of this method is that each scenario's AHP pair-wise comparison matrix is singular, and therefore a consistency ratio cannot be developed to check the reliability of the criteria weights. All studies used as a reference during AHP have been found to hold a consistency ratio of less than 0.1. The results of the similar studies' AHP criteria have been as Table 12. Raw weights assigned in previous studies were normalised for referral during AHP pair-wise comparison.

Table 12 Review of Similar AHP MCDM Suitability Assessments for Renewables

Criteria	Study A		Study B - Solar Model		Study B - Wind Model		Study C	
	Raw Weight	RN Weight	Raw Weight	RN Weight	Raw Weight	RN Weight	Raw Weight	RN Weight
Wind Speed	0.60	0.74	-	-	0.39	0.69	NA	NA
Solar Irradiance	NA	NA	0.36	0.56	-	-	NA	NA
Slope	NA	NA	0.05	0.08	0.03	0.05	0.08	0.14
Land Use	NA	NA	0.12	0.18	0.05	0.08	0.14	0.23
Proximity to Power Infrastructure	0.14	0.17	0.09	0.13	0.08	0.13	0.34	0.57
Proximity to Main Roads	0.08	0.09	0.03	0.04	0.03	0.05	0.03	0.05

Notes:

Raw Weight: The weight assigned within the original study

RN Weight: Relative normalised weight where the criteria weight has been normalised to account for criteria that are not required for this study

Study A: 'GIS-based site suitability analysis for wind farm development in Saudi Arabia' (Baseer et al., 2017)

Study B: 'GIS based site suitbaility assessment for wind and solar farms in Songhlka, Thailand (Ali et al., 2018)

Study C: 'GIS-based solar farms site selection using analytic heriarchy process (AHP) in Karapinar region, Konya/Turkey (Uyan, 2013)

For criteria uniquely related to green hydrogen production such as proximity to coasts and port infrastructure, AHP has been applied based on the findings Geoscience Australia in *Prospective Hydrogen Regions of Australia, 2019.*

3.2 Research Gaps

3.2.1 Application of Multicriteria Decision Making (MCDM) and Analytical Hierarchy Process (AHP) to Green Hydrogen Energy Sites

Several GIS based renewable energy site suitability assessments have been referred to within this study. It is a well-developed application of GIS software due to the level of investment in renewables internationally and maturing of GIS. The application of GIS based site suitability assessments within the context of green hydrogen production is a however, a novel field. Furthermore, the merging of GIS, MCDM, AHP for green hydrogen renewables on a regional scale in Queensland and Tasmania is a novel area of study within Academia. It is expected that research has been conducted within this space by Industry due to the recent announcement of the proposed Hydrogen production plant at Bell Bay and electrolyser manufacturing plant at Gladstone.

The context of green hydrogen production and export brings unique criteria and constraints that have not been considered in the aforementioned studies. This means there is limited resources for determining criteria weights. To minimise the potential of assigning arbitrary and potentially misleading criteria weights, three different models have been generated. Each can be analysed to suit the specific needs of industry. The three models have been categorised as follows.

- Dedicated Renewables
- Grid Connected Model
- Constructability Model

3.2.2 Regional Scale Site Suitability Assessment in Australia

P*rospective hydrogen production regions of Australia* published by Geoscience Australia (2019) provides a national scale spatial analysis of Australia's hydrogen production potential through the compilation of geospatial datasets in GIS software. This analysis, while critical to the process of green hydrogen solar farm site selection has been carried out on a scale that does not provide a sufficient level of detail to enable industry to effectively select potential solar farm sites for development.

This project was designed to provide a reduction in scale, from a national scale analysis to a regional scale analysis that will allow industry to be better informed during the implementation of site selection. A reduction in scale results in higher resolution data being used in the data processing stage of the model as well as in the presentation of the results. Through the comparison of Figures 3.1 and 3.2, an appreciation can be gained for the difference in data resolution. Higher resolution spatial data allows classification of land area suitability to be carried out on the scale of solar and wind farms rather than entire regions Figure .

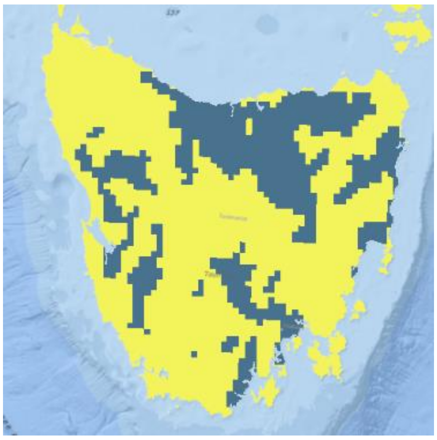


Figure 3.1 Wind speed data used within the national scale study published by Geoscience Australia

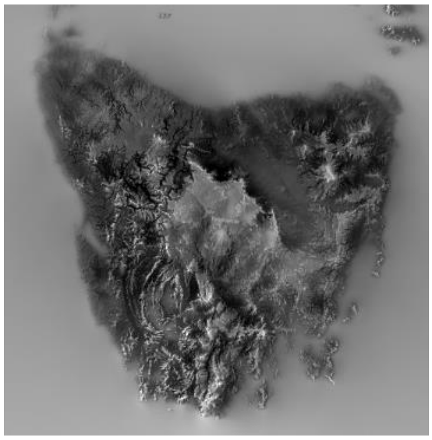


Figure 3.2 High resolution wind speed data obtained from Global Wind Atlas used within the Tasmania Suitability Assessment

4. Methodology

4.1 Outline

Figure 4.1 shows an outline of the methodology required for the data collection and analysis.

Figure 4.1 Methodology Outline

Data Collection

- Download datasets for spatial criteria
- Process datasets to construct geodatabase

Search Area Establishment

- Draw Extent of Search
- Determine areas considered to be unsuitable for development and merge areas to form single 'restricted land' layer

Geoprocessing

- Determination of criteria weights based on literature review and analytical hierarchy process (AHP)
- Geoprocessing of spatial parameters to form raster layers to store suitability weighting data
- Application of suitability weightings

MCDM Suitabiltiy Assessment

- Categorise normally distributed data in to suitability bands
- Calculate proportion of very high suitable land areas
- Output results of the assessment

4.2 Data Collection

To construct the geodatabase, spatial datasets were downloaded from public sources, typically government spatial data catalogues. Spatial data was downloaded in raw formats that included all metadata required for analysis and quality assurance. The spatial model is highly dependent on the quality and reliability of data. To control the risk of using unreliable data, all sources were checked for certification under '*ISO9001 quality management system'* standards for data sources.

A set of spatial parameters considered relevant to the development of the suitability assessment model was established. Individual datasets were downloaded for each spatial parameter in native file formats. While other parameters could be included in the list to add further detail to the assessment, it was decided to maintain a basic list of parameters so that data quality could be controlled and all data could be sourced in a reasonable timeframe. This model has been prepared as an example of how GIS tools can be applied to an MCDA framework in the context of renewables site selection. Should industry professionals follow this approach the spatial parameter list can be easily expanded to include additional spatial parameters following the methods of data analysis in Section 4.3 – 4.5.

Separate geodatabases and suitability assessment models were constructed for the Gladstone region and Tasmania region as data available on a regional scale was generally of a higher quality than data available on a national scale. By constructing separate geodatabases, processing times for data analysis is also reduced. Processing times can be significant depending on the capabilities of the computer running the GIS software and should be minimised where possible.

Table 13 summarises the datatypes and sources of the spatial datasets required for the geodatabase.

Maps for each dataset have been included in the Appendices of the Report.

Table 13 Spatial Datasets

Dataset	Data Type	Source	
		Gladstone	Tasmania
Solar Global Horizontal Irradiance	Raster	SolarGIS, BOM	-
Wind Speed at 100m	Raster	-	Global Wind Atlas
Land Use	Vector (polygon)	QSC	DPI - Tas
Conservation Areas	Vector (polygon)	GSA	GSA
Urbanised Areas	Vector (polygon)	QSC	ABARES
Surface Water	Vector (polygon)	QSC	GSA
Contour Lines	Vector (line)	QSC	TGLD
Roads	Vector (line)	QSC	TGLD
Existing power infrastructure	Gladstone Region: Vector (point) Tasmania: Vector (line)	QSC	TGLD
Coastline	Vector (line)	GSA, Esri	GSA, Esri
Existing Ports	Vector (point)	Drawn by author	Drawn by author

Notes:

BOM: Bureau of Meteorology

QSC: Queensland Spatial Catalogue

DPI: Department of Primary Industries

TGLD: Tasmania Government List Data

GSA: Geological Society of Australia

4.3 Search Area Establishment

4.3.1 Extent of Search Area

Prior to the processing any dataset, a search area polygon was formed such that all spatial datasets could trimmed for the area of interest only. By doing this, outputs could neatly present and file sizes could be reduced whilst maintaining data resolution and minimising processing times.

For the Gladstone Model, the search area extent was created by drawing a 400km x 400km square grid around the Port of Gladstone. A vector line file was downloaded for the Queensland coastline. The section of the coastline bounded by the square grid was selected and merged to the square grid file. These points of intersection were selected such that the square grid overlaying the ocean was then able to be removed from the layer, providing a search extent centred around the Port of Gladstone and bound by the coast. The total unrestricted search area was found to be 159,234 km2. Within the unrestricted search area there are 25,477 2.5 x 2.5km raster cells, each one representing 6.25km2.

The search area for the Tasmania Model was formed by downloading a Tasmania coastline vector file and trimming all islands from the layer such that only the mainland remained. The area of the search area was found to be 64,103km^2. In total there are 11,052 2.4 x 2.4km raster cells of, each one representing 5.8km^2.

4.3.2 Restricted Land Mask

Land areas considered restricted consisted of land classified as conservation areas by the Collaborative Australian Protected Area Database (CAPAD), heavily developed areas and areas of surface water. Other land uses that hold significant value or may be costly to redevelop for renewable energy production were not removed from the analysis but were assigned a low suitability weighting in the Suitability Assessment Model.

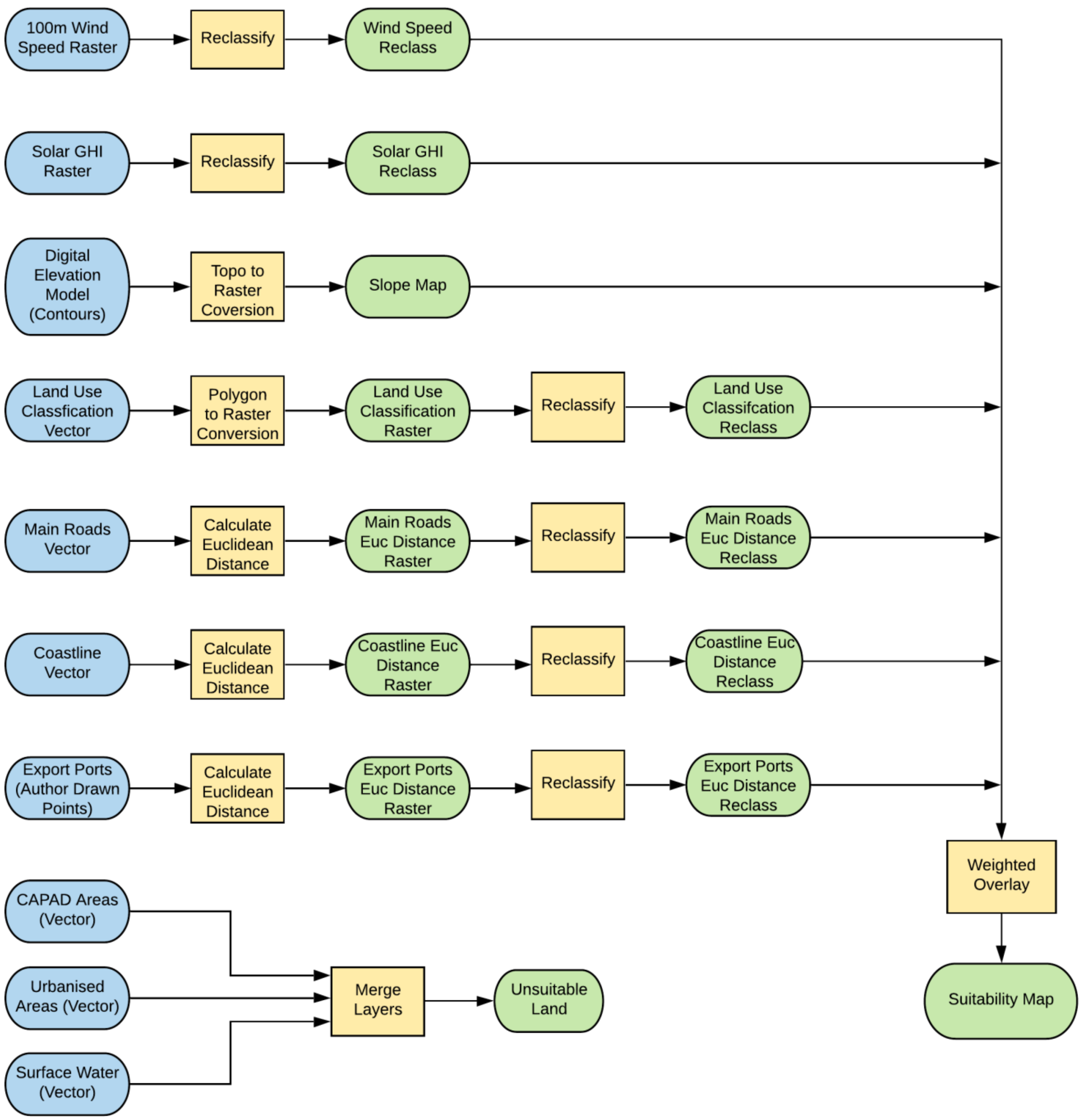
Unsuitable land layers were downloaded as vector shape files and did not require conversion to raster format for the suitability assessment model as the layers were not directly included in the suitability assessment model but rather included in the map outputs as an overlay.

Once merged to form a singled restricted land layer, the ArcGIS mask function was used when performing the suitability assessment to conduct only analyse areas 4considered as unrestricted.

4.4 Geoprocessing

For inclusion in the suitability assessment model, all data was required in raster format. The processing required to prepare data for inclusion in the suitability assessment model was dependent on the nature of each dataset. The processes required are summarised in Figure 4.2 below and described in Sections 4.4.1 – 4.4.4.

Figure 4.2 Summary of geoprocessing methods



4.4.1 GeoTIFF Data

Solar Irradiance and Wind speed data were downloaded as a high-resolution Geotagged image file formats (GeoTIFF). A TIFF file is a graphical file that stores raster or gridded data. GeoTIFF files enable georeferencing information to be attached to the metadata of a standard TIFF file. This allows for geographic projection and coordinate data to be included with any graphical data for the raster (Lacovella, 2017).

4.4.1.1 Solar GHI

For solar GHI data, each unique raster cell stores a discrete value for solar GHI in kWh/m^2 and attaches this value to the Universal Transverse Mercator (UTM) coordinates for the cell. Solar GHI was calculated as a long-term average over the period of 2007-2018 and expressed in annual average daily totals. Typical values for the Gladstone region ranged from 4.5 – 5.5kWh/m^2 while values across Australia ranged from 3.6 – 6.4kWh/m^2. Once trimmed to the extent of the search area, the raw raster GeoTIFF file was for inclusion in the MCDM Model. The raster is then reclassified in to 10 bands spanning minimum and maximum values for the search area for inclusion in the MCDM model. The reclassified solar GHI map is included in Appendix B.

4.4.1.2 Wind Speed

For wind speed data, each raster cell stores a discrete value for the wind speed measured at 100m above ground level in meters per second. 100m wind speed was chosen as this was the closest data available to the average turbine hub height of 90m. Wind data was calculated over a 10-year period of mesoscale time-series modelling by Global Wind Atlas. The data is combined from global wind speed data measured at 3km resolution and microscale model data at 250m resolution. Once trimmed to the extent of the search area, the raw raster GeoTIFF file was reclassified for inclusion in the MCDM model. The reclassified wind speed map is included in Appendix C.

4.4.2 Digital Elevation and Slope Map

Slope data was first downloaded as digital elevation model consisting of contour lines of 10 - 25m intervals. The vector line file was then processed using the ArcGIS 10.3 topo to raster geoprocessing method first developed for the ANUDEM program by Hutchinson (1989, 1993). This method carries out iterative finite difference interpolation for areas between contour lines to form a raster surface with slope represented in decimal degrees. Due to the high resolution of the raw contour data for both Gladstone and Tasmania search area, separate DEM contour maps were downloaded for smaller regions within the search area before being merged with the ARCGIS 10.3.1 mosaic geoprocessing tool. For overlapping regions, the mean of each DEM was used. Once the DEM was converted to a slope map raster, the raster was reclassified or inclusion in the MCDM model. The reclassified slope maps are included in Appendix B and C.

4.4.3 Land Classification

Land classification data was downloaded from public spatial catalogues; Queensland Spatial Catalogue and the Tasmania List Data website. Data was downloaded as vector polygon shapefile before being converted to raster format for reclassification. Reclassification was carried out by assigning a score from 1-10 based on the suitability of the existing land use for development to a solar or wind farm site. The criteria considered for this assessment consisted of the following:

- Level of existing development: Areas that were already highly developed would likely hold a higher level of property value and would be more expensive and difficult to redevelop. Areas of advanced existing development were subsequently assigned low suitability scores.
- Constructability: Areas that were considered difficult to construct on for technical reasons. For examples areas classified as wetlands / marshes were assigned low suitability scores due to the significant amount of ground preparation and earthworks that would be required.
- Environmental Impact: Areas of high environmental value were assigned lower suitability scores than those of low environmental values.

The reclassified land classification maps are included in Appendix B and C.

4.4.4 Calculating Euclidean Distances for Roads, Power Infrastructure, Ports and Coast

For criteria where the MCDM suitability assessment was based on the proximity of the potential site, to a spatial feature such as roads, power infrastructure, export ports or the coast, the Euclidean distance method was implemented. Euclidean distance calculates the distance for all raster cells within a given area to the input source.

The ArcGIS 10.3 Euclidean distance method requires the input data to take the form of either a feature class or raster. In this instance, Gladstone roads, and coastline were downloaded from the QSC as a vector shapefile and processed as a feature class. Gladstone substations were downloaded as a vector point data shapefile from QSC and processed as a feature class. The port of Gladstone was author drawn a feature class. Tasmania roads, coastline and high voltage power transmission lines were downloaded from TLD as a vector shapefile and processed as a feature class. Key Tasmania export ports were author drawn as a feature class.

Once the Euclidean distance calculation is run, input feature classes are internally converted to raster format prior to analysis. The raster is created such that the vector point or line is situated at the centre of the input source or (0,0) raster cell.

Each Euclidean distance raster output is then reclassified for inclusion in the MCDM model. The reclassified raster outputs are included in the report in Appendix B and C.

4.5 MCDM Suitability Model

As discussed in Section 3.2, criteria weights were assigned through the application of AHP. AHP pair-wise comparison matrices were completed with reference to similar AHP gis-based studies by Uyan (2013), Watson and Hudson (2015), Baseer (2017), Jensen and Pedersen (2017) and Ali et al., (2018). For criteria unique to green hydrogen production that have not been included in previous MCDM AHP studies, weights have been assigned with reference to the findings of (Geoscience Australia, 2019) to develop to the following models.

- Off Grid Connected Model
- Grid Connected Model
- Constructability Model

4.5.1 Analytical Hierarchy Model

4.5.1.1 Dedicated Renewables Model

The dedicated renewables model was formed to represent the requirements of positioning the potential solar or wind farm directly onsite with the hydrogen production plant or within a close enough distance to connect to dedicated renewables via transmission lines. The dedicated renewables model is the primary method of energy generation for green hydrogen production and can be considered as the baseline model for the study.

This is reflected in the stronger relative weights for criteria directly related to production plants such as proximity to ports and the coast. Proximity to power infrastructure was assigned a relatively low weight as the energy production could be managed off-grid as a standalone system. Appendix A Table 21 shows the results of the AHP pair-wise comparison matrix for the dedicated renewables model.

4.5.1.2 Grid Connected Model

The baseline model was formed to represent the traditional requirements of green hydrogen solar and wind farms. The AHP pair-wise comparison matrix was largely based on the results of similar studies. Appendix A, Table 22 shows the results of the AHP pair-wise comparison matrix for the grid connected model.

4.5.1.3 Constructability Model

The baseline model was formed to represent the traditional requirements of green hydrogen solar and wind farms with extra consideration for reducing the cost of construction. The AHP pair-wise comparison matrix was largely based on the results of similar studies with added weight to proximity to roads and power infrastructure. By selecting sites close to existing infrastructure, this would reduce the cost of construction connecting infrastructure. Slope rating weighting was also increased to reduce the coast in ground preparation and earthworks. Appendix A, Table 23 shows the results of the AHP pair-wise comparison matrix for the constructability model.

4.5.1.4 Final Normalised Criteria Weights

The results of the AHP pair-wise comparison matrices were normalised to form the criteria weights presented in Table 14. The combined weights for each model are equal to one hundred. By maintaining an equal sum of weights, it allows for the comparison of results between models upon completion of the study.

Table 14 Final Normalised Criteria Weights for inclusion in MCDM Suitability Model

Criteria	Dedicated Renewables	Grid Connected	Constructability
Solar Global Horizontal Irradiance / Wind Speed	48	54	48
Land Use	9	9	9
Slope	8	14	15
Proximity to Main Roads	6	5	10
Proximity to Power Infrastructure	N/A	6	10
Proximity to Coast	14	6	4
Proximity to Ports	14	6	4

Notes:

Proximity to power infrastructure has not been considered for the dedicated renewables model

4.5.1.5 Calculation of Suitability Score

Each raster cell of the search area was assessed against the suitability criteria. The total suitability score for each raster cell was determined by the weighted sum of the cell's properties as shown in equation 7.

$$S = \sum_{i=1}^{i=N} W_i P_i \qquad (7)$$

$$S = Suitability\ score\ for\ the\ raster\ cell$$

$$W_i = Weight\ of\ criterion\ i$$

$$P_i = Score\ of\ criterion\ i$$

The above computation was carried out within ArcGIS 10.3 for every raster the search area. The results of this computation formed the suitability maps for both Gladstone and Tasmania search areas.

4.5.1.6 Mapping of Results

Once suitability scores are calculated for each raster cell, a histogram of each raster cell's suitability score was produced for each model. The data was then divided in to 5 bands of equal bands of suitability scores shown in Table 15. The data was then colour coded from red to green to produce the maps shown in Section 5.2 and 5.3. As the data was categorised based on percentile of suitability scores, the area for each band is varied between models. The variation in areas for each suitability classification is the primary consideration for data interpretation.

Table 15 Classification of Suitability Scores

Suitability Classification	Percentile (%)
Unsuitable	0 – 20
Low Suitability	20 – 40
Moderate Suitability	40 – 60
High Suitability	60 – 80
Very High Suitability	80 - 100

5. Results

5.1 Search Area Definition

The suitability assessment was completed for a defined area only for the Gladstone Region solar model and Tasmania wind model. Areas considered unsuitable for development such as CAPAD restricted land, urbanised land and areas of surface water were merged to form the restricted land layer. The areas of restricted land and available land have been summarised in Table 16.

Table 16 Calculated Geodesic Area for Gladstone Region and Tasmania Search Areas and Restricted Lands

Land Type	Gladstone Region Search Area		Tasmania Search Area	
	Area (km^2)	Percentage (%)	Area (km^2)	Percentage (%)
Preliminary Search Area	159 234	100	64 054	100
Restricted Land	1 931	1.2	13 020	20.3
Available Land	157 302	98.8	51 032	79.7

5.2 Gladstone Region Suitability Assessment

5.2.1 Suitability Assessment Criteria

The Gladstone regional solar model criteria refer to the criteria maps included in the report as Appendix D. The Gladstone regional search area consisted of approximately 157,302km^2 of available land representing 98.8% of the original search area. More than 70% of the available land consists of grazing, cropping and modified pastures which have been deemed highly suitable for redevelopment. Solar GHI, the most heavily weighted criteria, ranged from 4.4-5.4kWh/m^2. Areas of low relative solar irradiance were typically found within 100km of the coast which a greater concentration to the south of Gladstone. Isolated areas within 10km of the coast were found to have a relatively high solar GHI. This could be a result of the topography of the area. In the southern hemisphere, where the regions are surrounded by mountains to the immediate north, there is generally a reduction in direct normal irradiance due to the effects of shading. This can be seen in areas south of Gladstone that have a lower solar GHI due to the mountainous areas located between Biloela and Monto.

Roads and power infrastructure were generally spread across the region with a higher density close to the coast. This is particularly evident for the substations data that did not extend west of Theodore. Transmission line data that would spread further west was unable to be sourced for the analysis.

5.2.2 Summary of Results

A solar farm site suitability assessment was constructed for a dedicated renewables model, grid connected model and constructability model for the Gladstone Region. Considered in the search area was a total of 25,290 raster cells each with an area of 6.20km^2. Table 17 summarises the results of the Gladstone Region solar suitability assessment models. Figures comparing the area for each suitability classification have been included in Appendix F.

Table 17 Comparison of Suitability Classification Areas between Gladstone Region Solar Models

Suitability Classification	Proportion of Search Area (%)		
	Dedicated Renewables	Grid Connected	Constructability
Unsuitable	5	4	3
Low	4	5	6
Moderate	33	21	22
High	56	63	64
Very High	1	6	6

Histogram was produced for each suitability assessment model. The histogram can be used to compare the overall suitability of the Gladstone region to the constraints attached to each of the model criteria. The results of the histogram have been presented in Table 18 and the histogram graphs have been included in the report as Appendix G.

Table 18 Summary of Results for Gladstone Region Suitability Assessment

Statistic	Dedicated Renewables	Grid Connected	Constructability
Mean	6,737	6,973	6,022
Max	10,000	10,000	8,740
Min	2,150	1,804	1,056
Sum of Suitability Scores	172,125,256	176,341,965	152,304,913
Median	6,981	7,372	6,459
Skewness	-1.34	-1.44	-1.42
Kurtosis	4.74	4.69	4.56
Standard Deviation	1,163	1,370	1,282

5.2.3 Dedicated Solar Model

Figure 5.1 maps the output of the Gladstone Region suitability assessment model for dedicated solar farm sites. The dedicated renewables model was designed to reflect the criteria for collocating solar farms with hydrogen production plants without reliance on the existing power grid.

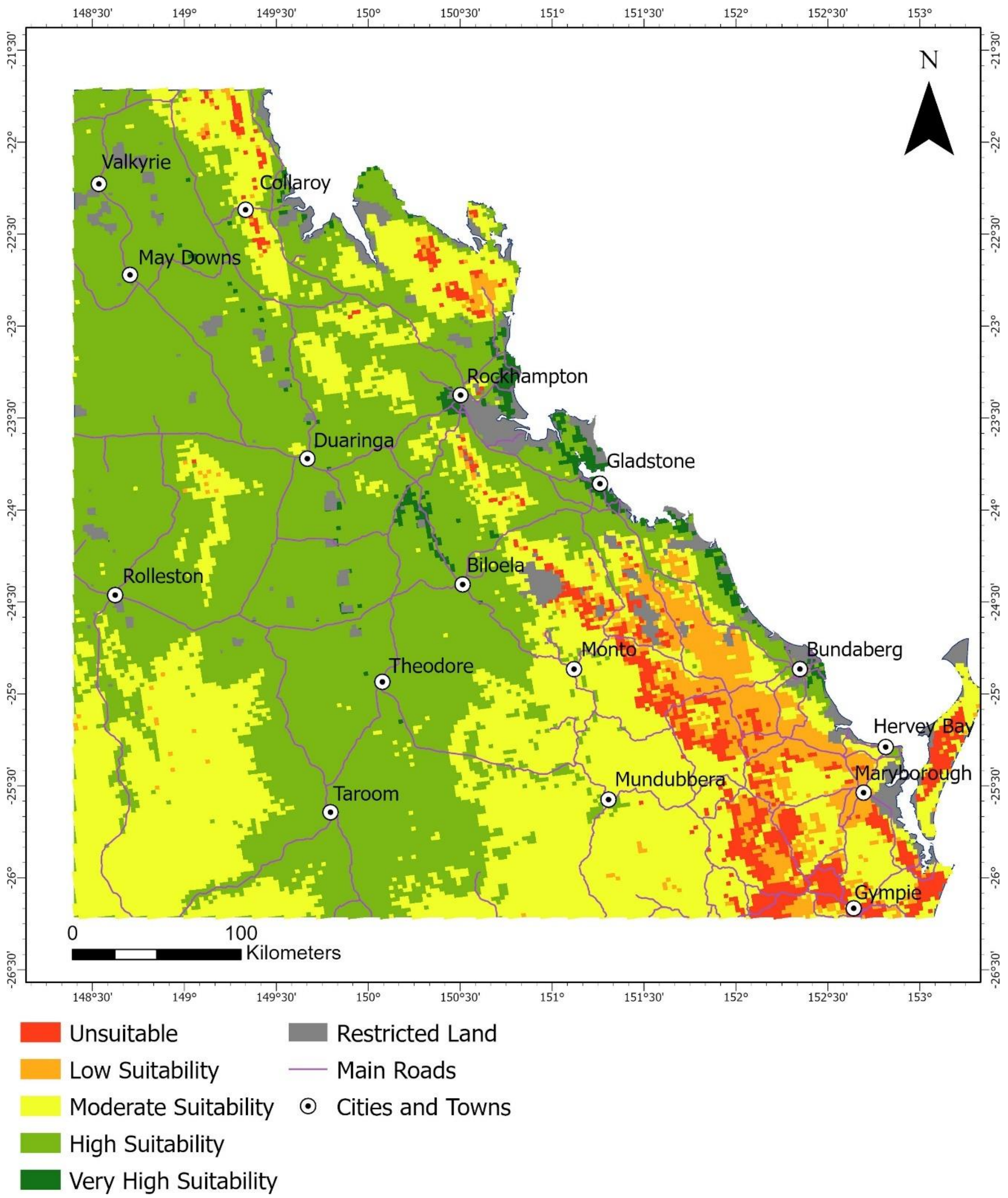


Figure 5.1 Suitability Assessment Map for Gladstone Region Dedicated Solar Farm Sites

5.2.4 Grid Connected Model

Figure 5.2 maps the output of the Gladstone Region suitability assessment model for grid connected solar farms. The grid connected model was designed to reflect the criteria for connecting the proposed solar farm to the existing power grid.

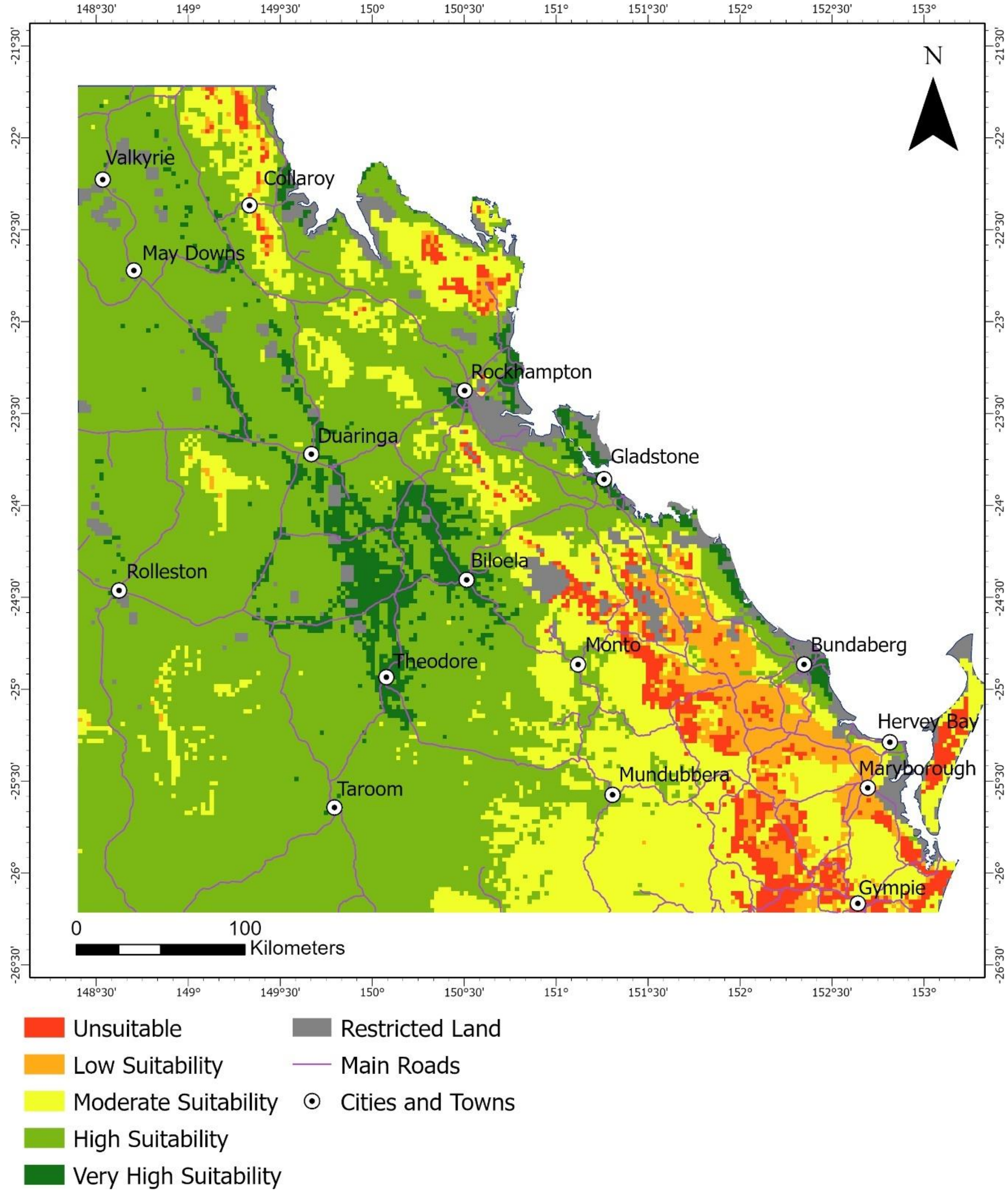


Figure 5.2 Suitability Assessment Map for Gladstone Region Grid Connected Solar Farm Sites

5.2.5 Constructability Model

Figure 5.3 maps the output of the Gladstone Region solar farm suitability assessment constructability model. The constructability model was designed to preference locations that were deemed to be easy to construct on.

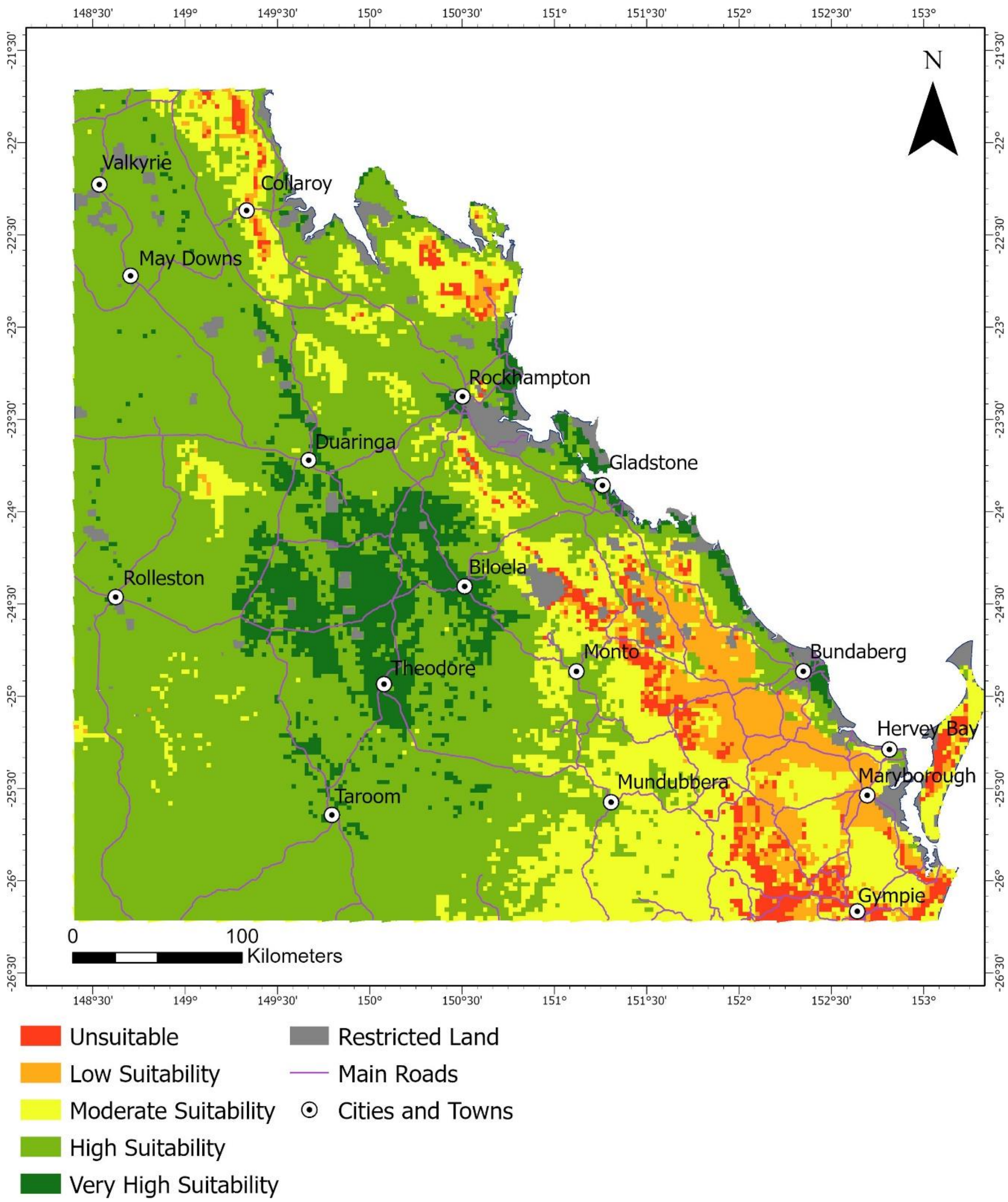


Figure 5.3 Suitability Assessment Map for Highly Constructible Gladstone Region Grid Connected Solar Farm Sites

5.3 Tasmania Suitability Assessment

5.3.1 Suitability Assessment Criteria

The Tasmania wind model criteria refers to the criteria maps included in the report as Appendix C. The Tasmania search area consisted of approximately 47,515km^2 of available land representing 79.7% of the original search area. From there available land approximately 40% consisted of degrade grazing, cropping and degraded land considered highly suitable for redevelopment. Wind speed at 100m above ground level, the most heavily weighted criteria, ranged from 3.2-11m/s for more than 98% of the search area with isolated areas ranging from 11-17.2m/s. These isolated sections were typically mountainous regions. Roads and power infrastructure were generally spread across the region. Four ports were located on the northern coast at Smithton, Burnie, Devonport and Bell Bay. One port was located on the south-east coast in Hobart and another up in the north up river at Launceston providing port access to inland areas.

5.3.2 Summary of Results

A wind farm site suitability assessment was constructed for a dedicated renewables model, grid connected model and constructability model for the Tasmania Model. Considered in the search area was a total of 8,188 raster cells each with an approximate area of 5.8km^2. Table 19 summarises the results of the Tasmania Region suitability assessment models. Figures comparing the area for each suitability classification have been included in Appendix F.

Table 19 Comparison of Suitability Classification areas between Tasmania Wind Models

Suitability Classification	Proportion of Search Area (%)		
	Dedicated Renewables	Grid Connected	Constructability
Unsuitable	3	4	3
Low	23	32	31
Moderate	44	44	42
High	27	19	21
Very High	2	2	3

Histogram was produced for each suitability assessment model. The histogram can be used to compare the overall suitability of the Gladstone region to the constraints attached to each of the model criteria. The results of the histogram have been presented in Table 20 and the histogram graphs have been included in the report as Appendix G.

Table 20 Summary of Statistical Data for Tasmania Suitability Assessment

Statistic	Dedicated Renewables	Grid Connected	Constructability
Mean	3,129	2,126	3,081
Max	5,263	3,660	4,942
Min	917	752	1,290
Sum of Suitability Scores	25,702,495	17,408,416	25,230,286
Median	3,107	2,088	3,010

Statistic	Dedicated Renewables	Grid Connected	Constructability
Skewness	0.04	0.23	0.29
Kurtosis	2.77	2.78	2.52
Standard Deviation	672	437	603

5.3.3

5.3.4 Dedicated Wind Model

Figure 5.4 maps the output of the Tasmania suitability assessment model for dedicated wind farm sites. The dedicated renewables model was designed to reflect the criteria for collocating wind farms with hydrogen production plants without the reliance on the existing power grid

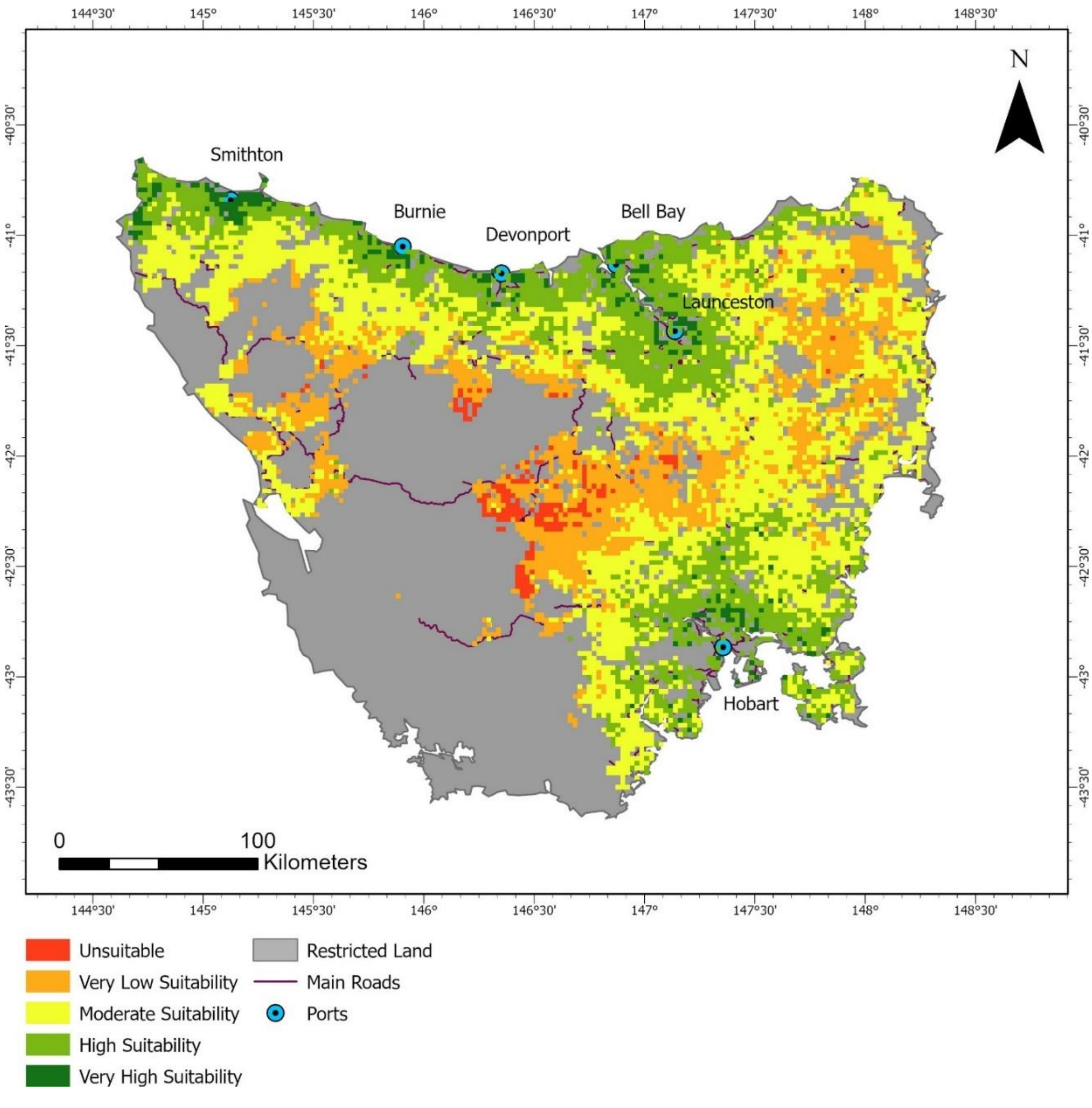


Figure 5.4 Suitability Assessment Map for Tasmania Dedicated Wind Farm Sites

5.3.5 Grid Connected Model

Figure 5.5 maps the output of the Tasmania wind farm dedicated renewables suitability assessment model. The dedicated renewables model was designed to reflect the criteria for siting a wind farm on site with a hydrogen production plant without the reliance on the existing power grid

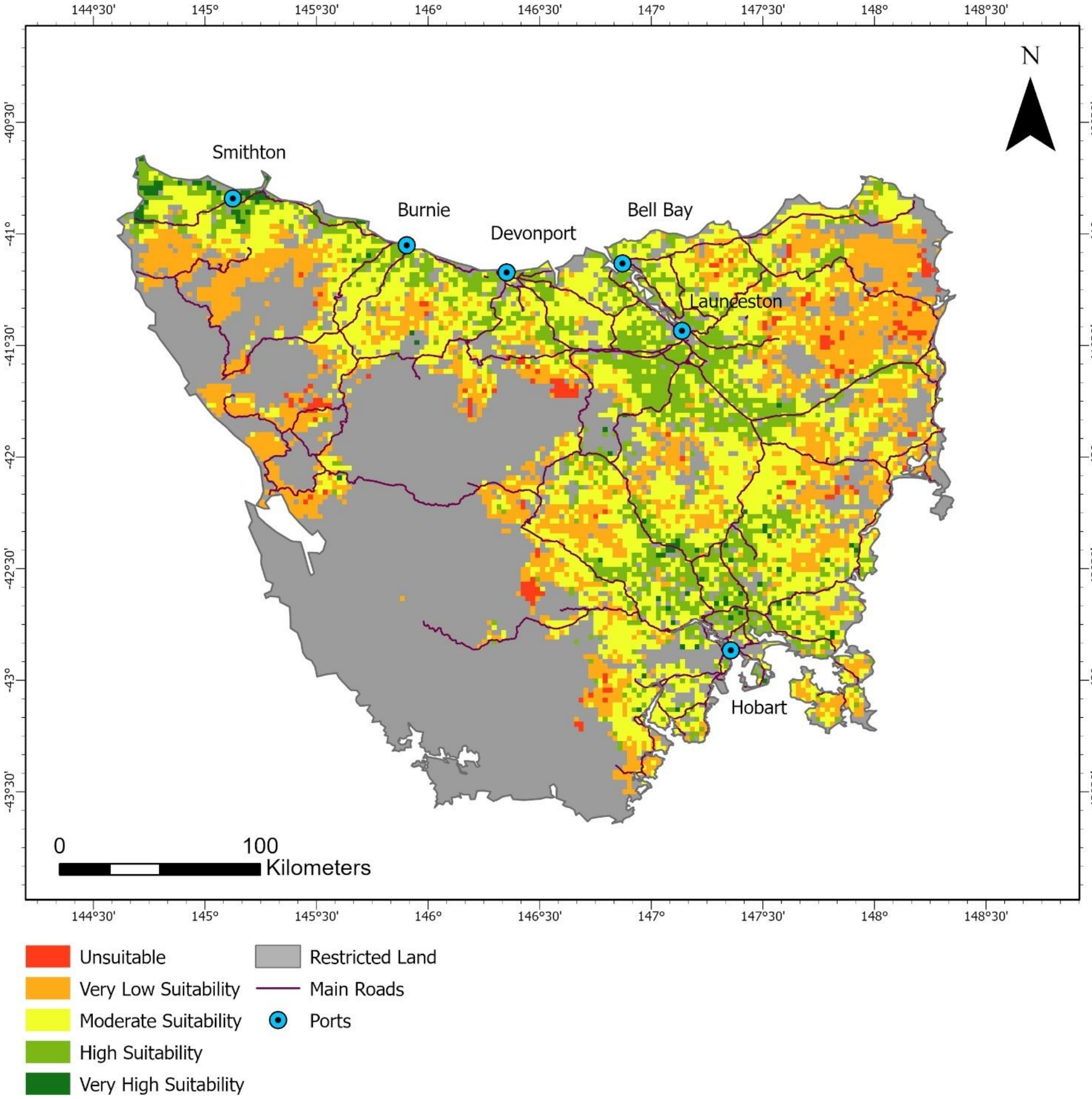


Figure 5.5 Suitability Assessment Map for Tasmania Grid Connected Wind Farm Sites

5.3.6 Constructability Model

Figure 5.6 maps the output of the Tasmania wind farm suitability assessment constructability model. The constructability model was designed to preference locations that were deemed to be easy to construct on.

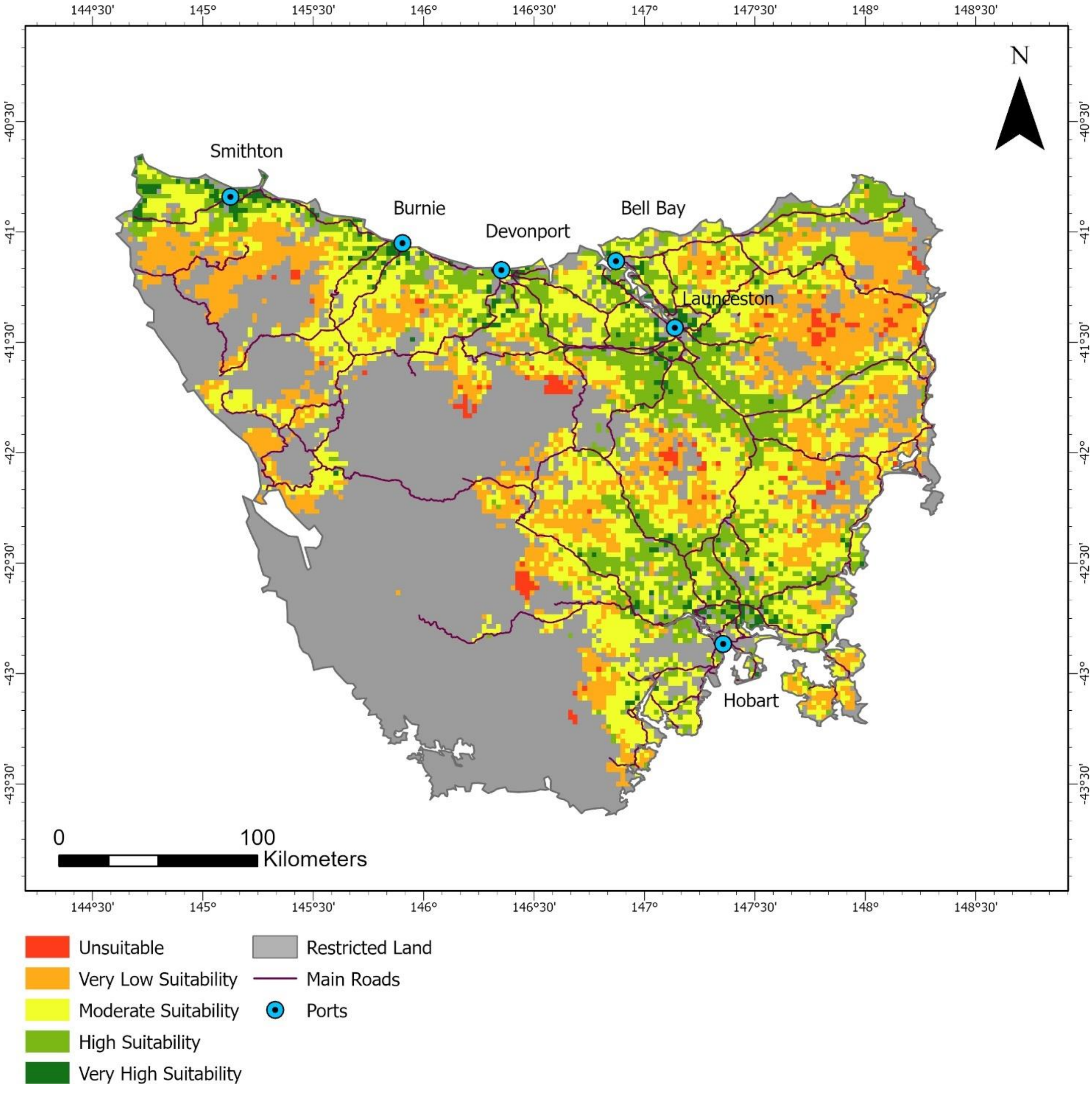


Figure 5.6 Suitability Assessment Map for Highly Constructible Tasmania Grid Connected Wind Farm Sites

6. Discussion and Conclusion

6.1 Gladstone Regional Solar Models

6.1.1 Gladstone Regional Dedicated Solar Model

The dedicated renewables model is the primary method of energy generation for green hydrogen production and can be considered as the baseline model for the study. The results presented in Table 16 show that 57% of the available land was classified as highly suitable while 1% of the land was classified as very highly suitable. No literature could be found be found to conduct a direct comparison for proportional suitability for green hydrogen production renewables sites on a regional scale within Australia. The national scale suitability assessment for prospective hydrogen production regions of Australia (Geoscience Australia, 2019) classified the Gladstone region as highly suitable for renewable energy development and green hydrogen production without the reliance on existing infrastructure. As the results of the suitability assessment suggest greater than 50% of the region is classified as highly suitable a mean suitability score of 6,737 or on the bounds of moderate to highly suitable, this aligns witj the expected range of results.

Figure 5.1 assessment shows very high suitability areas are concentrated along the coast between Rockhampton, Gladstone and Bundaberg as well as some areas close to the main road (Burnett Highway) north of Biloela. The very high suitability areas located on the coast are largely due to the combination of high solar GHI while maintaining close proximity to the coast and Gladstone port. The slope shows these areas are relatively flat with a slope rating of less than 4 degrees. Land use is mixed in these coastal areas and would likely determine the land value of the area which would be a major factory in the final selection for development.

For the area to the north of Biloela, the area holds maximum suitability scores for the criteria of solar GHI, land classification, slope and proximity to roads. The coast and port of Gladstone are 80-120km away resulting in medium suitability scores for proximity to coast and port criteria. The development of these areas is recommended however developers would need to consider the cost for pipeline and/or electrical transmission line construction linking the site to the coast.

Examination of the suitability assessment histogram for dedicated solar farm sites shown included in Appendix F as Figure 9.8 shows a two distinct and gap separated normal distributions for the dataset. One cluster ranging from a suitability scores of 2,900-4,400 representing unsuitable to low suitability and another cluster ranging from suitability scores of 5,500-8,800 representing moderate to high suitability. The first cluster of lower suitability scores is representative of the area ranging from Monto to the south east corner of the Gladstone regional search area with some smaller patches north of Rockhampton and surrounding Collaroy. This is likely a result of the lower solar GHI values in this region. The larger normal distribution cluster is representative of the remaining areas of the search area.

6.1.2 Gladstone Regional Grid Connected Solar Model

The results of the Gladstone regional grid connected solar model presented in Figure 5.2 and Table 16 show that 63% of the available land was classified as highly suitable while 6% of the available land was classified as very highly suitable. The national scale study conducted by Geoscience Australia (2019) suggest that region of Gladstone is classified as highly suitable from a national scale. With a mean suitability score of 6,973 and classification of high suitability, it can be inferred that the model aligns with the expected range of results.

Like the dedicated renewables model, areas of very high suitability can be found on the coast from Rockhampton to Bundaberg. A concentration of very high suitability areas has also been located between the towns of Duaringa to the north, Biloela to the west and Theodore to the south. This area offers a balance between high solar GHI, proximity to roads, power infrastructure, coast and ports.

Like the dedicated solar model, two discernible peaks can be observed in the histogram graph included in Appendix F, Figure 9.9. This is due to the same pattern of low suitability areas observed from Monto to the south east corner of the search area due to low solar GHI.

Examination of the key statistics presented in Table 17 shows that the mean suitability score of 6,973 is the highest of each Gladstone regional model. It should be noted that this statistic should not allow for an assumption that the Gladstone region is most suited to a grid connected solar model. Instead, the energy production component of green hydrogen production should be considered case by case to minimise LCOH and optimise the various other factors that need to be considered for development of a green hydrogen production system.

6.1.3 Gladstone Constructability Solar Model

The results of the Gladstone regional constructability solar model presented in Figure 5.4 and Table 16 show that 64% of the available land was classified as highly suitable and 6% of the available land was classified as very highly suitable. The constructability model also considers proximity to existing power infrastructure and can be compared to the same Geoscience Australia study scenario as the grid connected model that classifies the Gladstone region as highly suitable from a national scale. With a mean suitability score of 6,022 and a classification of high suitability it can inferred that the model aligns with the expected range of results.

The distribution of high to very high suitability scores is similar to that of the grid connected model. Very high suitability scores are concentrated in the area bound by Duaringa, Biloela and Theodore with some very high suitability sites along the coast between Rockhampton and Bundaberg. The constructability model has the highest proportion of very high suitability sites located inland, due to the lower relative weights for the proximity to coast and ports criteria.

Like the grid connected model, the histogram for the constructability model included in the report as Appendix F, Figure 9.10 shows two gap separated normal distributions due to the same pattern of low suitability areas observed from Monto to the south east corner of the search area due to low solar GHI and moderate to very high suitability areas throughout the remaining available land. Because the low suitability area in the south east of the map is relatively small the first peak is approximately 75% smaller than the second peak.

6.2 Tasmania Wind Models

6.2.1 Tasmania Dedicated Wind Model

The results of the Tasmania dedicated wind model presented in Figure 5.4 and Table 18 show that 27% of the available land was classified as highly suitable and 2% of the available land was classified as very highly suitable. The national scale study conducted by Geoscience Australia (2019) suggests Tasmania is of moderate to highly suitable for renewable wind, solar and hydropower resource potential without reliance on existing infrastructure. With a mean suitability score of 3,129 and classification of moderate suitability this falls lower than the expected results but is still within a reasonable range to consider to the results of the model as valid.

Like the Gladstone regional dedicated solar model, areas of high suitability are concentrated around ports on the coast due to the high weightings for these criteria. The histogram for this model included in the report as Appendix G, Figure 9.11 shows a typical normal distribution supported by the minimal skewness result of 0.04. With this shape of data distribution, the largest suitability classification by area was moderate suitability covering 44% of the available land and 21,047km^2.

6.2.2 Tasmania Grid Connected Wind Model

The results of the Tasmania dedicated wind model presented in Figure 5.5 and Table 18 show that 19% of the available land was classified as highly suitable and 2% of the available land was classified as very highly suitable. The national scale study conducted by Geoscience Australia (2019) suggests Tasmania is highly suitable for renewable power transported through existing power infrastructure. This is suitability assessment conducted by Geoscience Australia considers the existing hydropower infrastructure within Tasmania in improving the capacity of the state's electricity production. With a mean suitability score of 2,126 and classification moderate suitability this falls lower than the expected results but is still win a reasonable range to consider the results of the model valid. By removing the potential of the existing hydropower infrastructure, this may cause a lowering of the suitability classification provided by Geoscience Australia and align the assessment results of the two studies.

The areas of high suitability are more evenly distributed throughout the search area in the grid connected wind model compared to the dedicated wind model. To the west and south of Launceston there are large areas of consistent highly suitable land that provide a balance between proximity to ports and coast with 100m wind speeds of 4.8-7m/s.

6.2.3 Tasmania Constructability Wind Model

The results of the Tasmania dedicated wind model presented in Figure 5.6 and Table 18 show that 21% of the available land was classified as highly suitable and 3% of the available land was classified as very highly suitable. The constructability model also considers proximity to existing power infrastructure and can be compared to the same Geoscience Australia study scenario as the grid connected model that classifies the Tasmania as highly suitable from a national scale with the consideration of existing hydropower resources. With a mean suitability score of 3,081 and a classification of moderate suitability the results of the model are slightly lower than the expected values from obtained from literature review. The distribution of suitability scores is similar to the grid connected model. Areas of high suitability are concentrated around ports as well as the roads and power infrastructure that connects these areas.

6.3 Comparison of Results between Suitability Assessment Models

AHP was applied so that the maximum possible suitability score is consistent across each model. Because AHP has been applied in this way, a comparison of results can be carried out across the models for each search area. Reclassification of criteria was carried out separately for each dataset. Because of this the weighting of bands is not consistent between criteria for the Gladstone region and Tasmania search area, meaning the raw results cannot be compared like for like across search areas. To compare search areas proportional data has been considered.

The average proportion of land classified as highly suitable or better across all three models was 65.3% for the Gladstone region and 24.7% for Tasmania. This is likely due to the reclassification of wind speed data – the most heavily weight criteria for Tasmania models. There is a largely range in raw wind speed data than raw solar GHI data between the models. After reclassification, an inverse effect can be seen that results in the This is a result of reclassification being carried out for the entire range of the search area. For the Gladstone region, solar irradiance ranged from 4.4-5.4kWh/m^2 while wind speed ranged from 3.2-17.2m/s. The areas with high wind speeds were relatively small, isolated areas, typically located in mountainous regions. Reclassification of data in to ten bands resulted in in these small, windy areas being assigned band ten scores for wind speed while the typical wind speed bands ranged from 3-4 across the search area. This has skewed the data so that the relative suitability for Tasmania is less than half that of the Gladstone search area. This skewing effect could be minimised by removing outliers from the raw datasets. However, a like for like comparison would not provide reliable comparison without using the same datasets and reclassification bands. The most accurate analyses that can be carried out are spatial analysis of each model and a comparison of proportional suitability across models of the same search area.

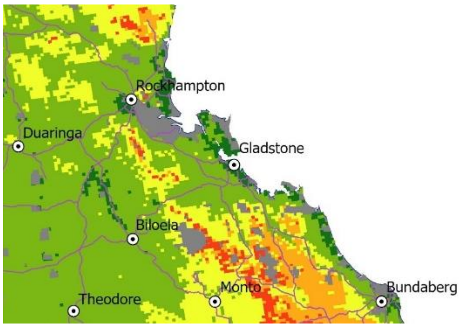
For the Gladstone regional search area, the grid connected and constructability models contained 69% and 70% high to very high suitability land respectively. The dedicated renewables model contained 57% high to very high suitability land. The key difference between the grid connected models and the dedicated renewables model is the relative difference in preference for land that is either close to the coast and ports or land that is close to existing power infrastructure. As the power infrastructure is distributed through a larger proportion of the search area than the coastline and the port of Gladstone, it supports the higher proportion of highly suitable land in the grid connected model.

For the Tasmania search area, the grid connected and constructability models contained 21% and 24% high to very high suitability land respectively. The dedicated renewables model contained 29% very high suitability land. This is the inverse relationship in comparison to the Gladstone regional solar models. While the reason for this is not confirmed, it is likely due to the reduced influence of wind speed data in the Tasmanian models than of the solar GHI data in Gladstone regional models. Where the inland areas of Gladstone regional models contain areas of solar irradiance ranging from bands 6-10, the Tasmanian models contain areas ranging from bands 3-4. Subsequently, these inland areas receive a relatively higher suitability score than the inland areas for the Tasmanian models. For the dedicated renewables models where proximity to the coast and ports is of high importance, a high suitability score is assigned to these areas. For the grid connected models where proximity to ports and the coast is less important, inland areas would be expected to gain a higher suitability score than what is seen in the Tasmanian map outputs. However due to the relatively low bands of these areas for wind speed, the overall suitability scores are reduced resulting in a lower proportion of high to very suitability areas.

6.4 Recommended Areas for Development

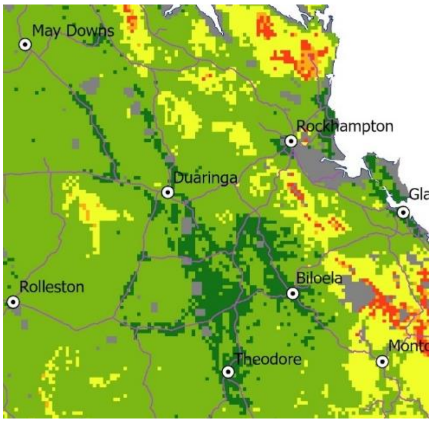
6.4.1 Gladstone Regional Search Area

6.4.1.1 Gladstone Region Dedicated Solar Model



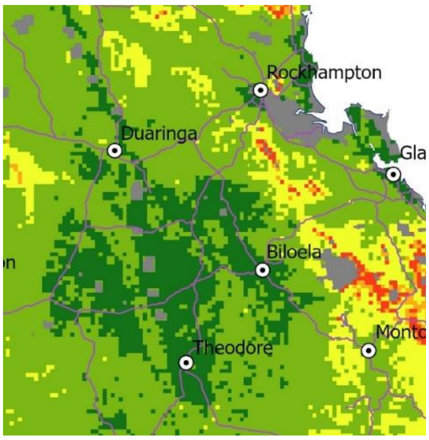
For an off grid dedicated solar farm, it is recommended to consider the coastal lands spanning from Rockhampton to Bundaberg. Areas surrounding the Gladstone coast would have the highest potential due to close proximity to the port. Sites located on the Burnett Highway north of Biloela hold high potential and would likely be cheaper to develop due to a reduced land value however a pipeline would be required if the solar farm and production plant were located inland, or a power transmission line if the production plant was located on the coast.

6.4.1.2 Gladstone Region Grid Connected Solar Model



For a grid connected solar farm, it is recommended to consider the coastal area surrounding Rockhampton and Gladstone as well as the inland area surrounded by Duaringa, Biloela and Theodore. By using the existing power grid to delivery electricity to a coastal hydrogen production plant it would eliminate the need to construct a pipeline required to service an otherwise collocated inland production plant.

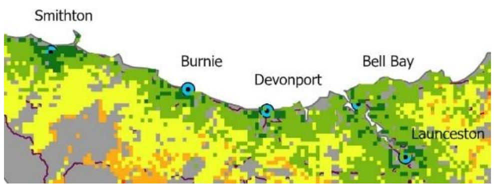
6.4.1.3 Gladstone Region Constructability Solar Model



For highly constructible solar farms, it is recommended to consider the same areas as the grid connected model with extra consideration for

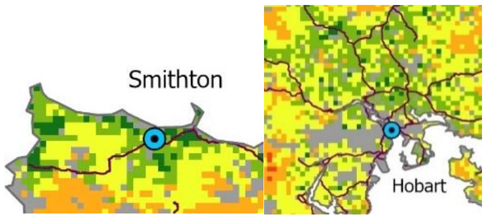
6.4.2 Tasmania Search Area

6.4.2.1 Tasmania Dedicated Wind Model



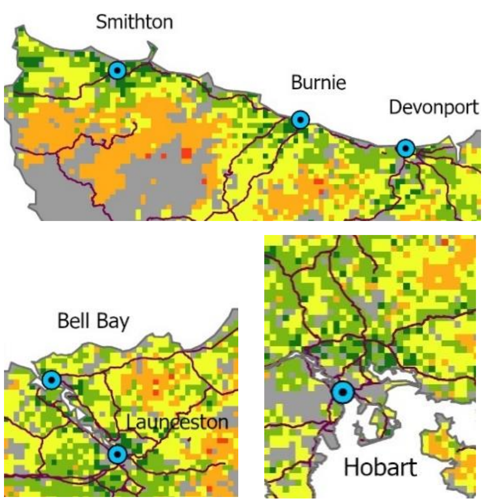
For off-grid, dedicated wind farms, it is recommended to consider the areas outside of the towns containing Ports on Tasmania’s north coast. The town of Smithton in particular has a large area of very high suitability.

6.4.2.2 Tasmania Grid Connected Wind Model



For grid connected wind farms, it is recommended to consider the areas outside of the towns of Smith or Hobart. For coastal locations, it is assumed that renewables and hydrogen production plants could be relatively close together and transmission distances would be low. Therefore, a grid connected wind farm is unlikely to be implemented rather than a dedicated wind farm.

6.4.2.3 Tasmania Constructability Wind Model



For highly constructible wind farms, it is recommended to consider all towns with ports. Like the grid connected model, the areas surrounding Smithton had clustered areas with very high suitability.

6.5 Conclusion

Through collection and geoprocessing of spatial datasets and application of AHP MCDM methodology within the ArcGIS 10.3 program, a regional scale assessment was conducted to assess the suitability of potential green hydrogen - renewable energy sites. This was conducted on a regional scale for solar farm sites within the Gladstone region and wind farm sites within Tasmania in order to refine the pre-existing national scale analysis of prospective hydrogen production regions performed and published by Geoscience Australia.

The assessment allowed for areas of high potential for renewable energy sites to be located, facilitating the development of a green hydrogen production and export industry within Australia. The aim of this study is part of a larger effort to reduce the levelized cost of hydrogen production by optimising site selection to maximise value in renewable energy production.

The suitability assessment used a set of criteria in weighted overlay format to efficiently compute suitability scores for various models. The results of the study support the hypothesis that highly suitable areas must be balance the criteria for energy production potential, constructability and constraints specific to green hydrogen production and export.

For off grid, dedicated renewables models highly suitable areas were concentrated within close proximity to ports and the coastline. For the grid connected and constructability models, the highly suitable areas were located within close proximity to the coastline for both models. For the Gladstone grid connected and constructability models there was a large area of very high suitability land approximately 100-200km from the coast bound by Duaringa to the north, Biloela to east and Theodore to the south. For both dedicated wind farm and grid connected wind farms in the Tasmania search area, areas of high suitability were concentrated around towns with Ports such as Smithton, Burnie, Devonport, Bell Bay, Launceston and Hobart.

The method for regional scale suitability assessment that was applied within this study was thoroughly documented so that it can be reproduced for other key hydrogen production regions of Australia with the goal of advancing Australia's green hydrogen production potential.

6.6 Limitations and Recommendations

- The economic considerations of the suitability assessment were limited to indirect criteria such that would affect the cost of construction and maintenance of the project. A detailed analysis considering land value could incorporate a more detailed cost estimate function.
- The results of the study are heavily dependent on the distribution of the criteria weightings. While this was reasonably managed via modified AHP, this could be eliminated through the development of a web map with live suitability assessment functions. By hosting the model online through the ArcGIS online web map platform criteria weights could be manipulated with live feedback. This could allow for total customisation of the model to reflect the concerns of the end user.
- For environmental and social considerations, the land classification vectors were implemented with a low suitability score and CAPAD conservation areas were removed from the analysis through the ArcGIS mask function. This could be further developed by creating a buffer zone around high value environmental areas with a reduced suitability score. For social considerations, buffer zones could be produced around urbanised areas to reflect the concerns of the public.
- Wind turbines operate better under consistent gentle winds. A negative suitability layer could be implemented to consider gusty areas for mountainous regions.
- A criterion for land aspect could be implemented to allow for more accurate solar energy production potential.

7. Timeline

The project was completed over two, fourteen-week semesters. Figure 7.1 shows the timeline of the activities required to complete the project.

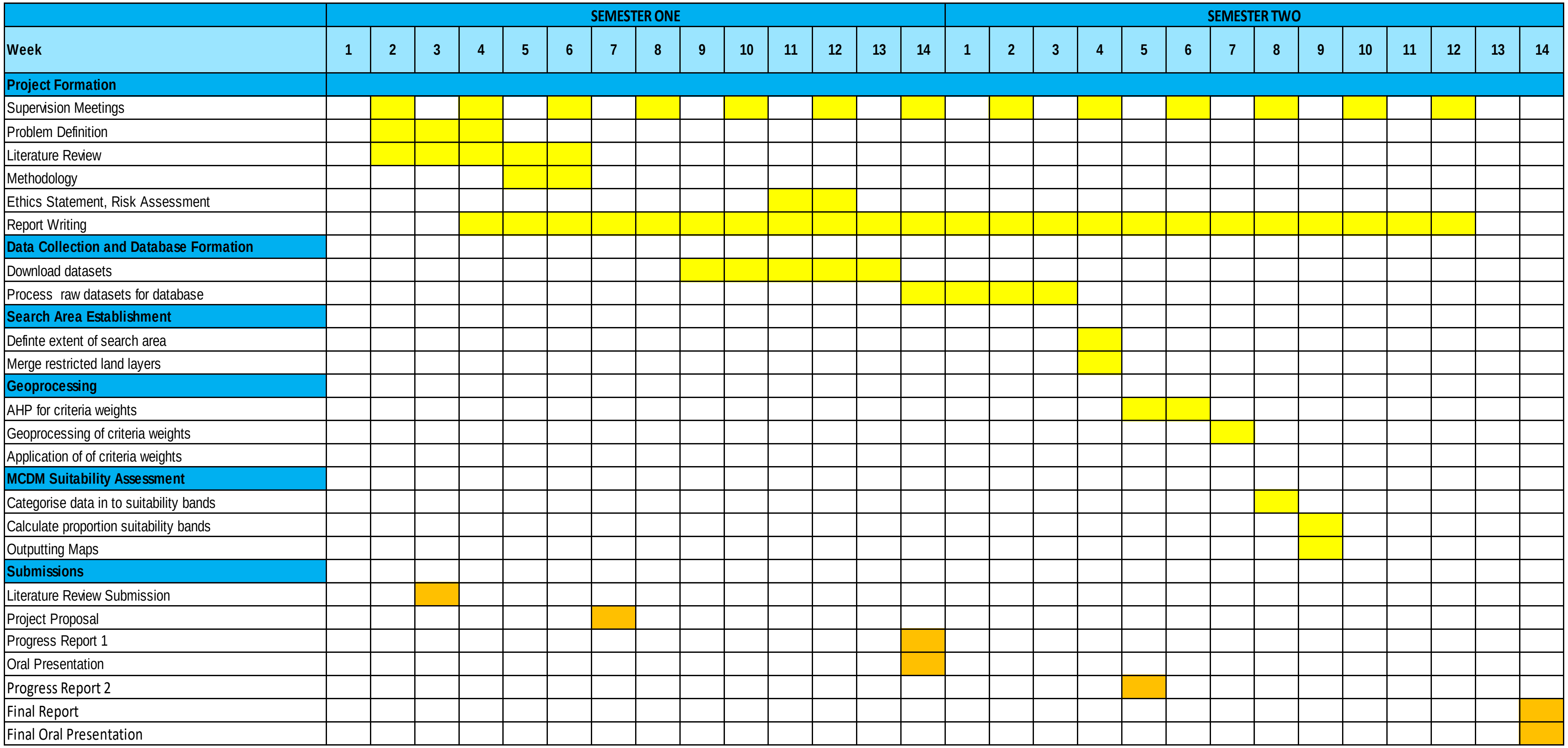


Figure 7.1 Gantt Chart used for Project Tracking

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9. Appendices

Appendix A AHP Pair-wise Comparison Matrices

Table 21 AHP Pair-wise Comparison Matrix for Dedicated Renewables Model

Criteria	Wind Speed/ Solar Irradiance	Slope	Land Use	Proximity to Main Roads	Proximity to Coast	Proximity to Ports
Solar Irradiance / Wind Speed	1.00	7.00	7.00	7.00	5.00	5.00
Slope	0.14	1.00	0.33	1.00	1.00	1.00
Land Use	0.14	3.00	1.00	1.00	0.25	0.25
Proximity to Main Roads	0.14	1.00	1.00	1.00	0.33	0.33
Proximity to Coast	0.20	1.00	4.00	3.03	1.00	1.00
Proximity to Ports	0.20	1.00	4.00	3.03	1.00	1.00

Fundamental Scale

Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	Two criteria contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favour one criterion over another
5	Essential or strong importance	Experience and judgement strong favour one criterion over another
7	Very strong importance	A criterion is strongly favoured and its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one criterion over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	Applicable when compromise is need
Reciprocals	If criterion *a* has one of the above numbers assigned to it when compared with criterion *j*, then *j* has the reciprocal value when compared with *b*	

Table 22 AHP Pair-wise Comparison Matrix for the Grid Connected Model

Criteria	Wind Speed/ Solar Irradiance	Slope	Land Use	Proximity to Main Roads	Proximity to Power Infrastructure	Proximity to Coast	Proximity to Ports
Solar Irradiance / Wind Speed	1.00	7.00	7.00	8.00	8.00	8.00	8.00
Slope	0.14	1.00	0.33	1.00	2.00	2.00	2.00
Land Use	0.14	2.00	1.00	2.00	3.00	3.00	3.00
Proximity to Main Roads	0.14	0.14	0.50	1.00	1.00	1.00	1.00
Proximity to Power Infrastructure	0.14	0.50	0.50	1.00	1.00	1.00	1.00
Proximity to Coast	0.13	0.50	0.33	1.00	1.00	1.00	1.00
Proximity to Ports	0.13	0.50	0.50	1.00	1.00	1.00	1.00

Fundamental Scale

Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	Two criteria contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favour one criterion over another
5	Essential or strong importance	Experience and judgement strong favour one criterion over another
7	Very strong importance	A criterion is strongly favoured and its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one criterion over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	Applicable when compromise is need
Reciprocals	If criterion *a* has one of the above numbers assigned to it when compared with criterion *j*, then *j* has the reciprocal value when compared with *b*	

Table 23 AHP Pair-wise Comparison Matrix for Constructability Model

Criteria	Wind Speed/ Solar Irradiance	Slope	Land Use	Proximity to Main Roads	Proximity to Power Infrastructure	Proximity to Coast	Proximity to Ports
Solar Irradiance / Wind Speed	1.00	6.00	6.00	6.00	6.00	7.00	1.00
Slope	0.17	1.00	0.33	1.00	2.00	2.00	0.17
Land Use	0.17	3.00	1.00	1.00	2.00	4.00	0.17
Proximity to Main Roads	0.17	1.00	1.00	1.00	0.50	3.00	0.17
Proximity to Power Infrastructure	0.17	0.50	0.50	2.00	1.00	3.00	0.17
Proximity to Coast	0.14	0.50	0.25	0.33	0.33	1.00	0.14
Proximity to Ports	0.14	0.50	0.00	0.33	0.33	1.00	0.14

Fundamental Scale

Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	Two criteria contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favour one criterion over another
5	Essential or strong importance	Experience and judgement strong favour one criterion over another
7	Very strong importance	A criterion is strongly favoured and its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one criterion over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	Applicable when compromise is need
Reciprocals	If criterion *a* has one of the above numbers assigned to it when compared with criterion *j*, then *j* has the reciprocal value when compared with *b*	

Appendix B Gladstone Region Reclassified Criteria Maps

Figure 9.1 maps the output of the Gladstone solar GHI reclassified between 4.4-5.4kWh/m^2.

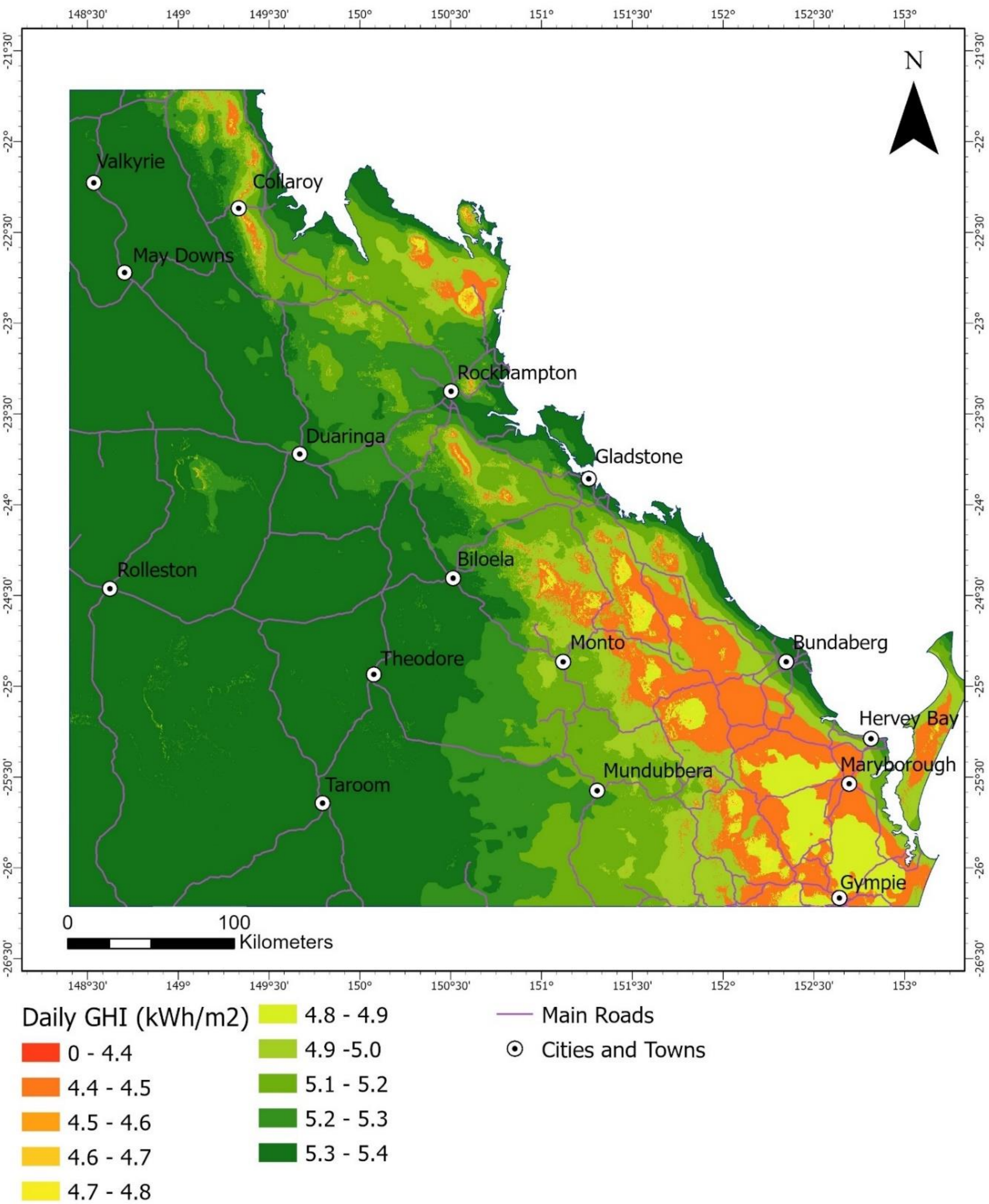

Figure 9.1 Gladstone Region Reclassified Daily Solar GHI (kWh/m^2) (SolarGIS, 2019)

Figure 9.2 maps the restricted land types for the Gladstone region.

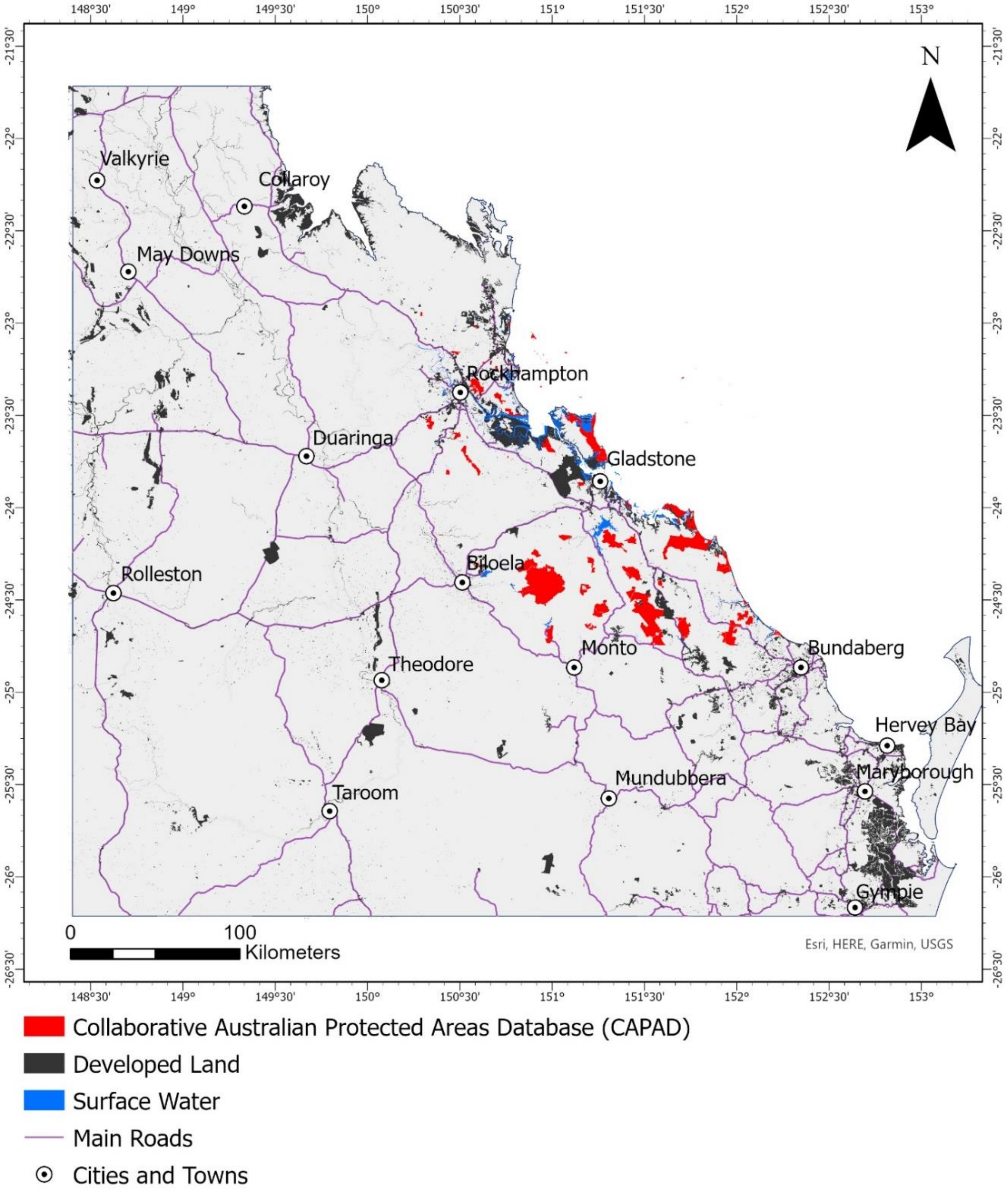

Figure 9.2 Gladstone Region Restricted Land (Queensland Spatial Catalogue) (Geological Society of Australia) (Esri)

Figure 9.3 maps the output of the Gladstone contour data, processed and reclassified in to a slope map ranging from 0-45 degrees slope.

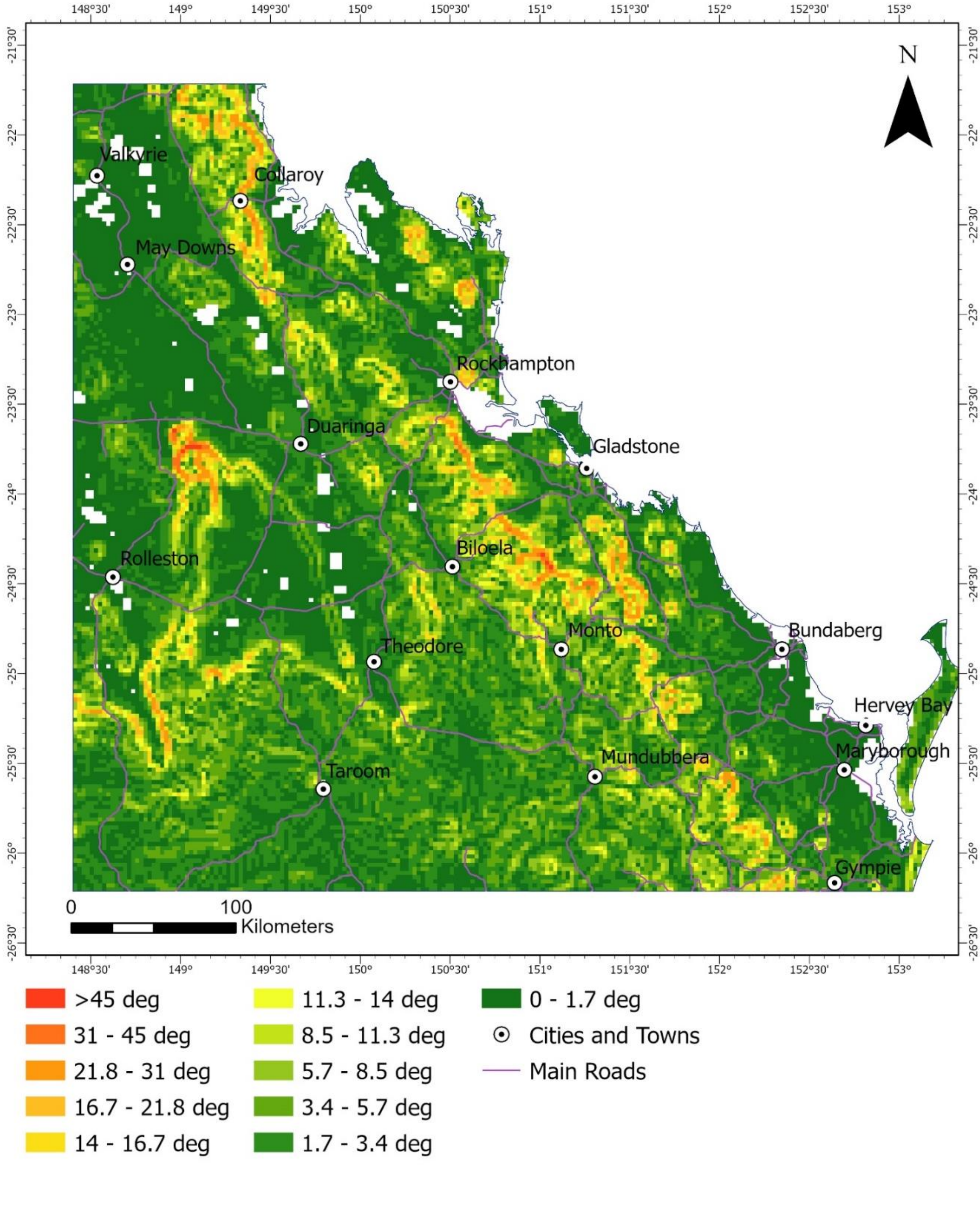

Figure 9.3 Gladstone Region Reclassified Slope Rating (Queensland Spatial Catalogue)

Figure 9.4 maps the reclassified land use classifications for the Gladstone region.

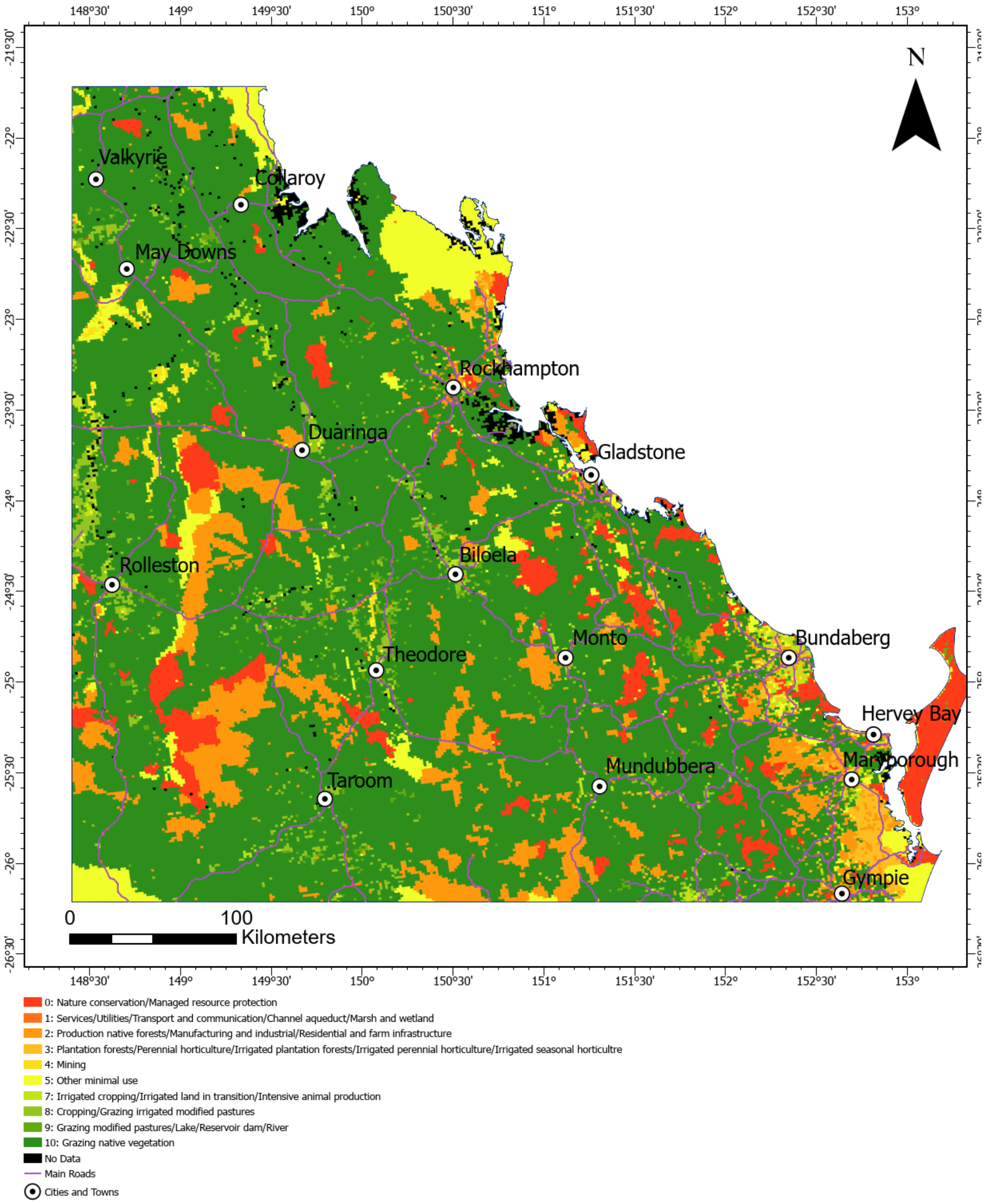

Figure 9.4 Gladstone Region Reclassified Land Use (Queensland Spatial Catalogue)

Figure 9.5 maps the Euclidean distance to main roads within the Gladstone region.

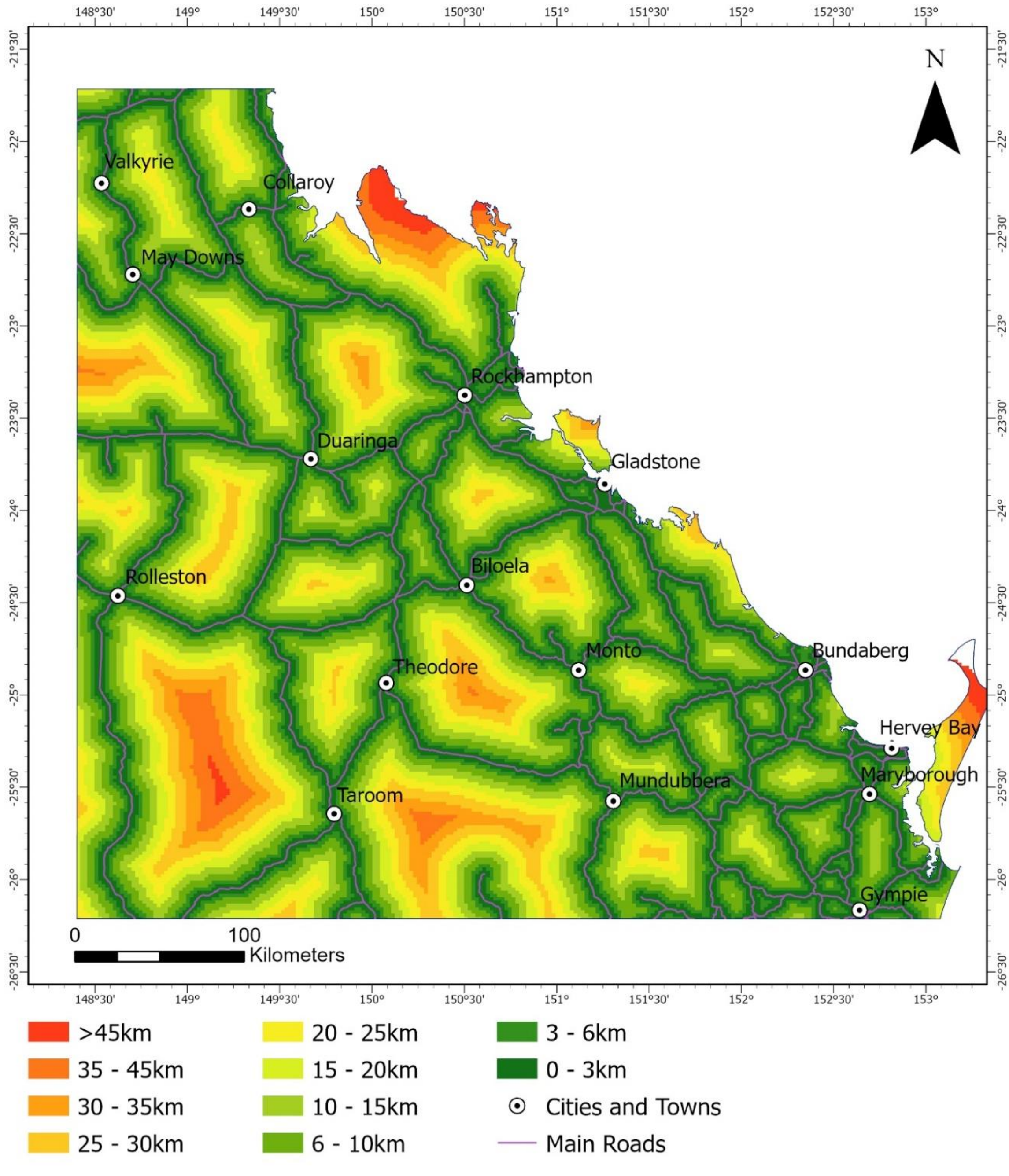

Figure 9.5 Gladstone Region Reclassified Proximity to Main Roads(Queensland Spatial Catalogue)

Figure 9.6 maps the Euclidean distance to substations within the Gladstone region.

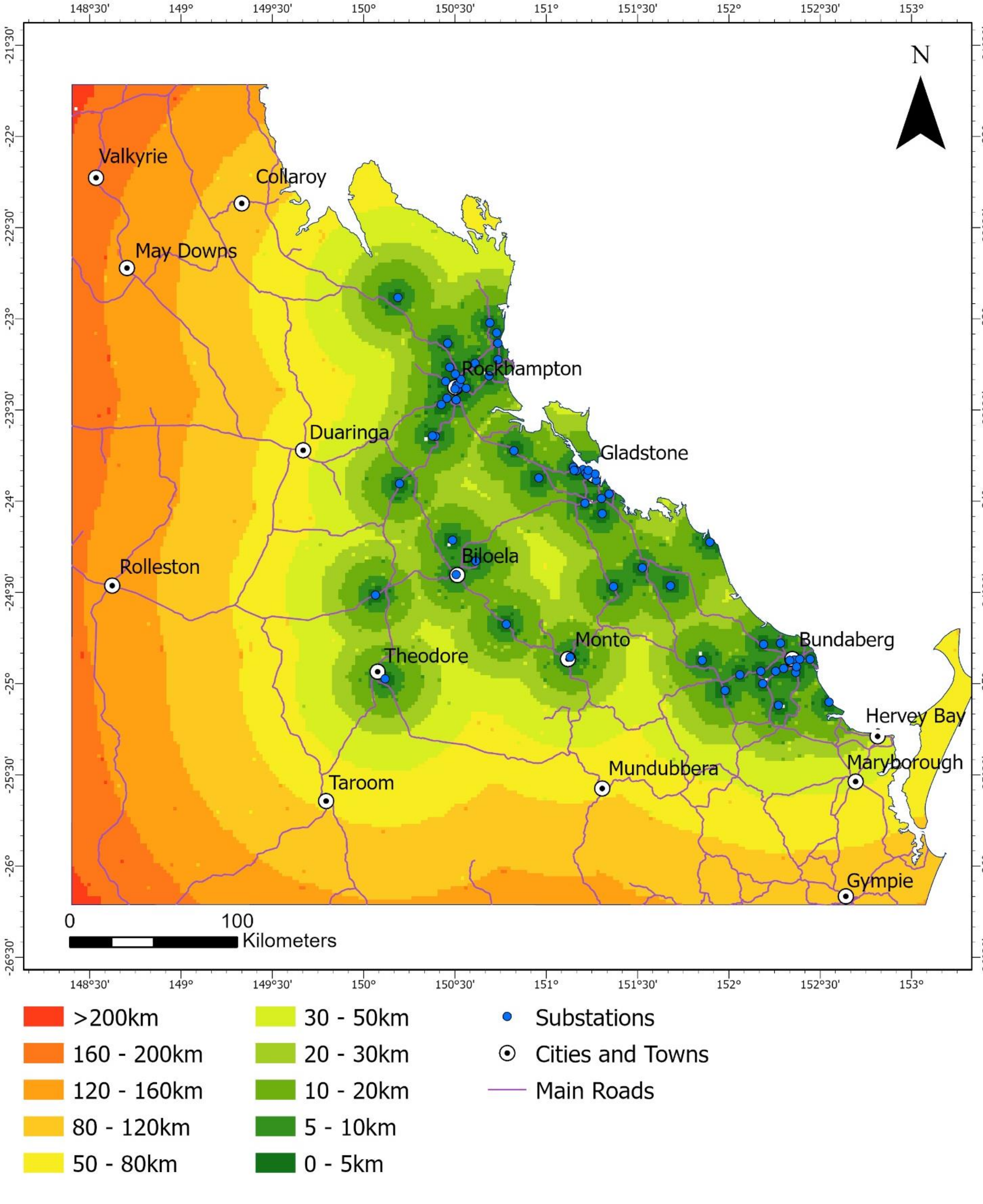

Figure 9.6 *Gladstone Region Reclassified Proximity to Existing Power Infrastructure (Queensland Spatial Catalogue)*

Figure 9.7 maps the Euclidean distance to the coast within the Gladstone region.

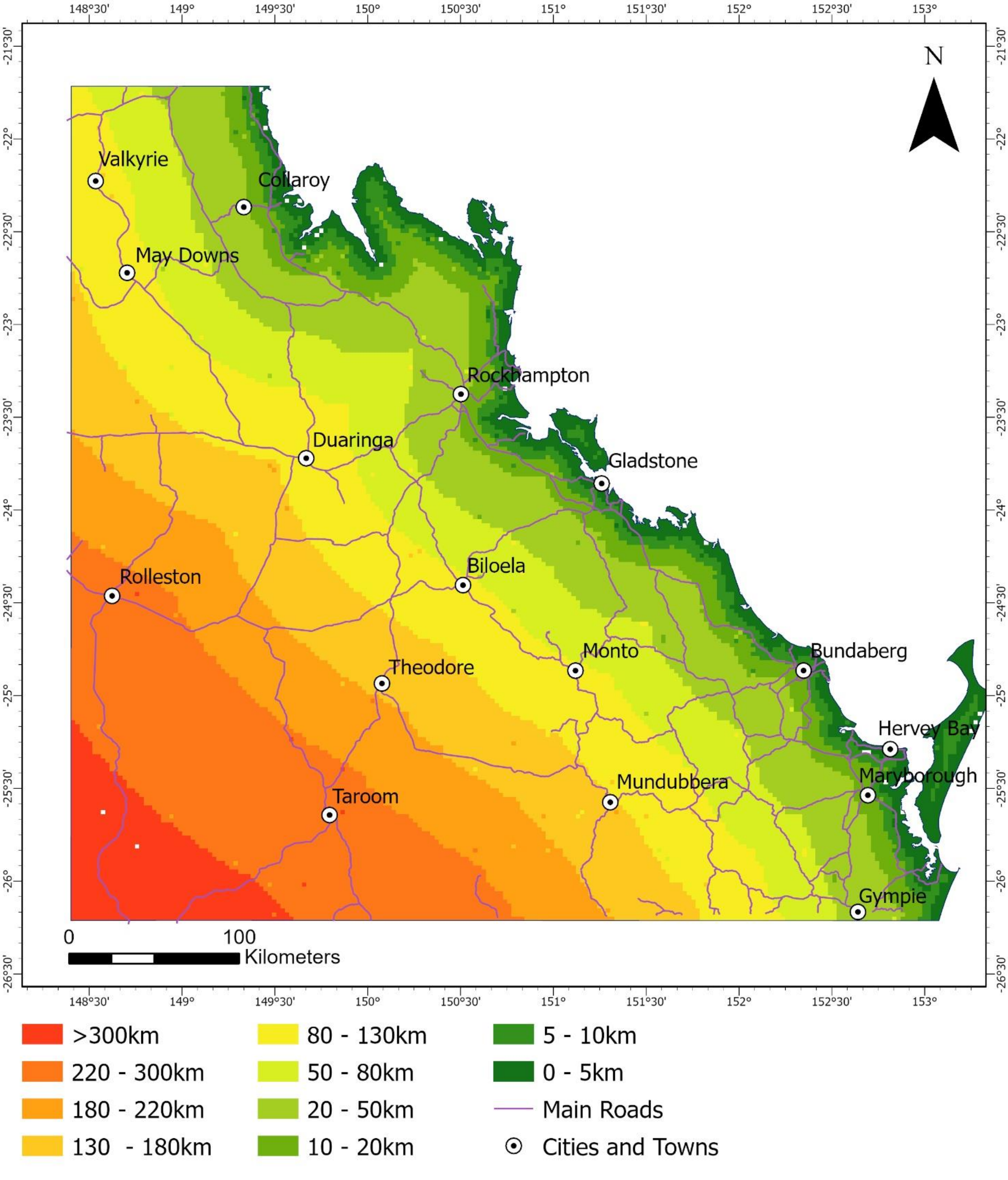

Figure 9.7 Gladstone Region Reclassified Proximity to Coast (Geological Society of Queensland) (Esri)

Figure 9.8 maps the Euclidean distance to the port of Gladstone.

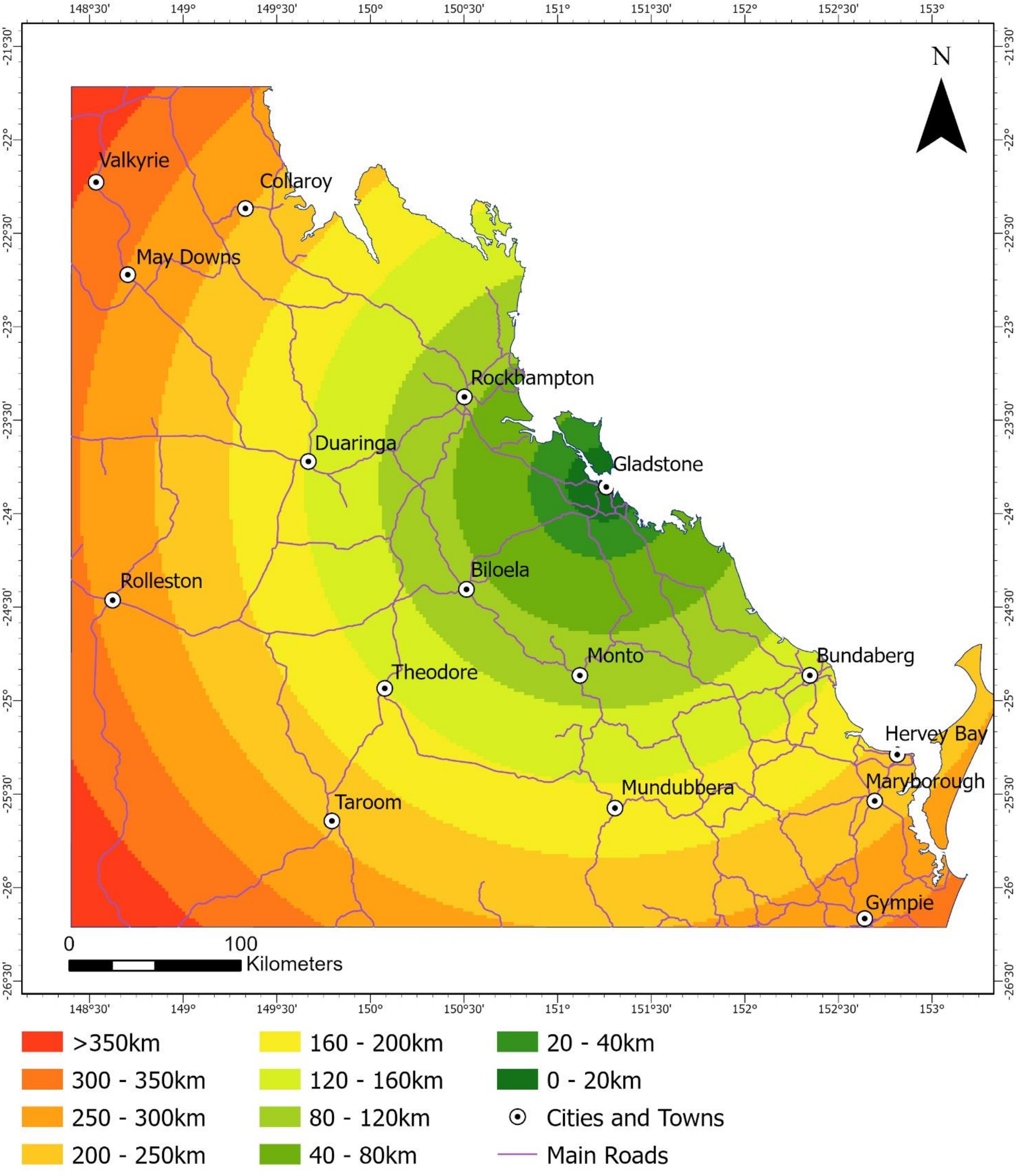

Figure 9.8 Gladstone Region Reclassified Proximity to Port of Gladstone (Esri)

Appendix C Tasmania Reclassified Criteria Maps

Figure 9.9 maps the output of the Tasmania wind speed at 100m elevation reclassified between 3.2-17.2m/s.

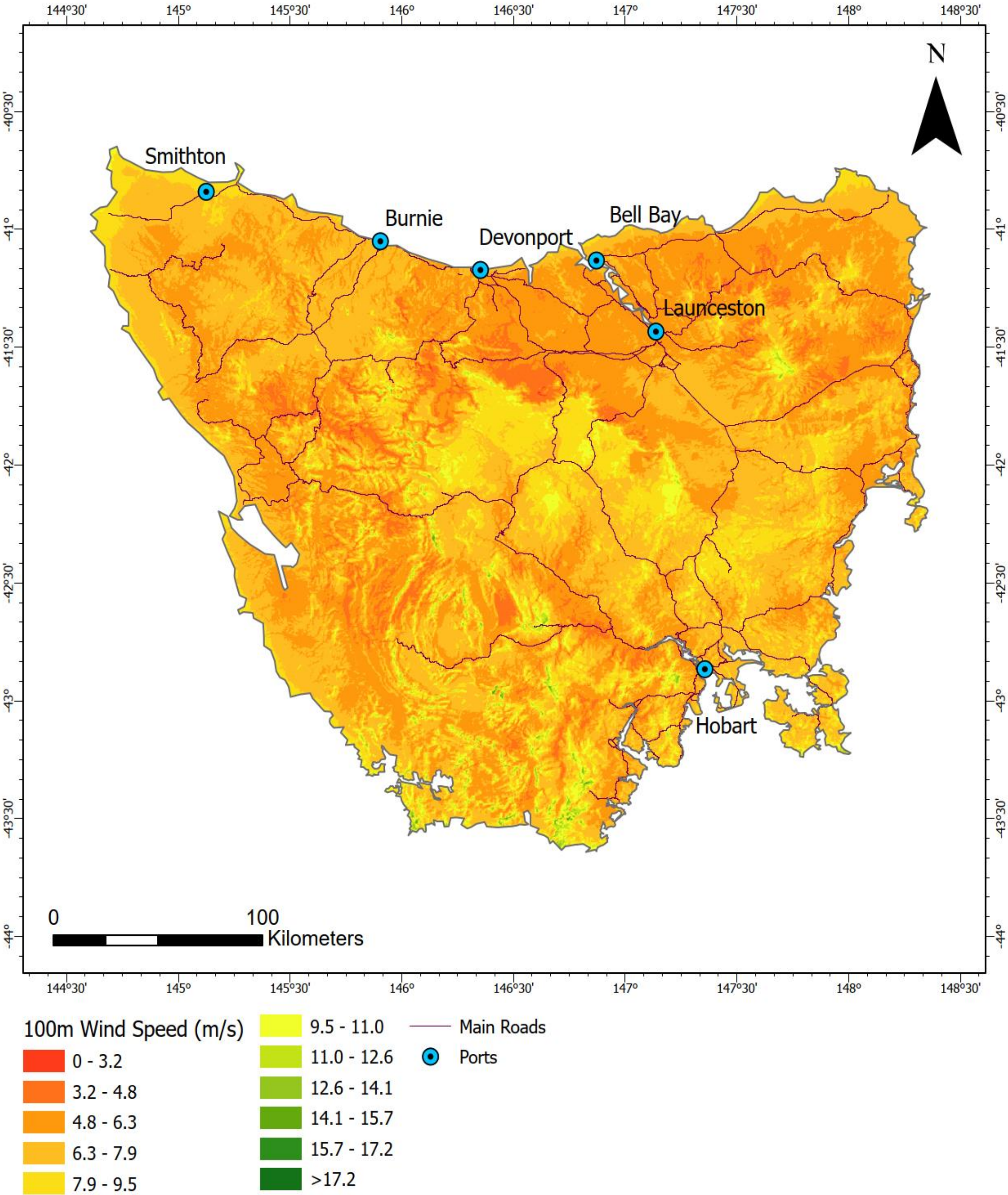

Figure 9.9 Tasmania Reclassified 100m Wind Speed (Global Wind Atlas, 2019)

Figure 9.10 maps the combined restricted land of Tasmania.

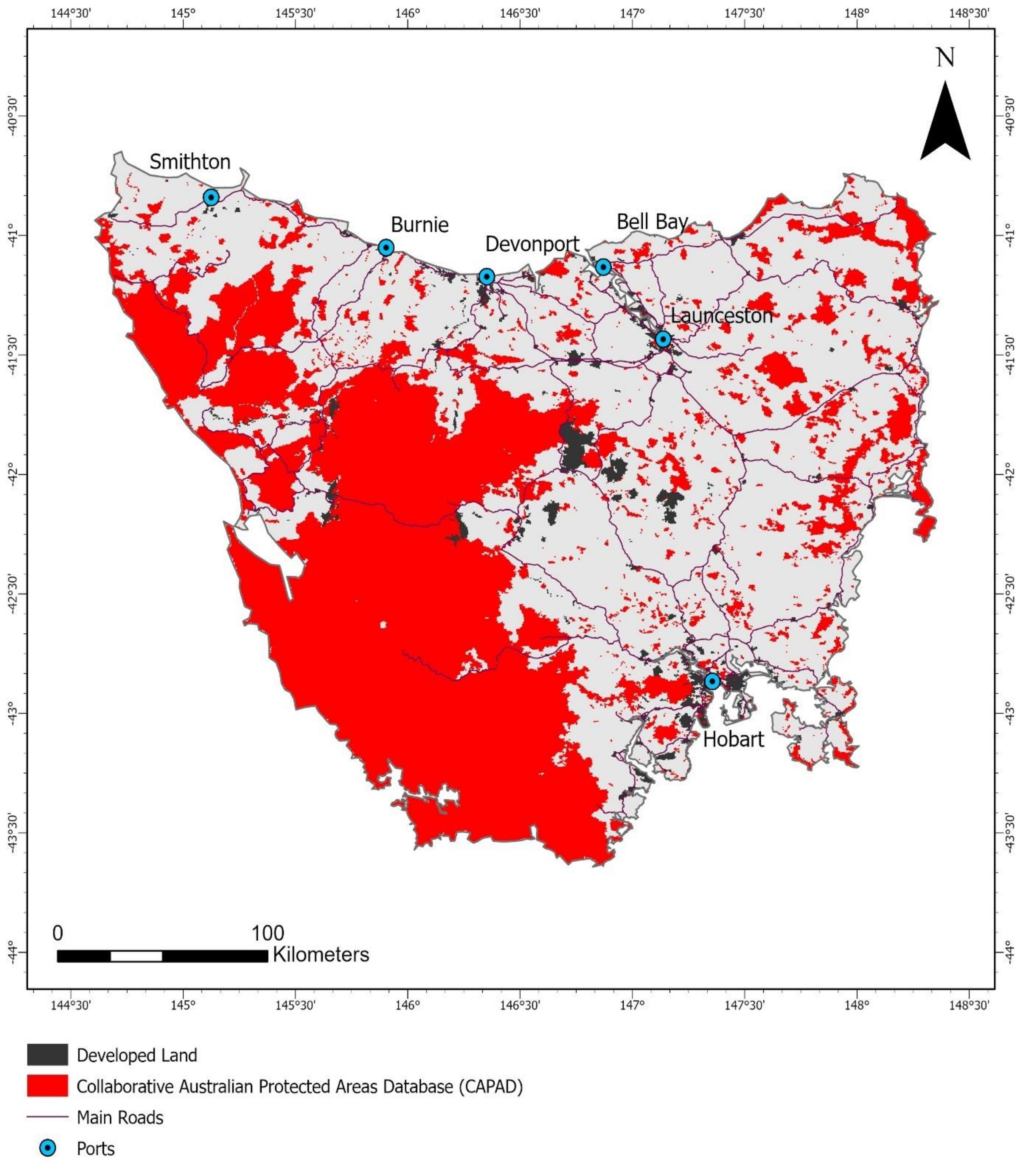

Figure 9.10 Tasmania Restricted Land (Geological Society of Australia

Figure 9.11 maps the reclassified land use classifications for Tasmania.

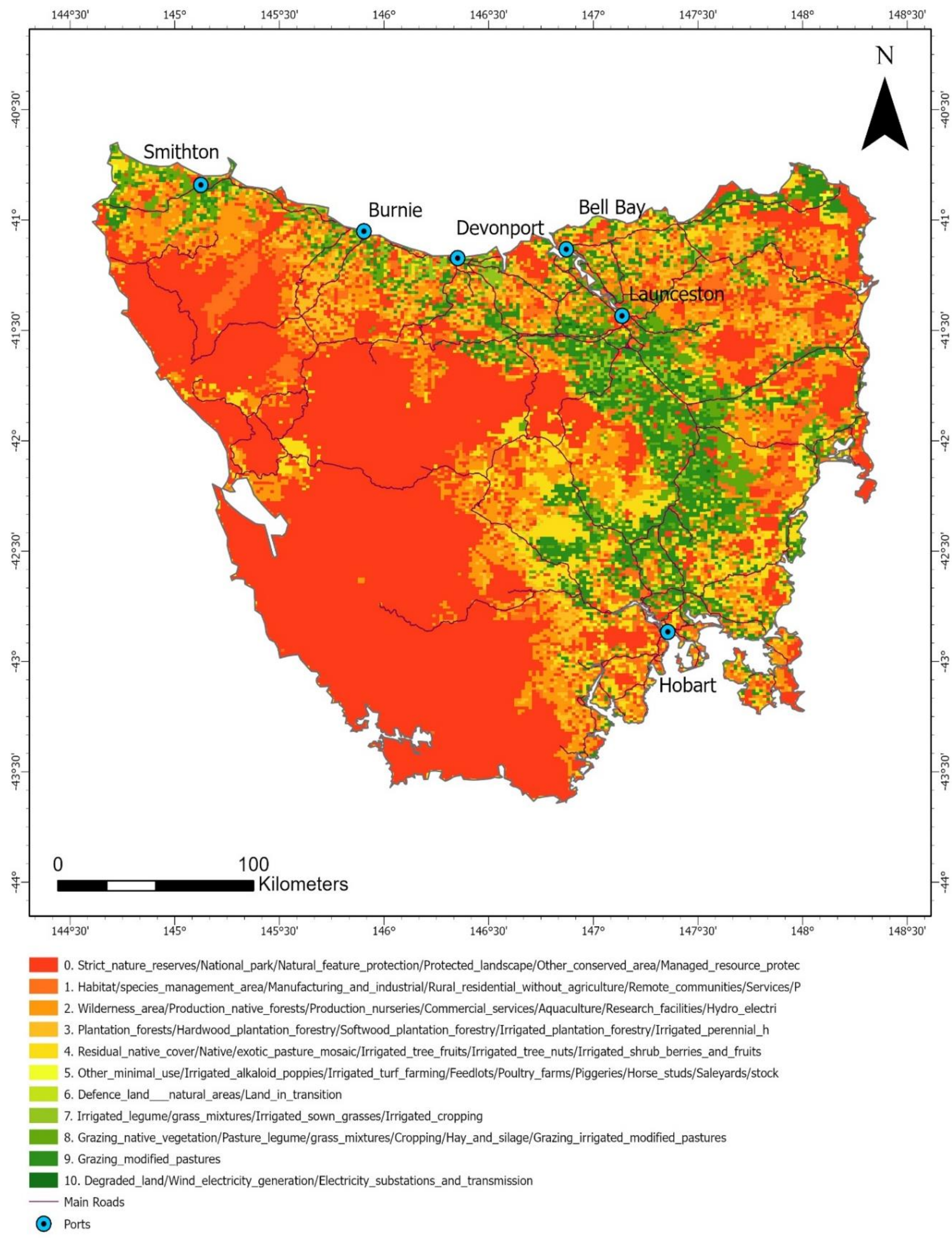

Figure 9.11 Tasmania Reclassified Land Use (Tasmania Department of Primary Industries)

Figure 9.12 maps the Euclidean distance to main roads within the Tasmania.

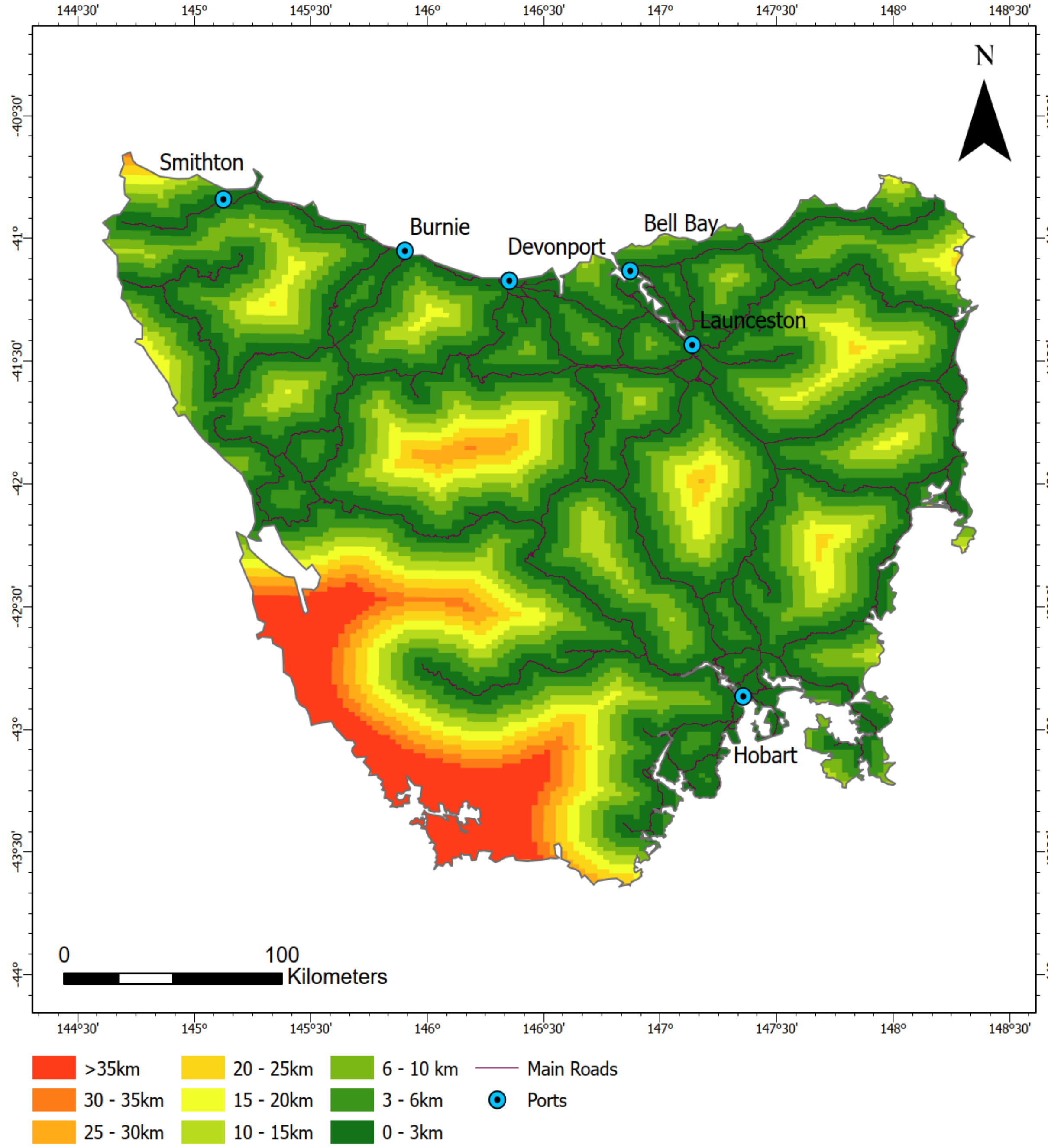

Figure 9.12 Tasmania Reclassified Proximity to Main Roads (Tasmanian Government List Data)

Figure 9.13 maps the Euclidean distance to power infrastructure within the Tasmania.

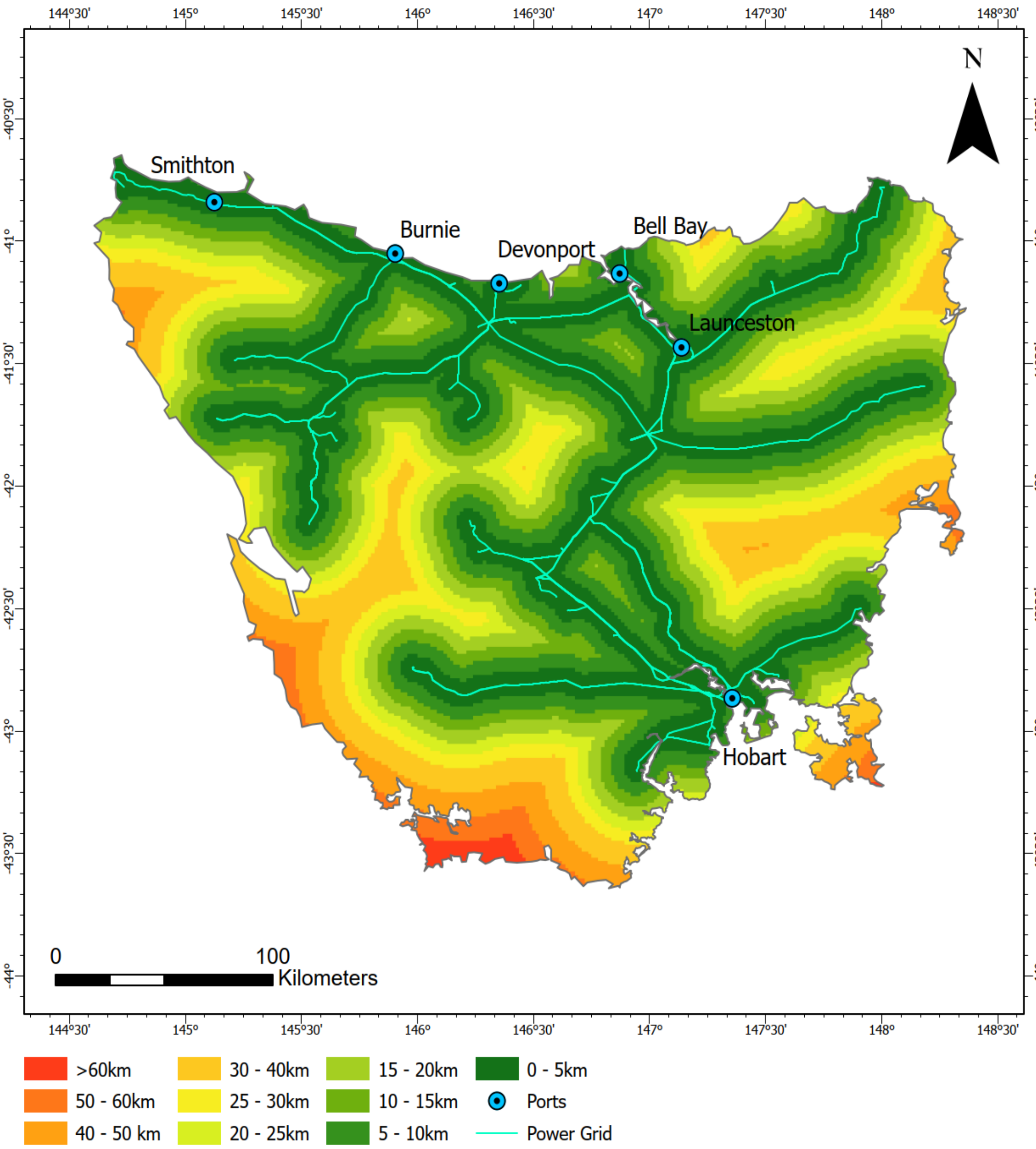

Figure 9.13 Tasmania Reclassified Proximity to Existing Power Infrastructure (Tasmanian Government List Data)

Figure 9.14 maps the Euclidean distance to the Tasmania coast.

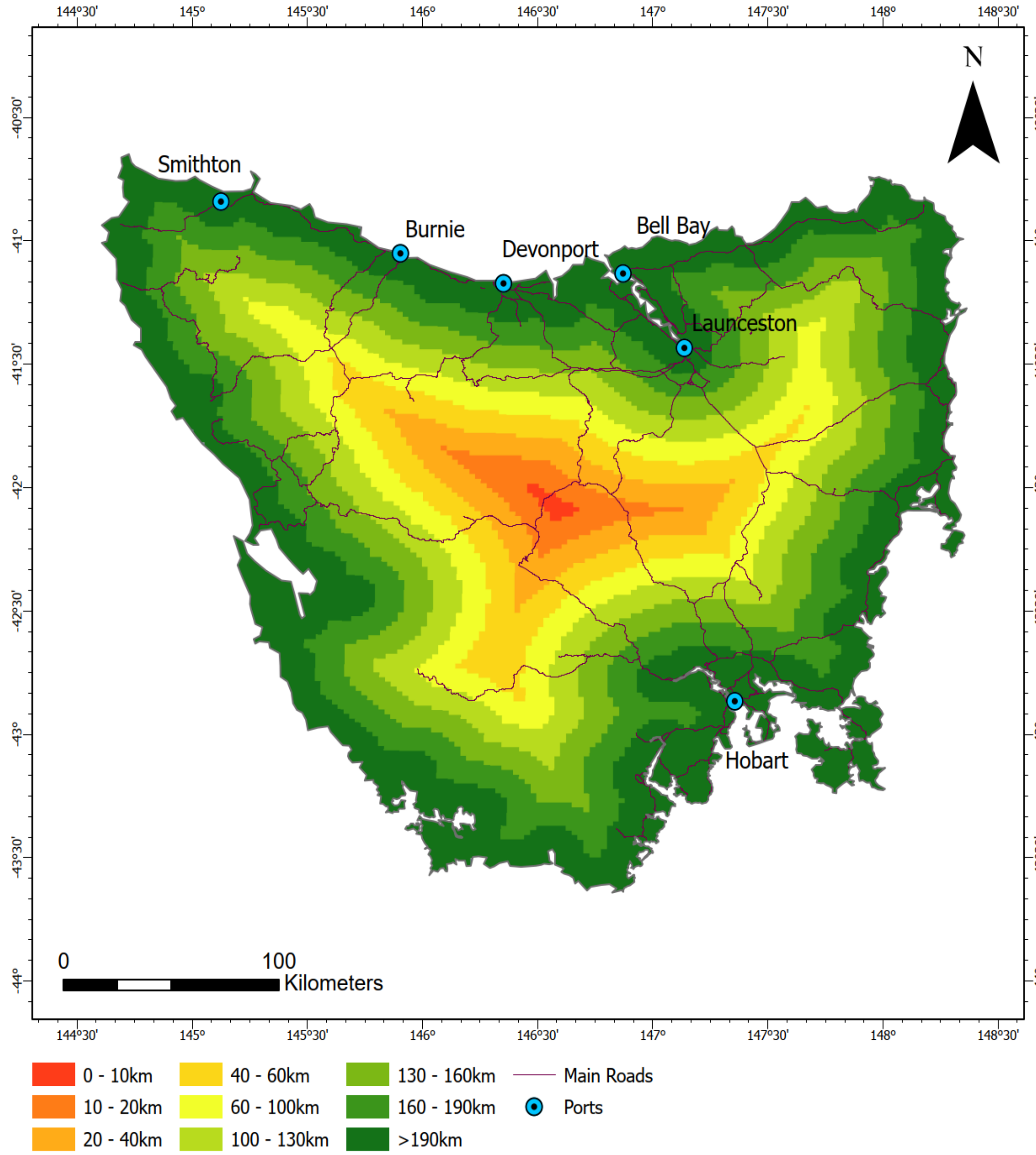

Figure 9.14 Tasmania Reclassified Proximity to Coast (Geological Society of Australia) (Esri)

Figure 9.15 maps the Euclidean distance to Tasmanian ports.

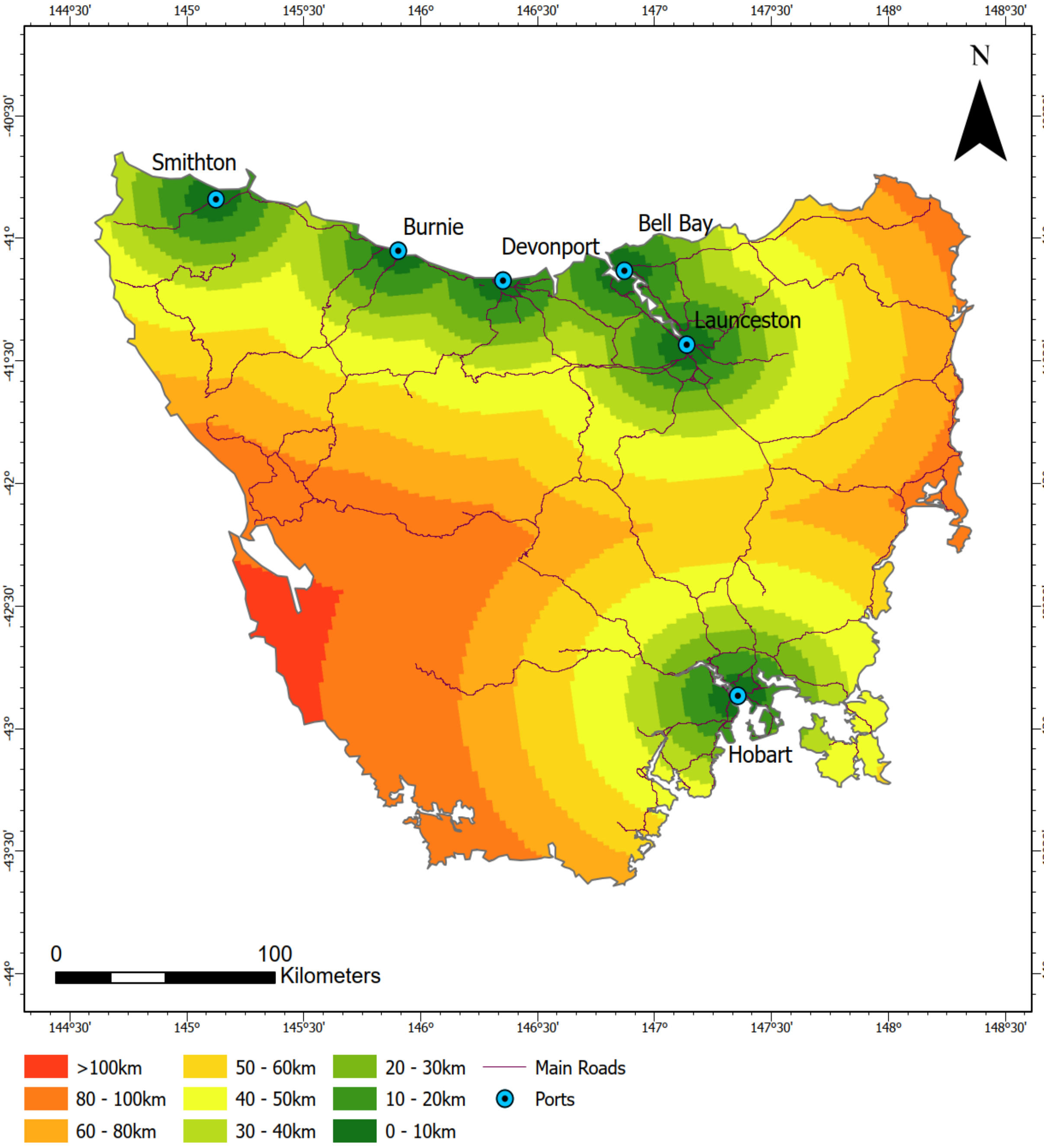

Figure 9.15 Tasmania Reclassified Proximity to Existing Ports (Esri)

Appendix D Gladstone Region Suitability Assessment: Comparison of Suitability Classification Areas

Figures 9.16-9.18 present the areas calculated within the Gladstone region search area for each suitability classification ranging from unsuitable land to very high suitability land.

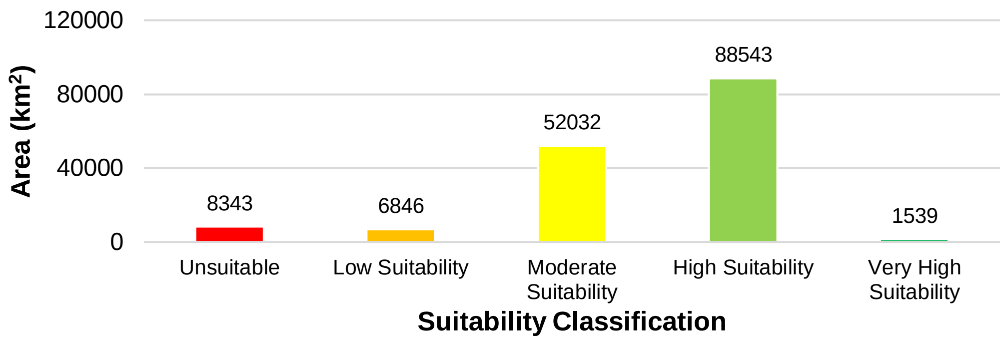

Figure 9.16 Gladstone Dedicated Renewables Model: Suitability Classification Areas

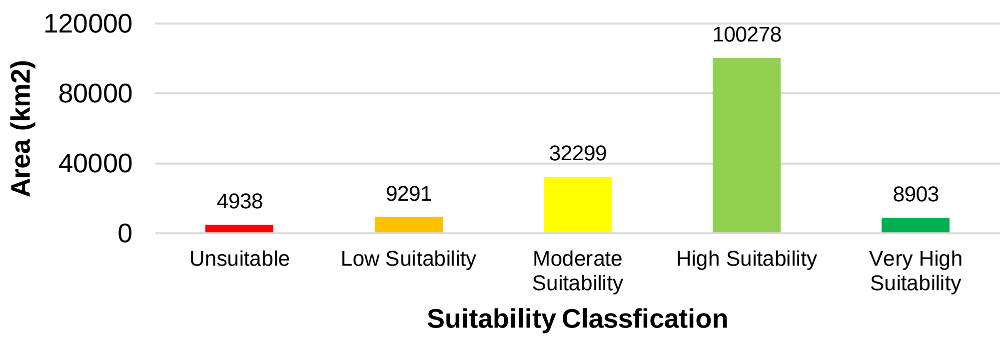

Figure 9.17 Gladstone Grid Connected Model: Suitability Classification Areas

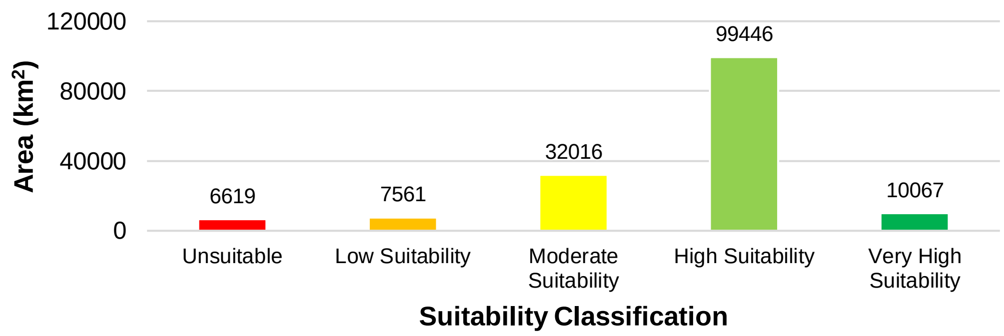

Figure 9.18 Gladstone Constructability Model: Suitability Classification Areas

Appendix E Tasmania Suitability Assessment: Comparison of Suitability Classification Areas

Figures 9.19-9.21 present the areas calculated within the Tasmania search area for each suitability classification ranging from unsuitable land to very high suitability land.

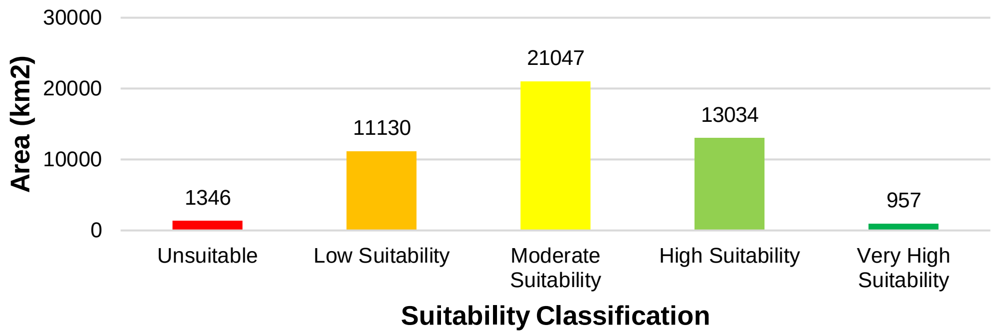

Figure 9.19 Tasmania Dedicated Renewables Model: Suitability Classification Areas

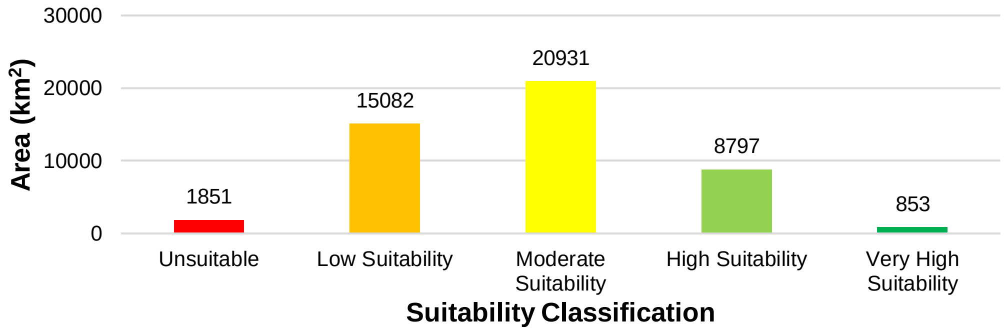

Figure 9.20 Tasmania Grid Connected Model: Suitability Classification Areas

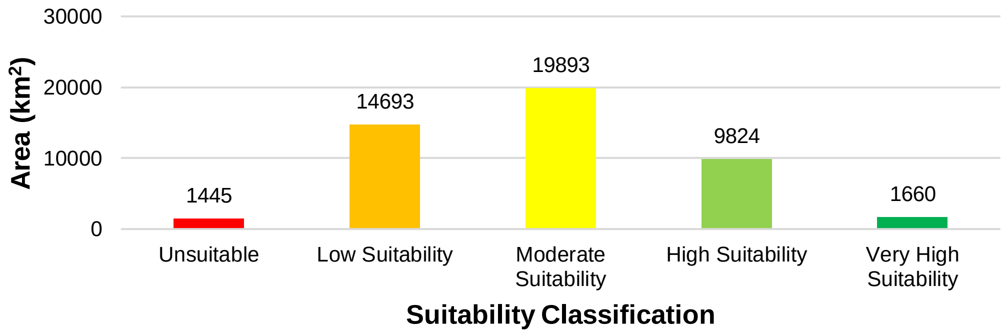

Figure 9.21 Tasmania Constructability Connected Model: Suitability Classification Areas

Appendix F Gladstone Region Suitability Assessment Histogram Results

Figures 9.22-9.24 present the distribution of suitability scores for Gladstone Region suitability models. Pixel count refers to the number of raster pixels classified for a given suitability score range.

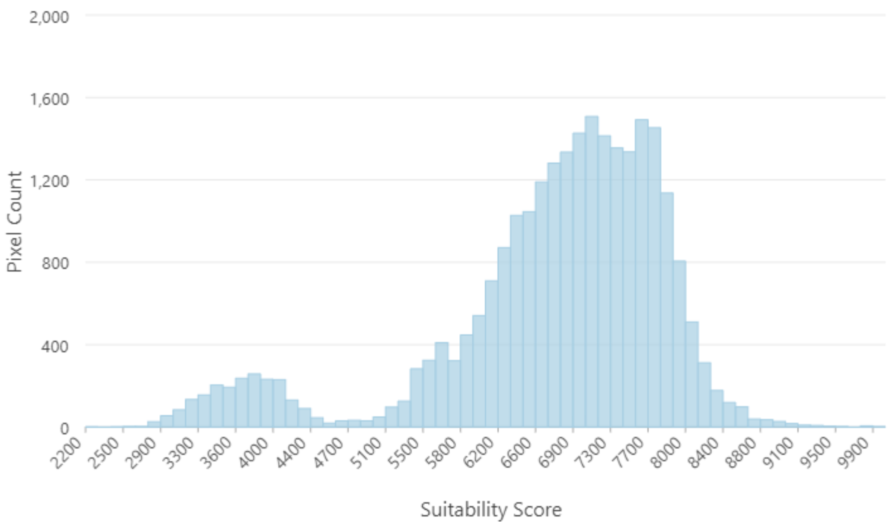

Figure 9.22 Suitability Assessment Histogram for Gladstone Region Dedicated Solar Farm Sites

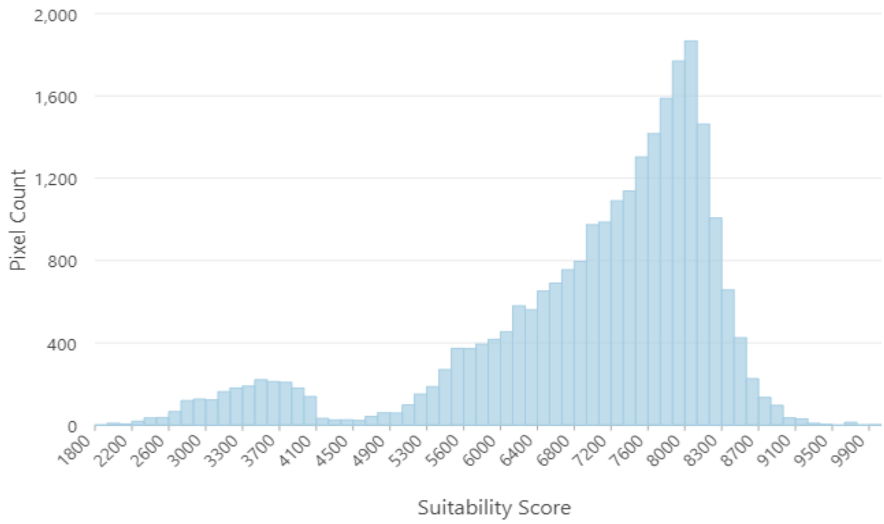

Figure 9.23 Suitability Assessment Histogram for Gladstone Region Grid Connected Solar Farm Sites

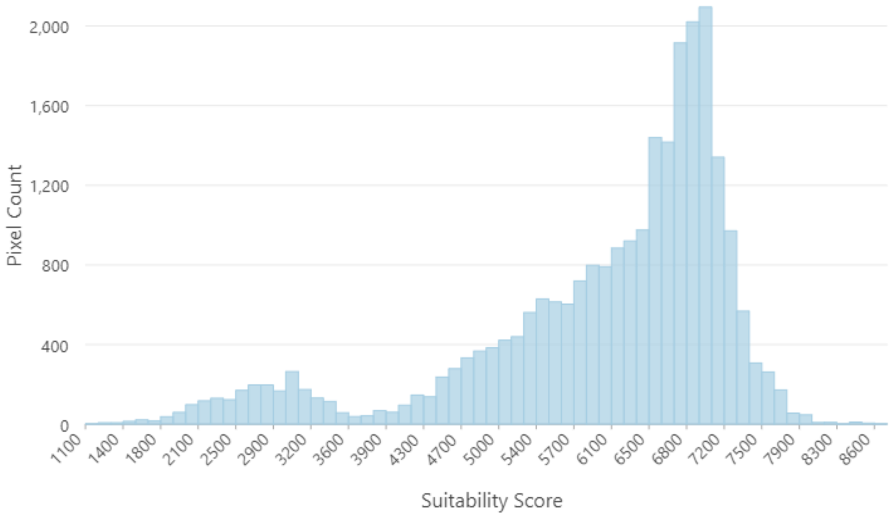

Figure 9.24 *Suitability Assessment Histogram for Highly Constructible Gladstone Region Grid Connected Solar Farm Sites*

Appendix G Tasmania Suitability Assessment Histogram Results

Figures 9.25-9.27 present the distribution of suitability scores for Tasmania models. Pixel count refers to the number of raster pixels classified for a given suitability score range.

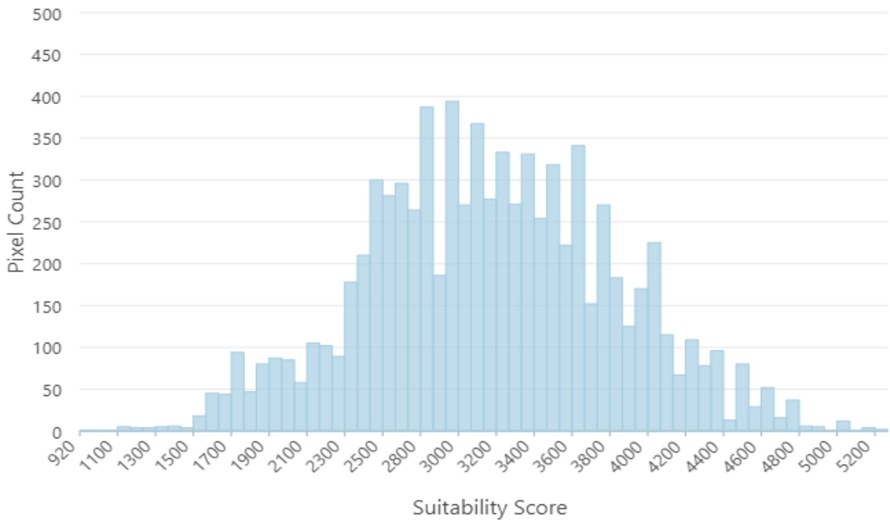

Figure 9.25 Suitability Assessment Histogram for Tasmania Dedicated Wind Farm Sites

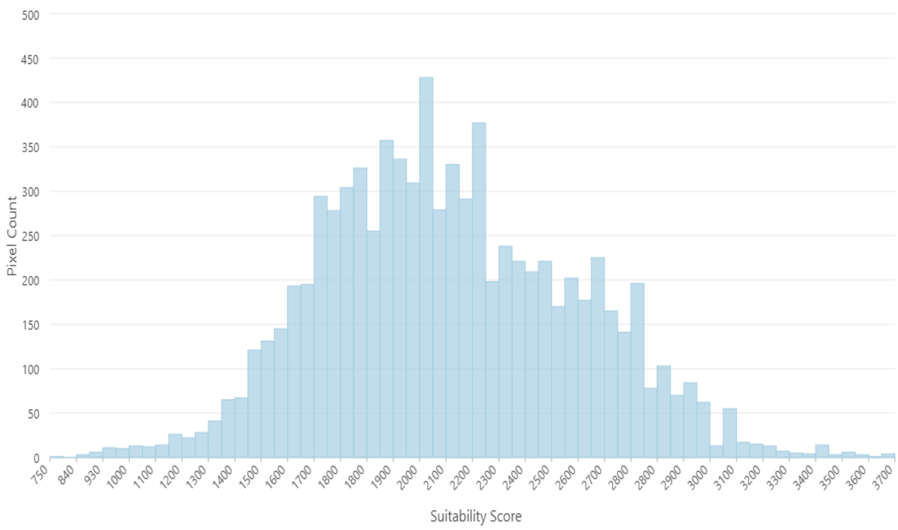

Figure 9.26 Suitability Assessment Histogram for Tasmania Grid Connected Wind Farm Sites

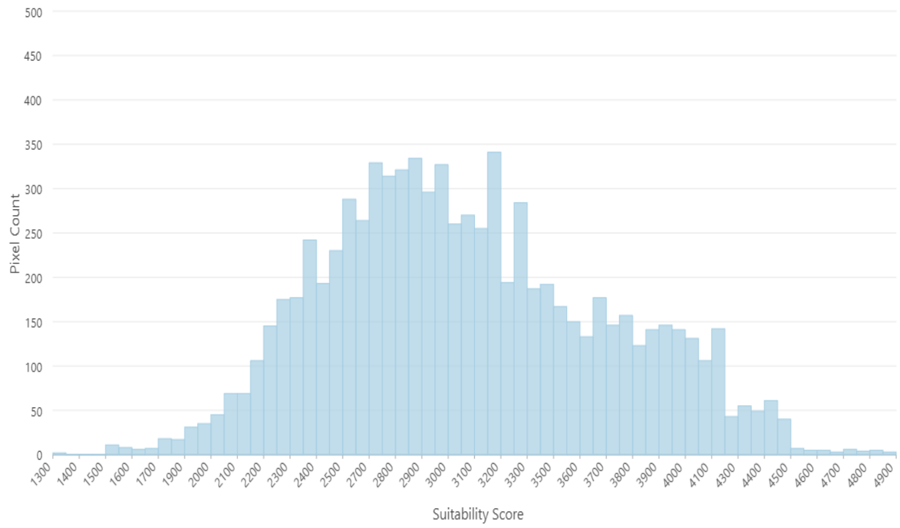

Figure 9.27 *Suitability Assessment Histogram for Highly Constructible Tasmania Grid Connected Wind Farm Sites*