Multi-Criteria Scoring for Identification of Renewable Energy Zones

Australian Energy Market Operator

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Task and objective: Wind and solar resource modelling and multi-criteria scoring or Renewable Energy Zones (REZ) over Eastern Australia.

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1 INTRODUCTION

The Australian Energy Market Operator (AEMO or "the Customer") has requested that DNV GL Australia Pty Ltd (DNV GL) provide support with the identification of potential Renewable Energy Zones (REZs) within the eastern part of Australia; as outlined in Figure 1.

In order to address the Customer's needs, DNV GL has utilised mesoscale wind flow modelling previously generated by DNV GL, in the form of a wind speed map with a horizontal resolution of approximately 5 km, at a height of 150 m above ground level. In addition, solar resource data was obtained from the Bureau of Meteorology (BoM) solar irradiance database, and defines the solar Global Horizontal Irradiance (GHI) and Direct Normal Irradiance (DNI) with a horizontal resolution of approximately 5 km.

The wind and solar resource grids were combined with a number of constraints in order to identify areas with above average potential for deployment of grid-connected wind, solar and/or hybrid electricity generation plants.

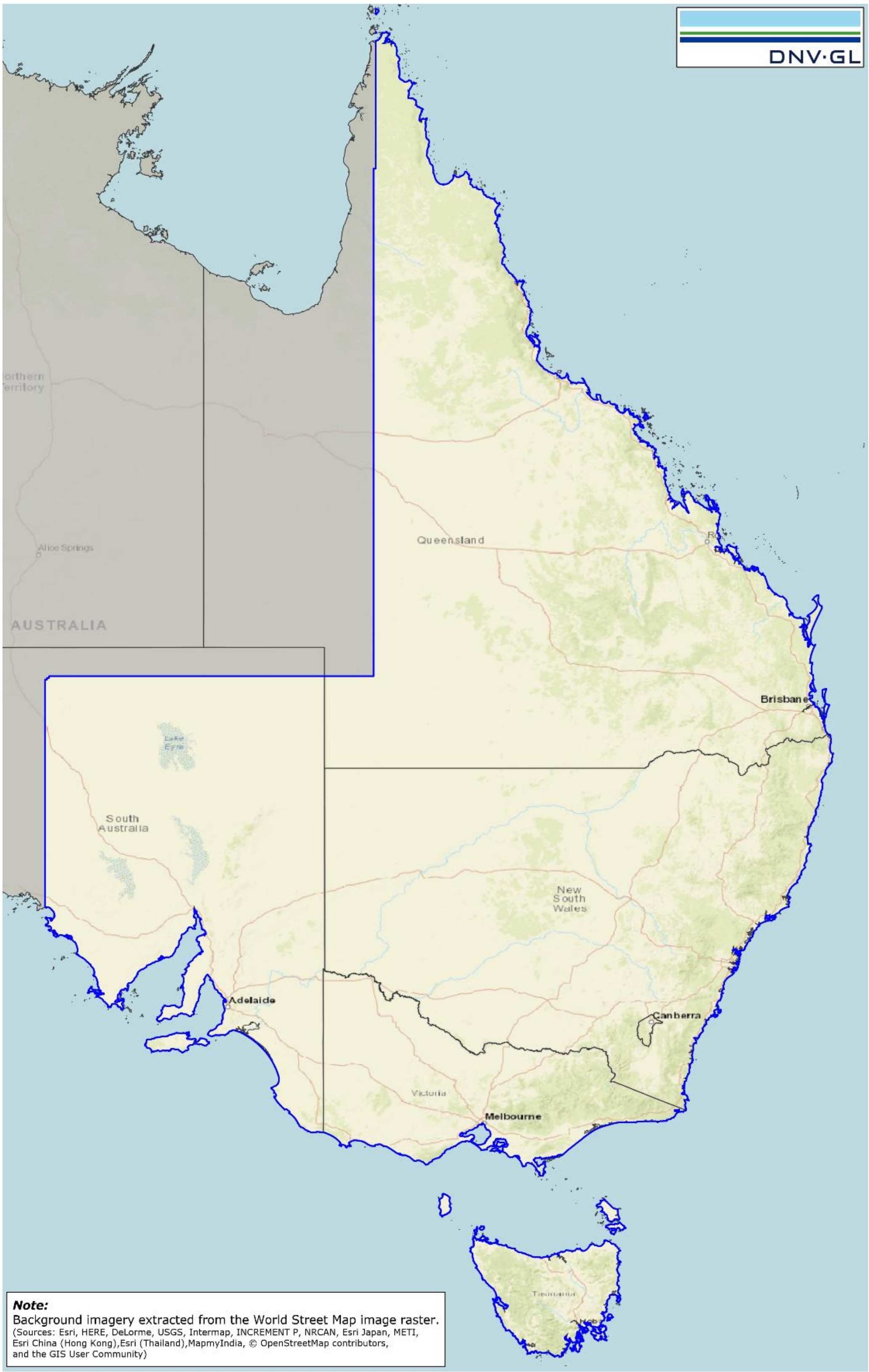
As part of the scoring process, virtual time series of the solar and wind resources were also compiled to provide a high-level overview of the ability of the wind and solar resources to meet electricity demand; based on average historical diurnal and seasonal demand profiles.

This report is issued to the Customer, and has been prepared pursuant to DNV GL proposal L2C-152142-AUME-P-01-E, dated 08th September 2017, and is subject to the terms and conditions contained in the Assignment agreed between DNV GL and AEMO.

2 MODELLING AREA OVERVIEW

The area for the resource mapping and scoring process covers the Australian Capital Territory, New South Wales, Victoria, Tasmania, as well as parts of Queensland and South Australia, as shown in Figure 1.

Figure 1. Modelling area overview.



3 RESOURCE MODELLING

3.1 Wind speed

The mesoscale wind map was created using the DNV GL Wind Mapping Service (WMS), which is based upon the Weather Research and Forecasting (WRF) model. WRF is a state-of-the-art community model that has been thoroughly documented in open peer-reviewed literature [1]. As one of the most widely used mesoscale models within the wind energy industry [2, 3, 4], its performance for wind mapping applications is well understood. The WMS methods are based on over two decades of research and development, and the simulations are performed using a complete multi-year integration to yield a continuous hourly time series which accurately represents the full range of wind and thermal stratification conditions. The latest, accurate high resolution inputs are used to drive the simulations, including 3-hourly and daily estimates of soil temperature and moisture, sea surface temperature, sea ice and snow depth, in conjunction with a sophisticated and proven land surface model (LSM), to accurately predict the land and ocean surface heat and moisture fluxes that drive the winds within the boundary layer.

The modelling was conducted to provide wind speed data sets for the AREMI Project [5]. To create these data sets, DNV GL has made use of NASA's Modern-Era Retrospective Analysis for Research and Applications (MERRA) reanalysis data set to define the climate inputs into the WMS model. DNV GL has used reanalysis datasets (including MERRA) for wind resource assessments worldwide, and has a thorough understanding of the quality and suitability of these datasets for use as a long-term reference. It is noted that the MERRA dataset has recently been superseded by the second generation MERRA-2 reanalysis data set.

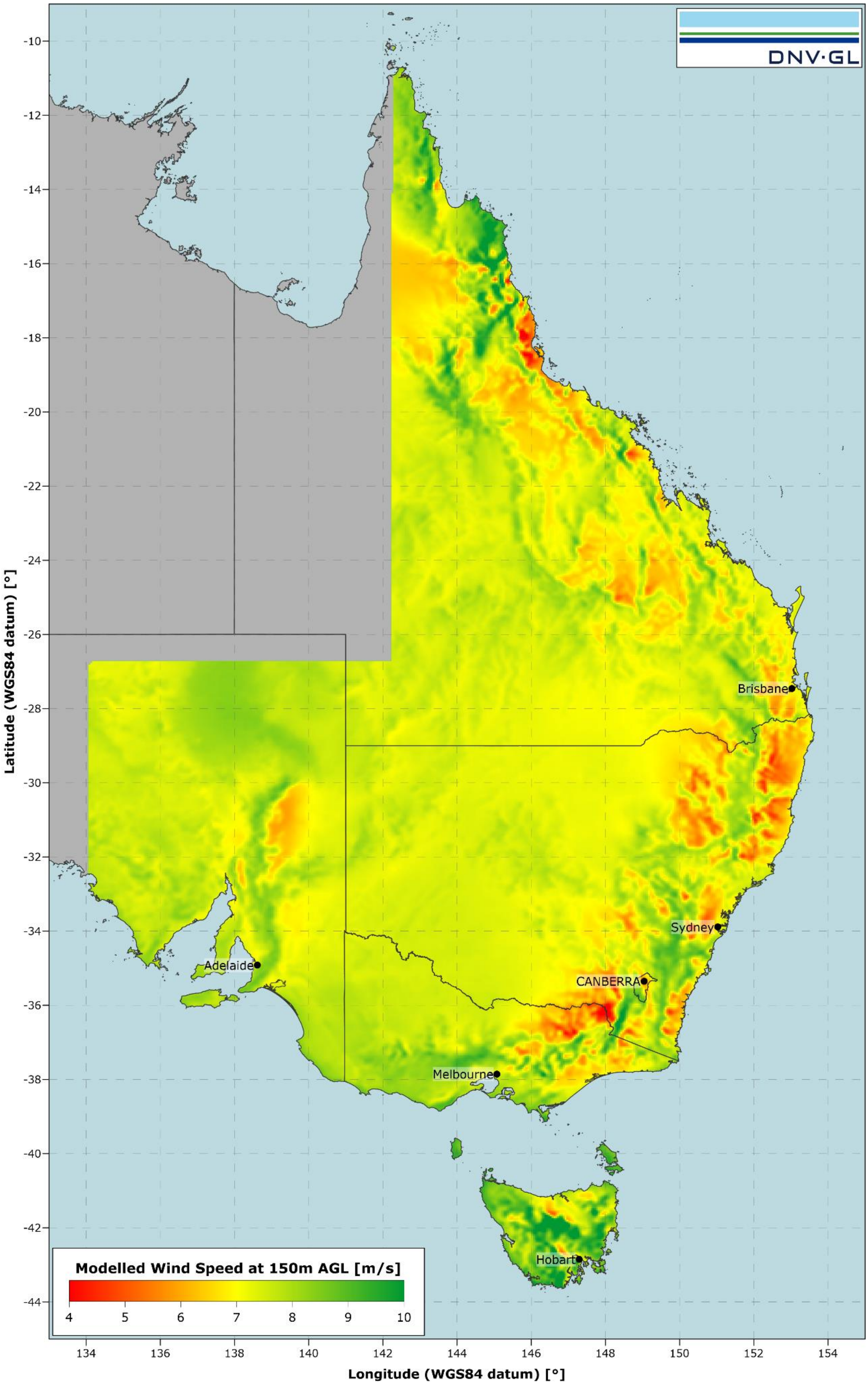
3.1.1 Mesoscale meteorological modelling

The mesoscale variation in wind speed over the modelled domain has been predicted using the WMS. The results are based on a complete multi-year integration that accurately represents the full range of wind and thermal stratification conditions over the selected area, and allows the hourly, daily, seasonal and up to inter-annual variations to be fully quantified.

The WMS has produced hourly time series of wind speed and wind direction at every point over the modelled domain at approximately 5 km horizontal resolution, and spanning a period of 10 years. These outputs were then used to compile wind statistics and assess the potential match with the expected demand, as discussed in Section 4.3.

It should be noted that the wind speed map, presented in Figure 2, and times series resulting from the modelling process have not been validated against measurements, and the absolute wind speed values extracted from these deliverables should be considered with caution due to the uncertainty inherent in the modelling process, as discussed in more detail in Section 3.1.2.

Figure 2. Modelled mesoscale wind speed map at 150 m



3.1.2 Consideration of wind modelling uncertainty

As described in Section 3.1.1, the mesoscale wind map was created using the latest state-of-the-art techniques and the highest quality up-to-date input datasets available at the time the modelling was conducted for the AREMI Project [5]. This mesoscale wind speed database consists of a continuous hourly time series at each 5 km grid cell for the entire 10-year modelled period. While it represented the best possible estimate of the wind resource within the region available at the time, it must be stressed that the mesoscale map is in no way intended to replace measurements. On-site measurements at standard turbine hub heights are essential to any wind resource assessment project. Also, even though this dataset was created using the latest advances in mesoscale modelling, it does have inherent limitations.

Firstly, small localised landscape features are poorly resolved or not resolved at all. For instance, narrow canyons or inlets, isolated mountains and bluffs, or small clearings in forested areas are not resolved by this dataset. As a general rule of thumb, the WRF model is capable of resolving spatial variations in the wind field at scales ranging from about 3 to 7 grid lengths [6].

Secondly, mesoscale weather prediction models are not complete and true representations of the workings of the real atmosphere, owing to science's incomplete knowledge of the myriad of governing physics. Uncertainty also arises because the atmosphere can never be completely or perfectly observed, either in terms of spatial-temporal coverage or accuracy of the measurements. This leads to a variety of unavoidable errors and uncertainties in the modelling process including:

- necessarily imperfect input datasets, based on incomplete measurements;
- numerical approximations used in the dynamical core of the model;
- necessarily imperfect spatial and temporal discretization of the real atmosphere;
- imperfect representation of the various physical processes including, clouds, rainfall, solar radiation, land surface processes, atmospheric boundary layer processes; and
- inherently limited predictability of the real atmosphere, particularly at the smaller length and time scales.

It is not considered appropriate to formally quantify the uncertainty associated with the results presented here, but due to the uncertainty associated with the modelling process, DNV GL recommends that the results are used for pre-feasibility purposes only.

In addition, it should be noted that no measured wind data has been supplied and therefore the results are based on modelling only and have not been verified or validated using measurements. This should be considered when interpreting the wind speed map produced.

3.2 Solar irradiation

The Solar resource was compiled from the Australian Bureau of Meteorology (BoM) hourly direct normal irradiance and global horizontal solar irradiance database [7]; which includes satellite-derived solar irradiance at a resolution of approximately 5 km over the whole of Australia.

The annual average irradiance (GHI and DNI) maps over the 2005 to 2016 period resulting from this process are presented in Figure 3 and Figure 4.

Figure 3. Modelled annual solar GHI map

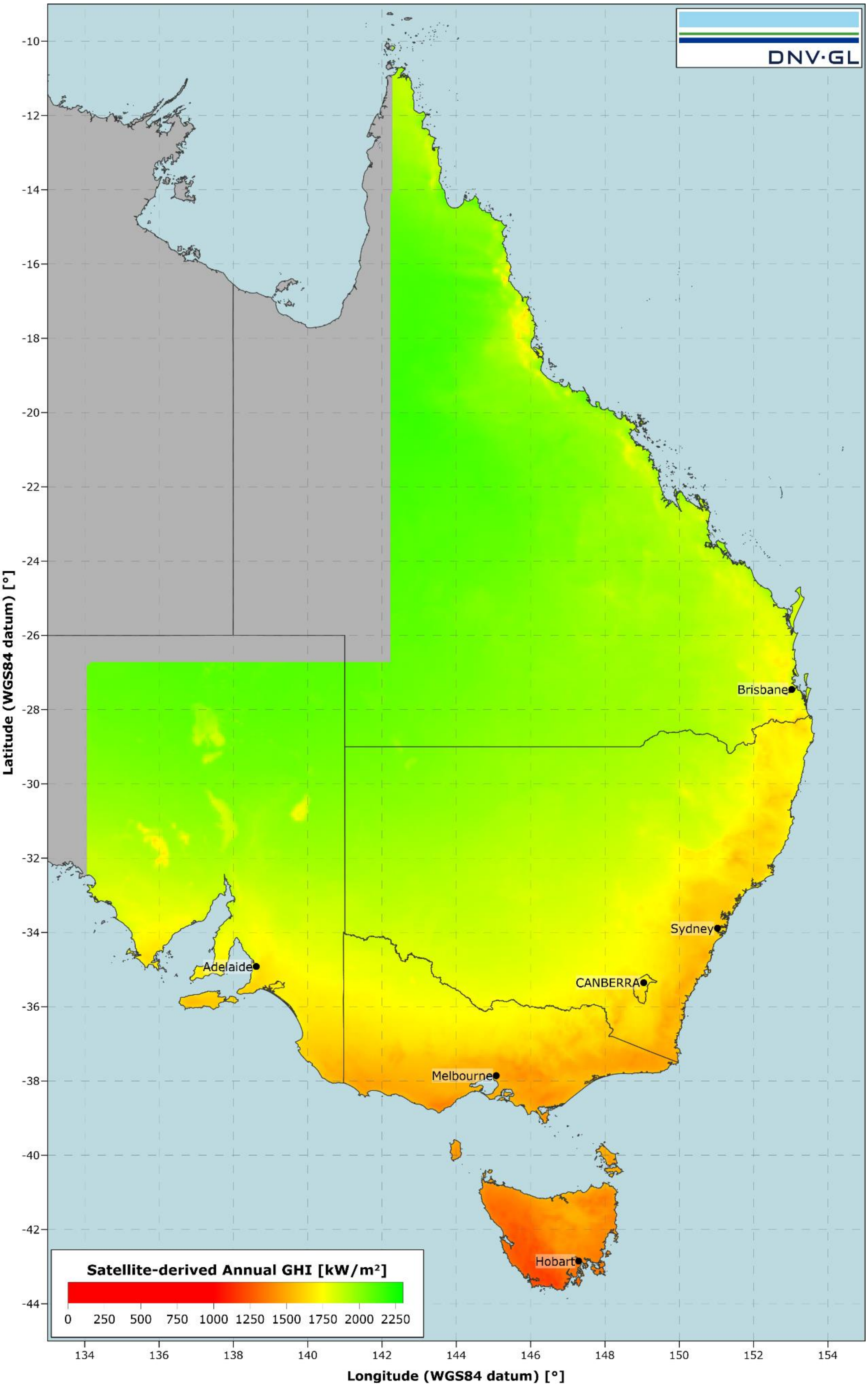
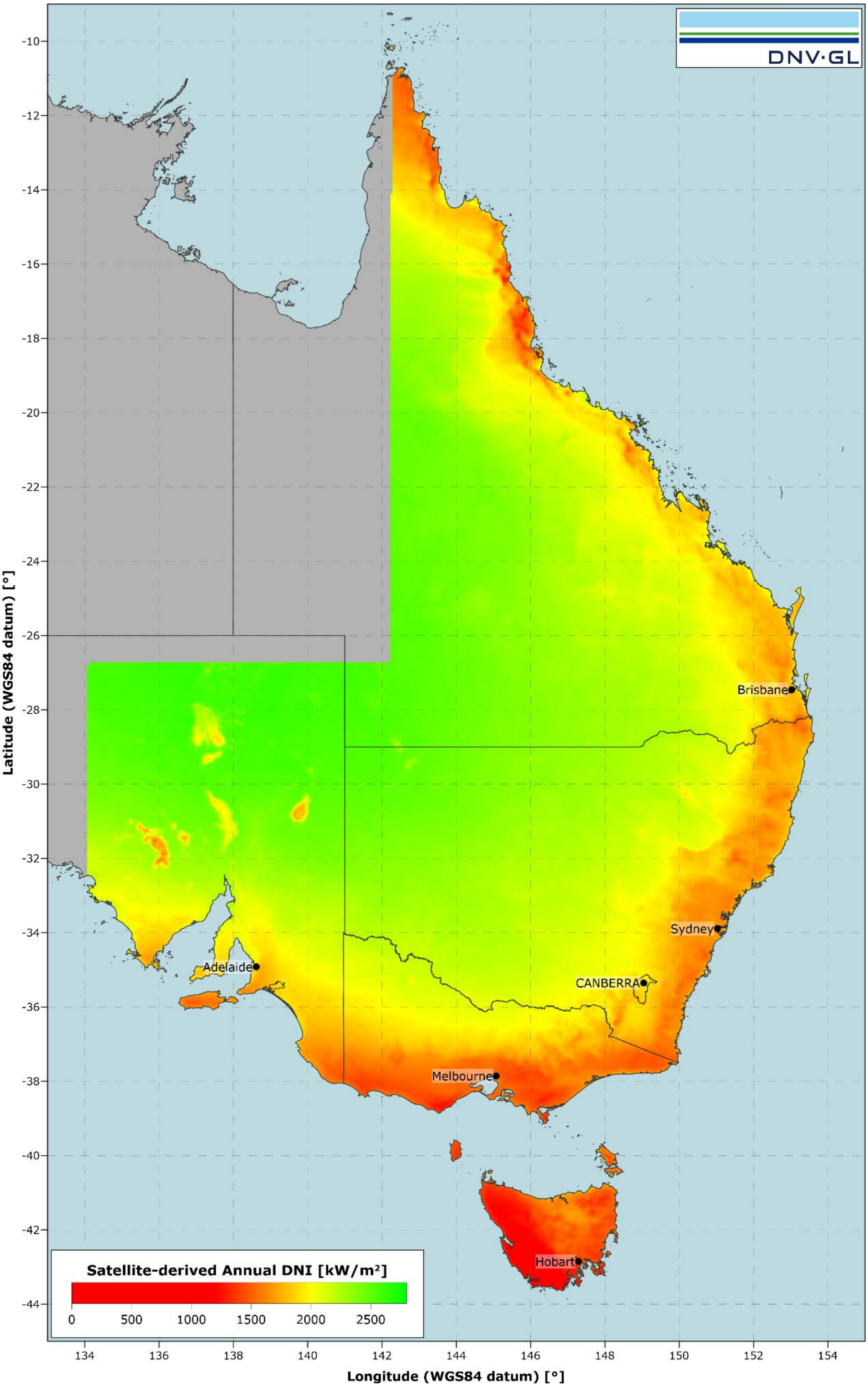


Figure 4. Modelled annual solar DNI map



4 IDENTIFICATION OF RENEWABLE ENERGY ZONES

The wind and solar resource maps described in section 3 have been used to identify areas with increased potential for the deployment of grid-connected wind, solar or hybrid (i.e., combined wind and solar) energy generation plant, through the use of a scoring process which considers a range of constraints that may influence the viability of such plant.

The area shown in Figure 1, was adopted as the site scoring area, and the modelled resources were combined with a number of constraints in order to assess the potential of each grid point for the deployment of wind, solar or hybrid energy generation plant. A separate scoring process has been used to assess the potential for wind, solar or hybrid (wind & solar) plant.

When assessing the suitability of potential sites for wind and solar energy generation, many issues must be considered, including: the nature of the wind and solar resource, access to the electricity network, restricted or protected land areas and others. The site identification study conducted here attempts to quantify these considerations and provide a graphical representation of areas suitable or unsuitable to development. A grid of 5 km horizontal resolution was generated over the study area, and each grid cell assigned scores based on the constraint scoring discussed in the following sections.

4.1 Constraints considered

The constraints considered for the scoring process are listed in Table 1.

Table 1. Site scoring constraints

Constraint	Format	Source
Wind resource	Data Grid	DNV GL
Solar resource	Data Grid	BoM [7]
Electrical network	Polylines	Geoscience Australia [8]
Cadastral parcel density	Image Raster	Geoscience Australia [9]
Land cover	Image Raster	Geoscience Australia [9]
Roads	Polylines	Geoscience Australia [10]
Terrain complexity	Data Grid	SRTM Global Digital Elevation Model (DEM) [11]
Airports and airfields	Points	OurAirports [12]
Population density	Image Raster	Australia Bureau of Statistics [13]
Protected areas	Polygons	Department of the Environment and Energy [14]

When relevant, and the necessary data attributes were available, the features of the constraints listed in Table 1 were categorised, and a constraint-specific score was calculated for each cell of the survey grid.

4.2 Constraint score calculations

Two scoring methods were used, depending on the nature of the constraint, as described in Table 2. Each constraint is discussed in detail in the following sub-sections.

This process resulted in a score ranging from 0 to 1 for each constraint; with 0 being least desirable and 1 begin most desirable. Grid points located within exclusion areas were assigned a score of -1.

Table 2. Site scoring methods

Scoring approach	Description
Distance scoring	This scoring method was used to assign a score based on the distance from a grid point to an object. The distance from each point in the grid to the nearest object was calculated, and the score evaluated as a function of that distance and. This method was used to calculate scores associated with all the constraints defined by points, polylines or polygons.
Grid point scoring	This method involved calculation of a score based on a quantity known at each point in the grid. This method was used for assigning a score for all grid-formatted constraints.

4.2.1 Wind resource

The wind speed grid described in Section 3.1 was normalised based on a linear ramp going from a score of 0 at 6 m/s to a score of 1 at 9 m/s.

4.2.2 Solar resource

Similarly, to the wind resource, the solar irradiation grids described in Section 3.2 were assigned a score ramp going from 0 to 1. The GHI grid used a linear ramp from 0 to 1 over the 1600 kW/m^2 to 2100 kW/m^2 annual irradiation range, and this range was increased to 1800 kW/m^2 to 2500 kW/m^2 for the DNI grid.

4.2.3 Electrical network

The data set obtained from Geoscience Australia was used to calculate the distance from each survey cell to the nearest transmission line; with lines with a capacity of 66 kV and above considered. In order to reflect the benefit for a project to be developed in proximity to existing transmission infrastructure, all scoring points located within approximately 50 km for a line were assigned a score of 1, with the score then linearly ramping down to 0 at approximately 200 km.

4.2.4 Cadastral parcel density

In order to reflect the increased complexity of the development of a project involving a large number of land owners, an estimate of the parcel density within the area covered by each scoring point was generated based on the parcel line raster. A cubic ramp down of the score from 1 to 0 was assumed; with a value of 0 reached at an 80% density.

4.2.5 Land cover

The land cover classes from the 2014-2015 Dynamic Land Cover Dataset were used to assess the potential impact of land cover on project viability, and this was done in a 2-step process.

The first factor, contributing to 75% of the land cover score, assess the possible exclusion areas due to land cover; with the following classes assumed as exclusion areas: "*No Data*", "*Extraction Sites*", "*Inland Waterbodies*", "*Salt Lakes*", "*Wetlands*" and "*Urban Areas*". As with land fragmentation, a cubic ramp down of the score from 1 to 0 was assumed; with a value of 0 reached at an 80% density of area considered as exclusion.

The second factor, contributing to the remaining 25% of the land cover score, assess to a higher level the preference to develop project in certain type of land more than others. The vegetation class covering the majority of each survey cell was assessed, and a reduced score was assigned to forested areas and areas with prime potential for crops.

4.2.6 Roads

The data set obtained from Geoscience Australia defines polylines representing road centrelines. Scoring was assigned to all survey cells based on their proximity to roads, linearly ramping down from 1 to 0 over a distance range of 10 km to 50 km.

4.2.7 Terrain complexity

The digital elevation model (DEM) used to assess the terrain complexity and slope aspect was obtained from the Shuttle Radar Topography Mission (SRTM) data, which provides near-global coverage of terrain elevation at a horizontal resolution of 1 arc-second, or approximately 30 m.

The terrain complexity was assessed by calculating the terrain slope at each point of the DEM, and then calculating the median of these values within the area covered by each scoring point. The terrain complexity, considered in a similar manner for both the wind and solar scoring, was assigned a cubic ramp down of the score from 1 to 0 was assumed; with a value of 0 reached at a median slope of 15°.

The terrain aspect (i.e. the compass direction where the slope faces) was only considered for the solar component of the scoring process, and only when the median slope angle was above 3°. The percentage of points within each score cell where the DEM slope aspect was within 20° from North was calculated and a cubic ramp of the score from 0 to 1 was assumed; with ramp starting at 40%, and reaching 1 at 100%.

4.2.8 Airports and airfields

The information obtained from *OurAirport* defined point locations for a number of air service facilities throughout the survey area. The features were categorised depending on the type of facility it defined, and exclusion zones with a 6 km to 10 km radius were defined for wind and hybrid generation scoring. The size of these exclusion zones was reduced by 50% for solar production to acknowledge the smaller impact these installations have on air traffic. All grid points located outside these exclusion areas were assigned a score of 1.

4.2.9 Population density

The average and maximum population density within each scoring cell was compiled from the ABS 2011 and 2016 Australian population density raster. These four factors were then combined and normalised in order to obtain a score ranging from 0 to 1; with lower scores assigned to densely populated areas.

4.2.10 Protected areas

The 2014 Collaborative Australian Protected Area Database (CAPAD) was used to define polygons covering protected areas. Using these polygons, the percentage of protected areas found within each scoring cell was calculated, and a linear score ramp ranging from 0 to 1 was defined for coverage ranging from 50% to 0%. Scoring cells with more than 50% covered by protected areas were considered as exclusion.

4.3 Overall score calculations

The normalised score for all the constraints detailed in Section 4.2 were assigned a certain weight, and these were then all added together to obtain the total site survey score.

A high-level assessment on how well could the wind or hybrid generation could match demand on a seasonal and diurnal basis was conducted. It should be noted that, due to the nature of the resource, the solar only score calculation did not account for this parameter. Average seasonal and diurnal demand profiles were compiled for the entire survey area based on historical demand data provided by the customer [15]. The corresponding solar and wind resource profiles were then derived from the modelled data. For both the seasonal and diurnal demand trends, an algorithm was developed to iteratively optimise the wind and solar generation capacity needed to best match the average demand trend. This was conducted for each scoring cell and a score was assigned based on proportion of demand met by the optimised wind and solar generation capacity. A normalised score value was then calculated from the average diurnal and seasonal cases.

Details about the contribution of each constraint to the wind, solar and hybrid scores are provided in Table 3.

Table 3. Constraints weighting

Constraint	Weighting for ... score?		
	Wind	Solar (GHI & DNI)	Hybrid[3]
Wind resource	35%	-	30%
Solar resource	-	30%	
Demand matching	5%	-	5%
Electrical network	10%	10%	10%
Cadastral parcel density	10%	10%	10%
Land cover	5%	10%	10%
Roads	5%	5%	5%
Terrain complexity[1]	10%	15%	10%
Airports and airfields[2]	0%	0%	0%
Population density	10%	10%	10%
Protected areas	10%	10%	10%

Note:

1. *Terrain aspect contribution not considered for the calculation of the wind score.*
2. *No contribution to the overall score calculation apart from exclusion areas*
3. *Two separate cases of resource split was considered for the hybrid score calculation: 60% wind/40 solar or 70% wind/30% solar.*

The resulting score maps; for wind, solar and hybrid systems, are presented in Figure 5 to Figure 9. It is noted that at the request of the Customer, these maps exclude consideration of scoring associated with proximity to the electrical network

In addition to these scoring maps, DNV GL has produced maps highlighting areas of high development potential, based on the scoring approach detailed earlier in this document. These maps, presented in Appendix A, show the grid points which have scores above and below range of P*{#}* probability of exceedance value, meaning the highest *{#}*% of scores.

It should be noted that, the results of the scoring process are based on a desktop study considering a limited selection of constraints. As such, the areas identified as having good development potential should be considered as indicative, and a review of this process considering a different set of constraints may highlight different development areas.

Also, the areas highlighted by this assessment have been found to have high wind, solar or hybrid development potential relative to the survey area considered, but it does not necessarily provide confirmation of the financial viability of a project developed in these areas.

Figure 5. Site scoring map – wind

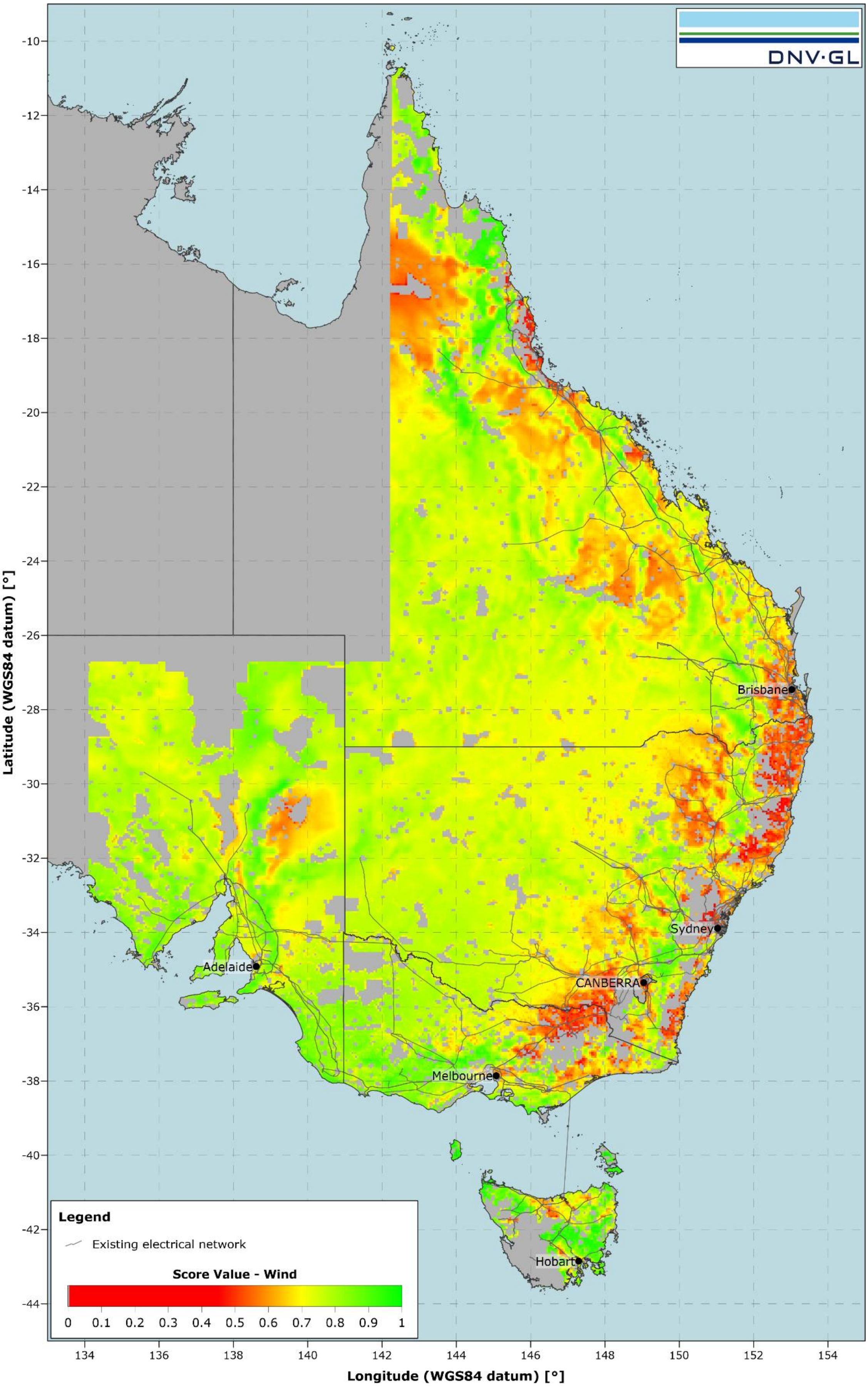


Figure 6. Site scoring map – solar GHI

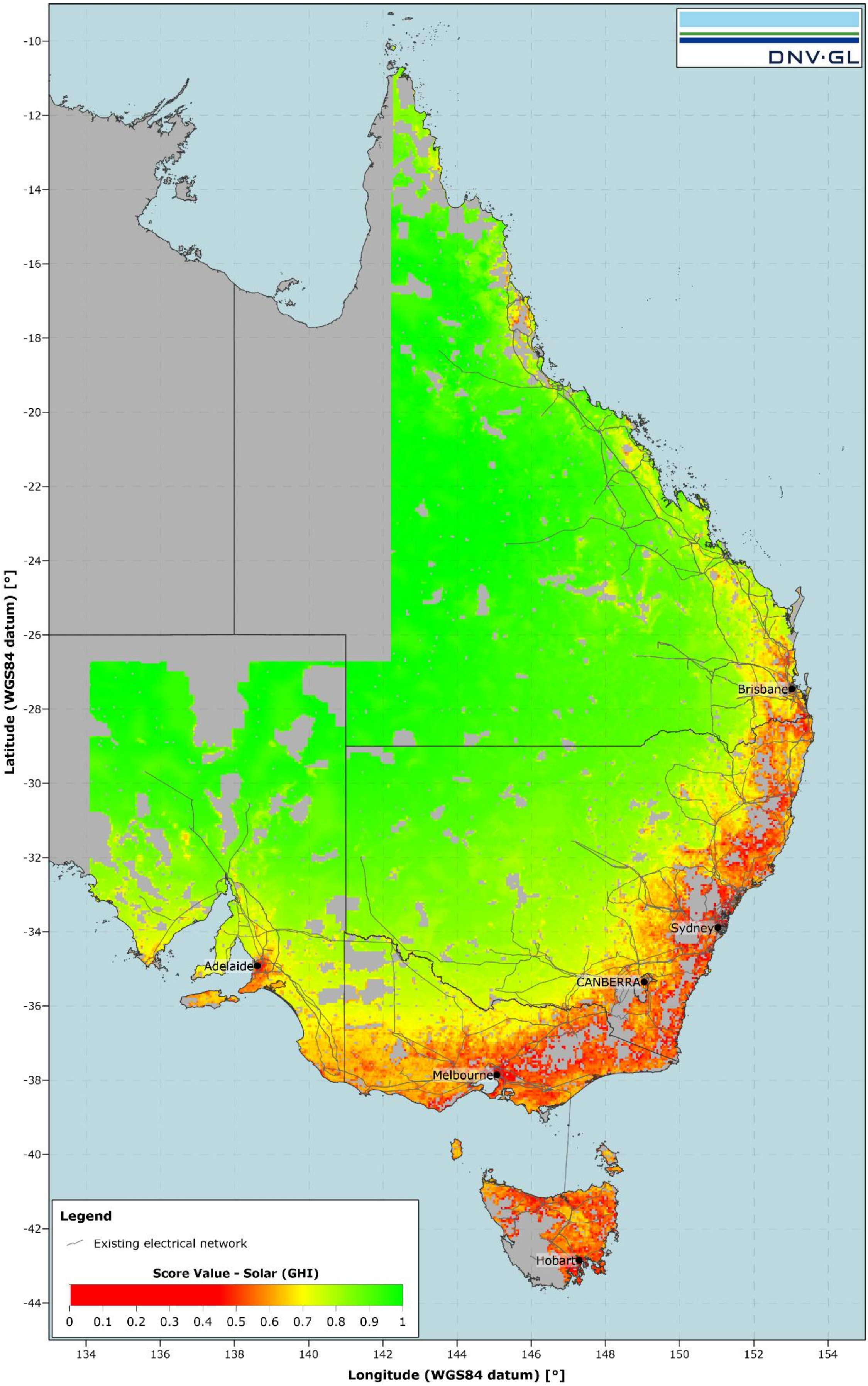


Figure 7. Site scoring map – solar DNI

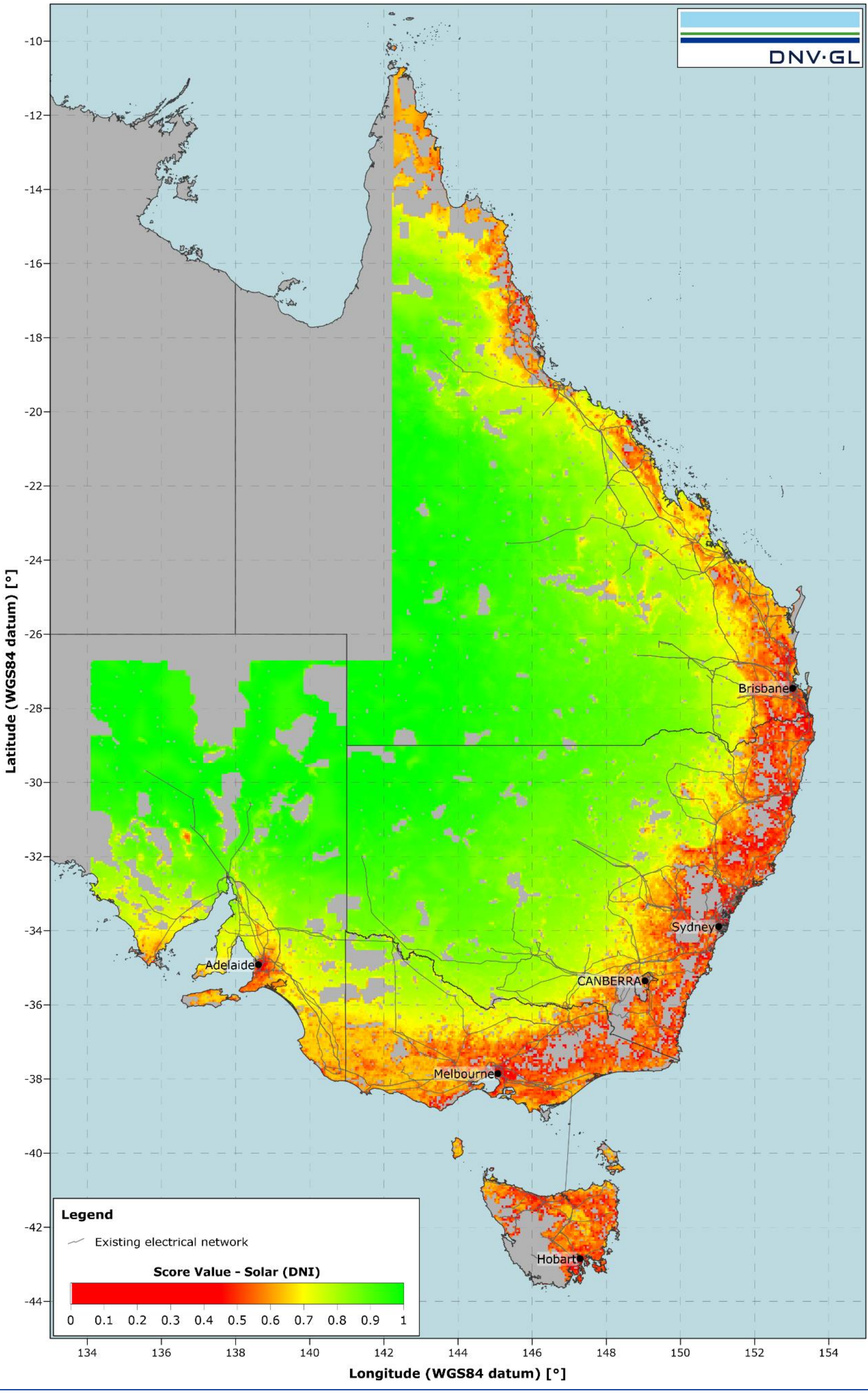


Figure 8. Site scoring map – wind (60%) & solar GHI (40%) hybrid

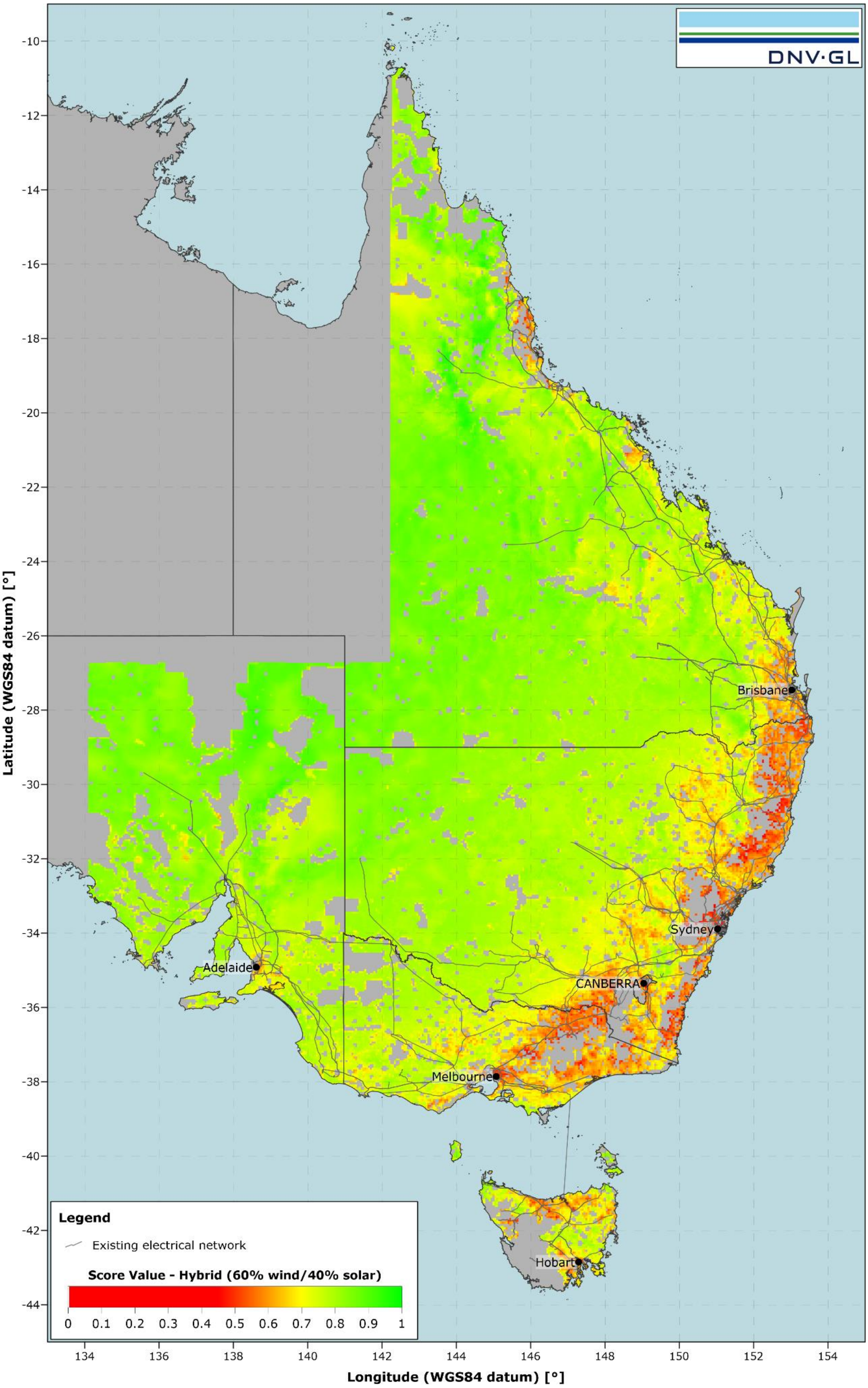
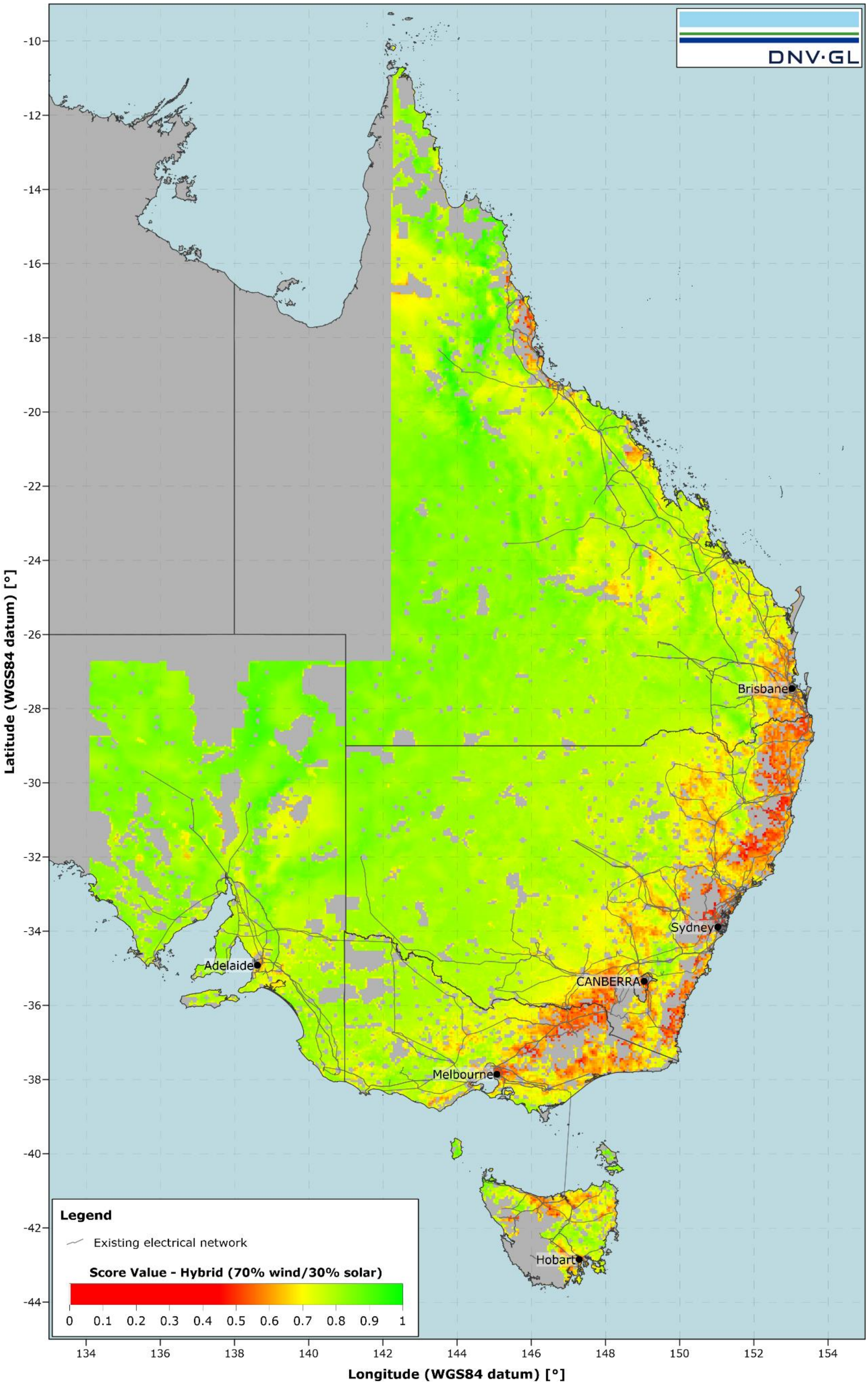


Figure 9. Site scoring map – wind (70%) & solar GHI (30%) hybrid



5 CONCLUSIONS

The results of the assessment presented in this report can be broken down in two distinct phases:

1. Resource modelling; detailed in Section 3.
2. Identification of preferred areas for deployment of wind, solar or hybrid generation plant; detailed in Section 4.

The resource modelling phase was aimed at obtaining an appreciation of the variation of wind speed and solar irradiation over the eastern portion of Australia. The main outcome of this work is presented in the form of resource maps in Figure 2 to Figure 4. The wind modelling was conducted by DNV GL whereas the solar resource compiled from the Australian Bureau of Meteorology solar irradiation database.

The mesoscale wind map has been created using state-of-the-art techniques and the highest quality up-to-date input datasets available at the time, however, the limitations associated with the modelling techniques used must be taken into account when considering these results. It is not considered appropriate to quantify the uncertainty in this analysis. DNV GL recommends that the resource modelling results are used for pre-feasibility purposes and high level assessment of the wind and solar resource only.

The site identification phase combined the modelled resource grids with a number of constraints obtained from publicly available sources in order to assess the potential for wind, solar and/or hybrid project development throughout the survey area. The main outcome of this phase of the project is presented in the form of scoring maps in Figure 5 to Figure 9. In addition to these heatmaps, maps presenting various level of probability of exceedance of the scores are presented in Appendix A.

It should be noted that, the conclusions of the site identification process are based on a desktop study considering a limited selection of constraints. As such, the areas identified as having good development potential should be considered as indicative, and a review of this process considering a different set of constraints might highlight different development areas. Also, the areas highlighted by this process have been found to have high wind and/or solar development potential relative to the survey area considered, but it does not confirm the financial viability of project developed in these areas.

However despite the limitations listed above, the desktop study conducted here represents a useful first step in the identification and development of potential renewable energy generation sites. During the early stages of the development of a renewable energy project, there is a risk of investing in sites with potential issues such resource, infrastructure, environmental or landholder constraints. A desktop site finding study is an inexpensive method to help mitigate these risks before investing further resources into the development of specific sites.

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APPENDIX A ADDITIONAL SITE SCORING MAPS

Figure A1. Probability of exceedance map – wind

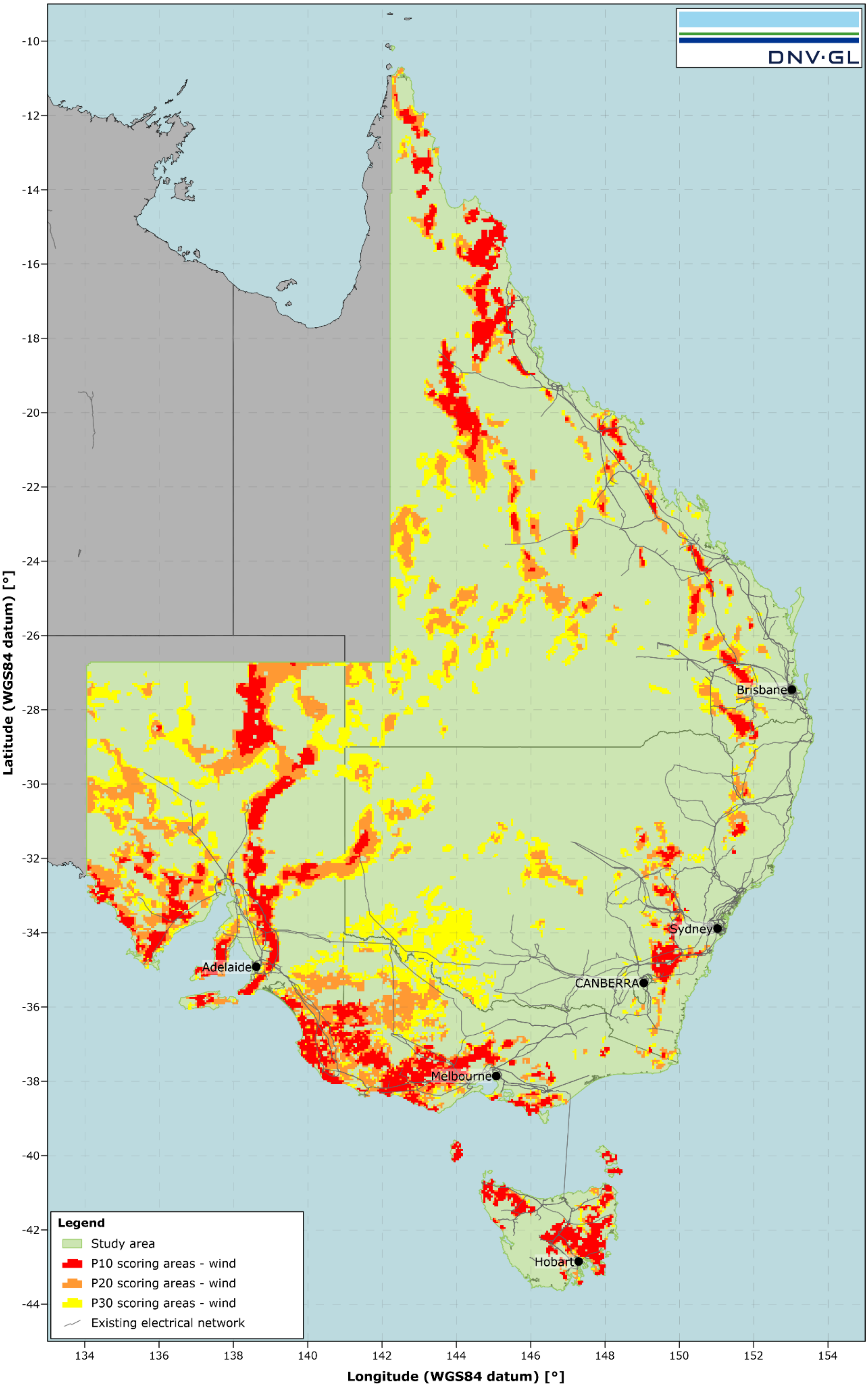


Figure A2. Probability of exceedance map – solar GHI

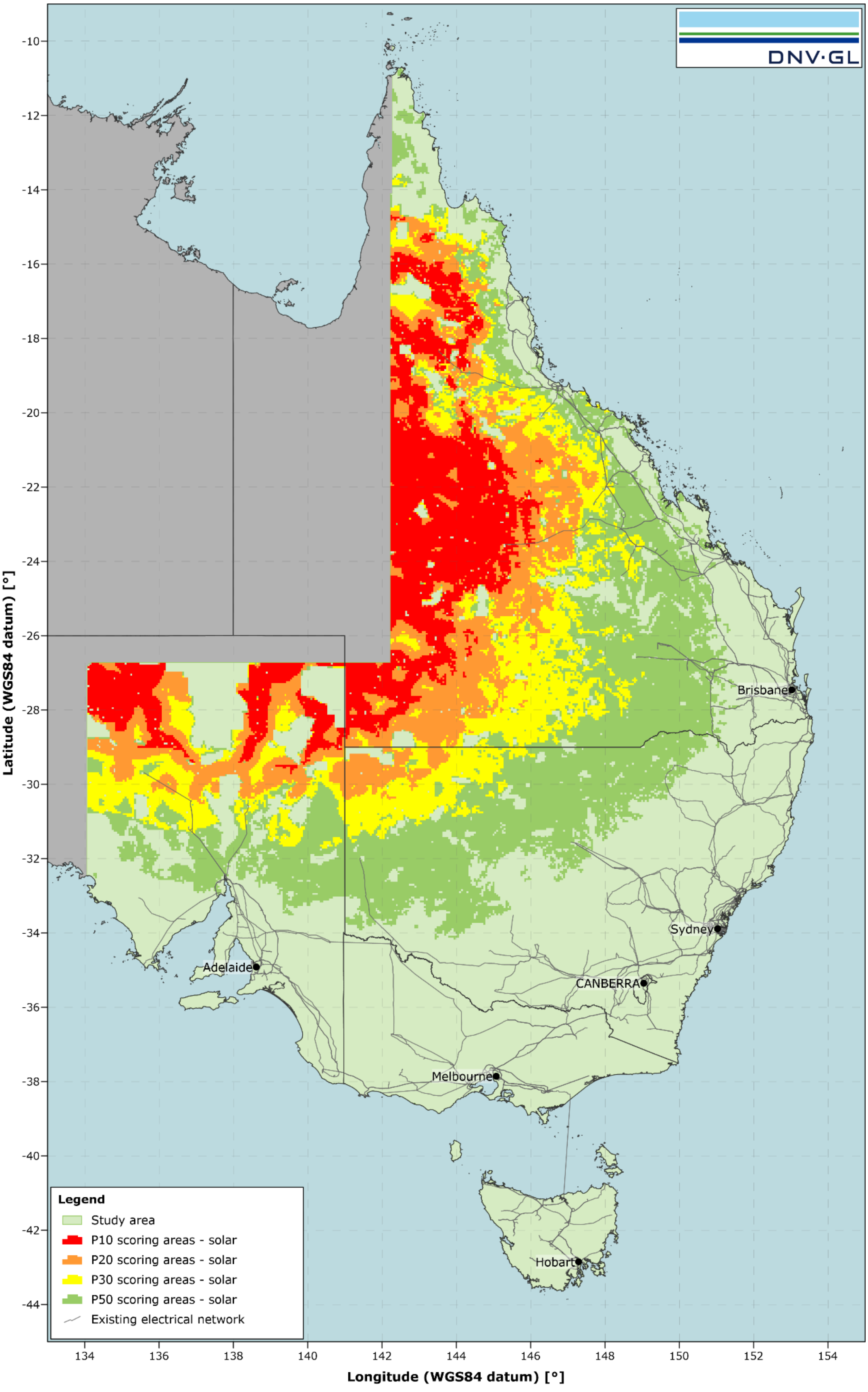


Figure A3. Probability of exceedance map – solar DNI

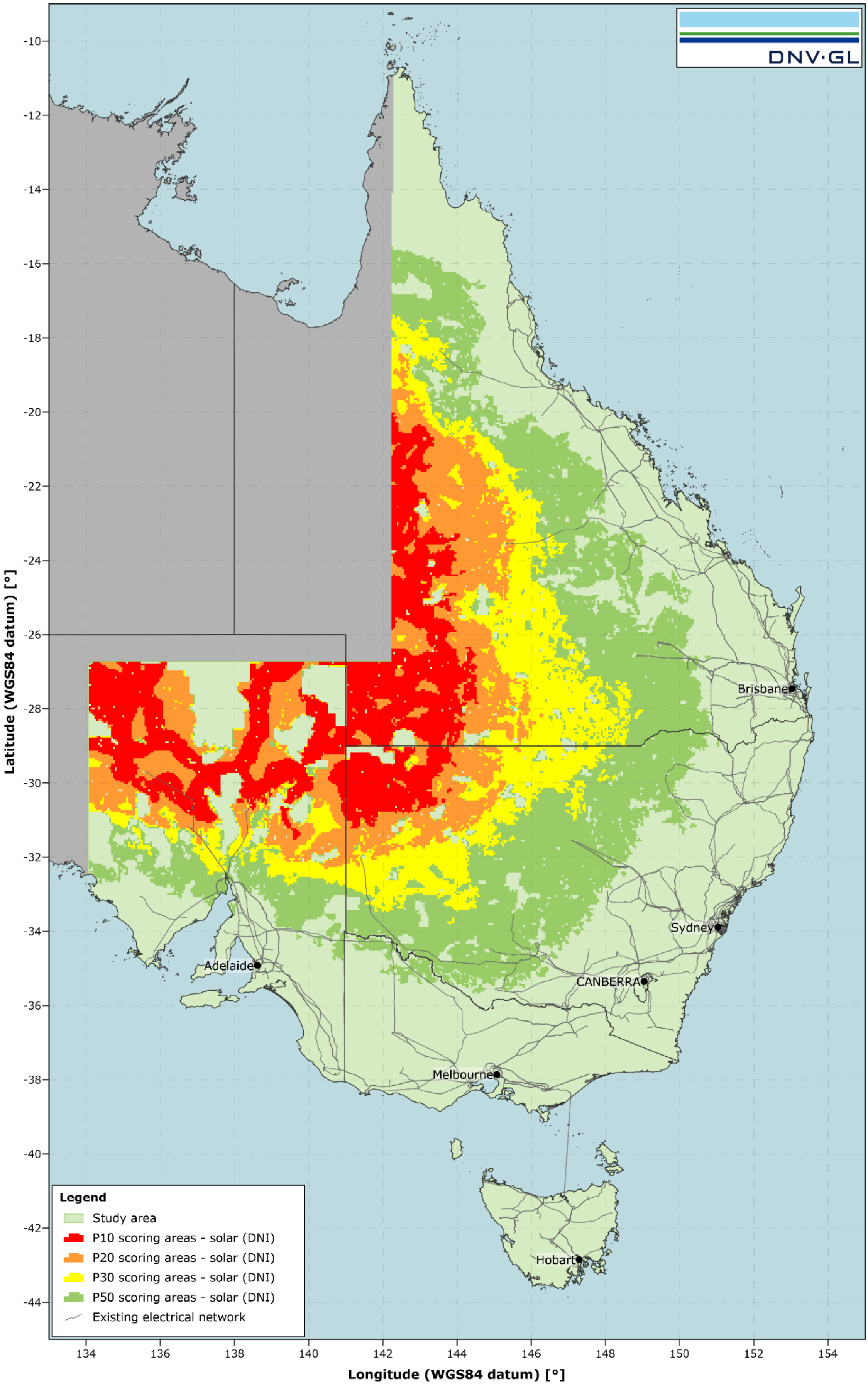


Figure A4. Probability of exceedance map – wind (60%) & solar GHI (40%) hybrid

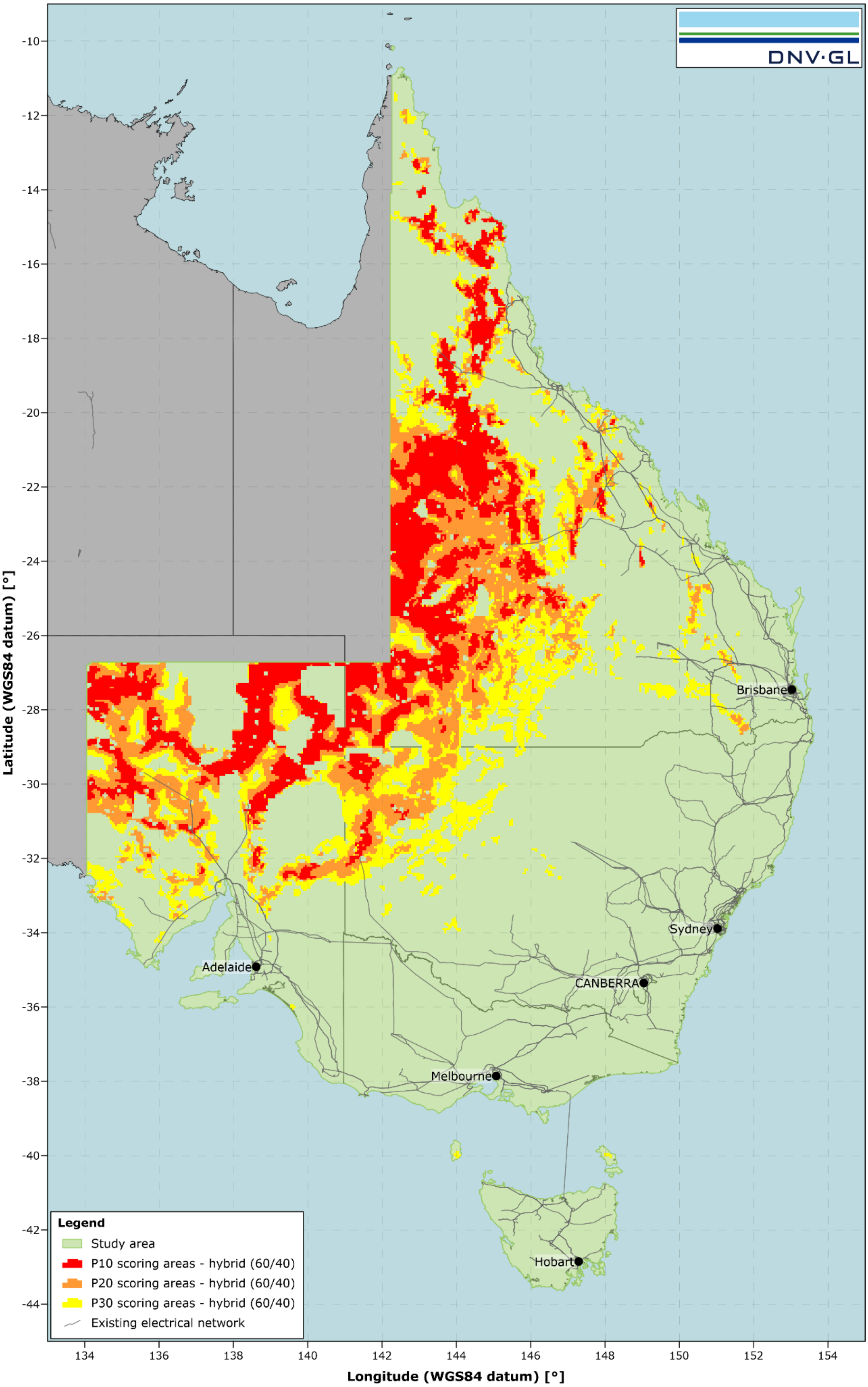
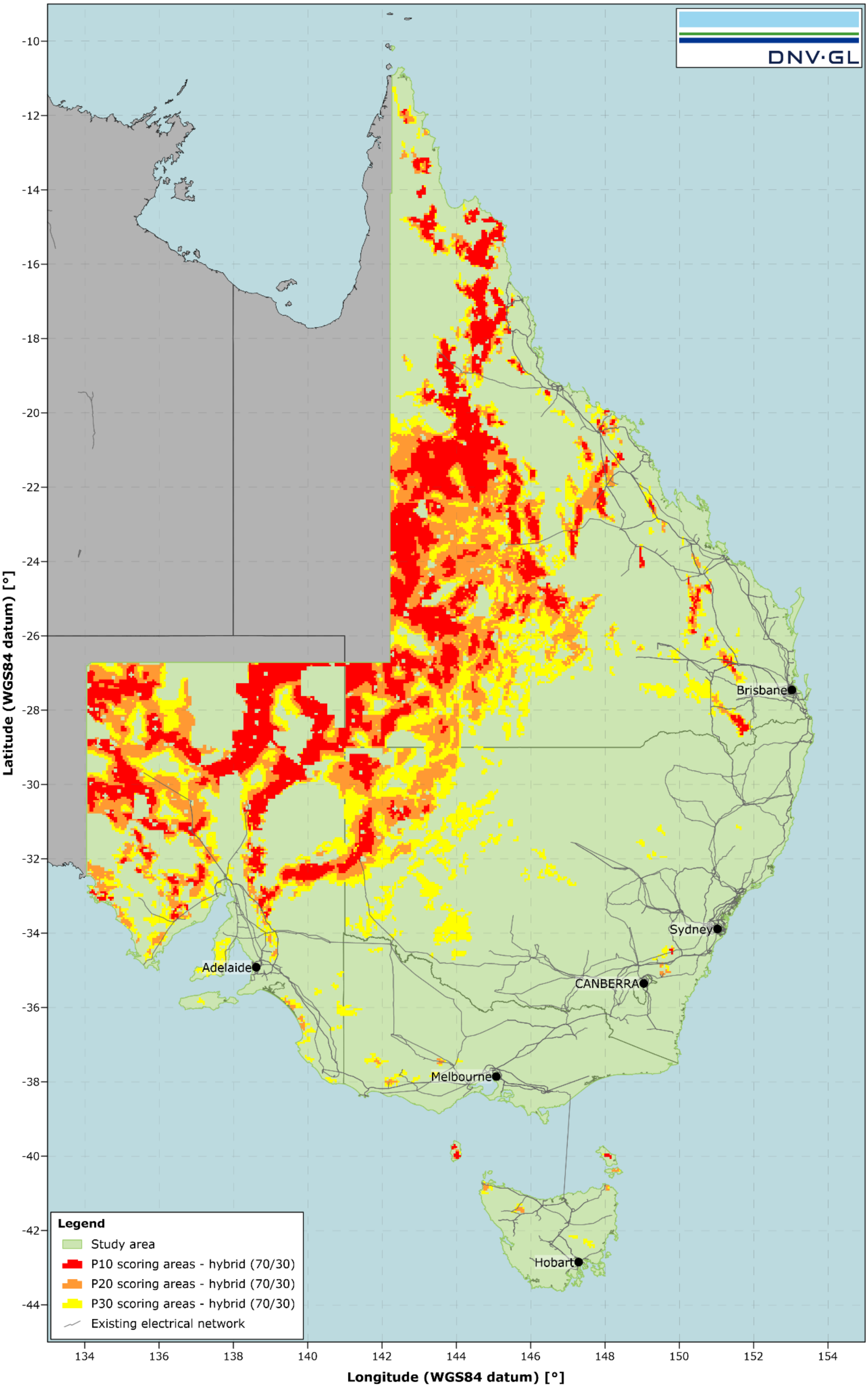


Figure A5. Probability of exceedance map – wind (70%) & solar GHI (30%) hybrid



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