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Solar and wind energy potentials in Australia: a GIS-based assessment for Australia's ability to transition to net-zero emissions by 2050

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Abstract

Australia is positioning itself to become a 'renewable energy superpower' and achieve net-zero emissions by 2050. A GIS-based spatial analysis was conducted to assess the country's renewable energy potential relative to projected electricity demand in 2050. The results highlight that Australia is exceptionally well-placed to lead the global renewable energy transition. Over 5.1 million km^2 of land was identified as potential for solar energy development, and 4.8 million km^2 for onshore wind energy- capable of generating electricity 256 and 132 times greater, respectively, than the projected 2050 demand. This suggests that utilising only 0.4% of the solar potential areas or 0.8% of the onshore wind potential area could meet the country's electricity demand in 2050. Additionally, 347,578 km^2 of offshore wind potential area (at water depths $\leqslant$50 m) was identified, with the capacity to generate electricity 11 times greater than the projected 2050 demand. Beyond energy generation, renewable energy development could deliver substantial benefits for remote and regional communities in Australia, including enhanced energy security, reliability, independence, and socio-economic development. However, challenges remain, particularly community concern and oppositions related to land-use competition from large-scale renewable energy projects and associated infrastructure in regional areas. Successful energy transition can be enabled through a combination of approaches: developing and promoting effective planning and community engagement processes, adopting emerging technologies to reduce competition for land and the potential socio-economic and environmental impacts, and leveraging existing support for renewable energy. In this context, the finer resolution of spatial analysis and mapping considering local contexts could also play a significant role in initiating conversations with local communities, supporting the engagement process, enabling local input, and guiding informed decision-making in the energy transition of regional areas.

1. Introduction

Under the Paris Agreement, the energy transition has progressed on a global scale. The total global electricity generated from renewable sources increased from 5,304 to 8,440 terawatt hours (TWh) between 2014 and 2022 (IRENA 2024), and the additions to the global renewable capacity set a new record every year. The global renewable power capacity reached 4,448 gigawatts (GW) by the end of 2025. During 2024, 92.5% of total expansion in the power generation capacity, representing 585 GW, involved the establishment of renewable power plants, with a record rate of annual growth of 15.1% compared with 2023 (IRENA 2024).

Solar and wind energy have shown particularly rapid growth in many parts of the world over the past decade. The global electricity generated from wind tripled from 712 to 2,098 TWh between 2014 and 2022, and that from solar increased approximately seven-fold (192 TWh to 1,294 TWh) during the same period (IRENA 2024). The scale of growth in renewable energy generation, in order to reach net-zero greenhouse gas (GHG) emissions by 2050, has been substantial. The One Earth Climate Model (OECM) projects that more than 90,000 TWh of

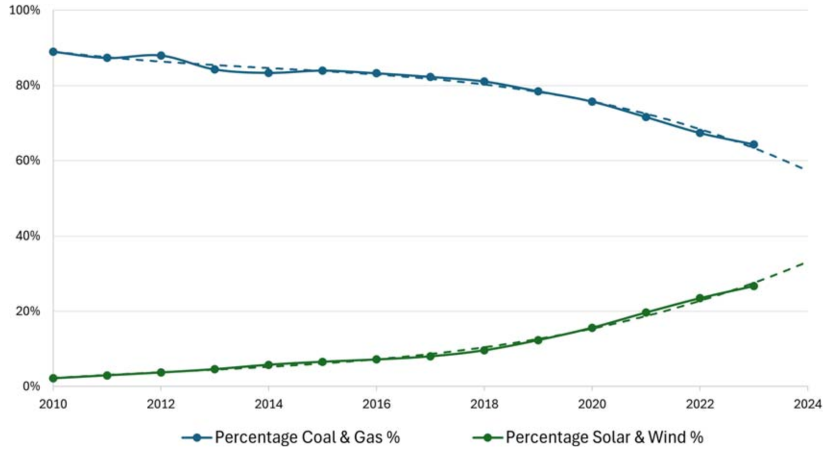

Figure 1. Electricity generation in Australia by source: comparing fossil fuels and variable renewable energy. Source: generated from (IEA 2024a).

renewable energy generation will be required to meet the global energy demand by 2050 (Teske *et al* 2023). While the long-term prediction of the growth in renewable energy has a high degree of uncertainty, the short-term forecast by the International Energy Agency (IEA) is that the total renewable energy generated will account for 42% of the total generation by 2028 (up from 22% in 2014), with solar and wind accounting for 25% of the total generation (IEA 2024b).

Although the uptake of renewables is increasing internationally, the distribution of this uptake is not across the world, with China the clear leader in today's solar and wind energy markets. China currently has over 40% of the installed capacity for solar photovoltaic (PV) and onshore wind power worldwide, and more than half the global installed capacity for offshore wind. Therefore, China was responsible for 35.6% of the total production of global solar electricity and 38.1% of the total global wind production in 2023, constituting 584.2 TWh and 885.9 TWh, respectively (Energy Institute 2024). It was followed by the USA, which generated 14.7% of global solar electricity and 18.5% of global wind electricity, and India, with 6.9% of solar electricity and 3.5% of wind electricity. Germany remains the leader in Europe, generating 3.7% of the global solar electricity and 6.1% of the global wind electricity in 2023. As well as demonstrating their gross renewable energy production, these statistics reflect each nation's total energy demand, its population size, and GDP. Therefore, it is appropriate to consider the energy demand when considering the statistics of a nation, including Australia, which hosts 2.4% of global solar generation capacity and 1.1% of global wind generation capacity, but accounts for only 1% of the global primary energy consumption (Energy Institute 2024).

Australia aims to rapidly transform its economy to become a 'renewable energy superpower', achieving 82% of electricity generation from renewable energy by 2030 (Australian Government 2024d) and a 43% reduction of GHG emissions by 2030 (relative to 2005) (Australian Government 2023). However, the country is facing both opportunities and challenges as it transitions to a low-carbon economy. Despite its strong ambition to adopt renewables, Australia is still one of the world's largest producers and exporters of coal and natural gas. Historically, Australia's electricity has been predominantly supplied by coal- or gas fired power plants. However, the last 15 years have shown a marked move towards renewable energy production. There was a gradual shift away from fossil-fuel-based power generation towards its generation from renewable sources between 2010 and 2018, with the uptake of variable generation sources such as solar and wind technologies increasing rapidly after 2019 (figure 1). Starting from a low base of 2.2% of generation in 2010 (5.4 TWh), solar and wind subsequently surged to meet more than 26% of Australia's demand by 2023 (73.3 TWh from variable renewables), a trend that indicates strong growth in coming years (IEA 2024a).

Despite accounting for 1% of the globe's total renewable energy production as of 2023 (Energy Institute 2024), the data demonstrates that Australia's energy transition is well underway (figure 1). The state of Australia's energy transition is also reflected in statistics such as the installed solar capacity per capita, which shows that Australia has had the most solar capacity installed per person for several consecutive years (1,296 Wp/CAP as of 2023) (Masson *et al* 2024). Apart from the uptake of variable renewable energy, the Australian Government has identified renewable hydrogen, low-carbon liquid fuels (including biofuels and synthetic fuels), and batteries as priority sectors for innovation and commercialisation (Australian Government 2024c).

The expansion of renewable energy requires the increased use of land area for the development of these projects and for the transmission infrastructure to support them. Offshore wind energy has been embraced in many land-constrained countries, but is yet to be harnessed in Australia, even though it does not increase competition for land resources. Therefore, Australia's continued expansion of renewables will require the use of increasing amounts of land resources. This will involve a wide range of stakeholders; especially landholders and neighbouring communities, who will co-exist with these projects in the future. The competition for land is becoming more intense worldwide, so the issue is not restricted to Australia's energy transition (Nonhebel 2005, McKinsey and Company 2023). In this context, social licence has emerged as an important factor determining the success of individual projects, and when viewed from a macro perspective the energy transition as a whole.

Australia's energy transition was also at a critical stage as a controversial nuclear energy policy, which had been developed by the opposition party for the 2025 federal election[1]. Energy policy was one of areas featuring a sharp contrast between two national parties in the election. The nuclear policy purports to meet the geo-political requirements for transitioning to a net-zero energy system by 2050, while supporting the continued use of existing fossil-fuel generation assets in the medium term. The plan stated that only 54% of electricity generation will derive from renewables by 2050, with 38% planned to come from nuclear power (Grattan 2024). The federal election in May 2025 resulted in the re-elected of the Labour government and loss of the Liberal Party. This results clearly highlighted that the public did not support the nuclear plan. However, one of the political factors driving this nuclear policy was the emerging issue of land competition across Australia (especially involving agricultural lands), social licence, and community sentiment regarding the development of renewable energy infrastructures in proximity to regional communities.

Concerns about the competition for land use occurring internationally arises from tensions between the development of renewable energy, biodiversity conservation, and food security and production. In this context, an increasing number of studies have assessed the potentially suitable areas for renewable energy projects and the generation potential of those areas, with constraints upon the areas that are considered suitable. Most of these studies have integrated spatial analysis or modelling with a Geographic Information Systems (GIS). In particular, GIS-based multi-criteria decision-making (MCMD) analysis gained significance in planning solar and/or wind farms and assessing solar and/or wind energy potentials in recent years. Some studies have assessed global potentials (Miyake *et al* 2024), whereas others have focused on an individual country, a specific region, or a site. Country-scale analyses have assessed the renewable energy potentials of China (Huang *et al* 2018, Feng *et al* 2020, Chen *et al* 2022, Li *et al* 2022, Ji *et al* 2022, Wang *et al* 2022a, 2022b, Jiang *et al* 2023), Saudi Arabia (Al Garni and Awasthi 2017, Baseer *et al* 2017, Almasad *et al* 2023), and other leading countries, such as Europe (Perpiña Castillo *et al* 2016, Ruiz *et al* 2019, Vázquez *et al* 2022) and India (Jain *et al* 2020). Some recent assessments were related to their pathways to net-zero and their increasing future energy demands (Li *et al* 2022, Ji *et al* 2022). Countries with more available land resources, such as Australia, are considered to have an advantage in the transition to renewables However, only a limited number of spatial assessments for renewable energy were found in the literature for Australia, such as Islam *et al* (2022) and Bobeck (2017). The academic literature did not contain a national-scales study based on an economy wide net-zero transition pathway, assessing Australia's renewable energy land use requirements relative to projected demand by 2050.

This study was conducted to fill this knowledge gap, aiming to inform a wide range of stakeholders of our findings about the renewable energy potentials in Australia. These stakeholders specifically include key policy makers in the climate, energy, and environmental sectors at different level of governments, industry leaders, the non-government sector, and the research community in both Australia and internationally. By communicating results, this analysis aims to support the acceleration of the renewable energy transition within the country, and international co-operation within this sector There are three main objectives:

- to identify the solar and wind energy potentials in Australia under land and ocean resource-constrained conditions using GIS-based spatial analysis and mapping, and to calculate the available land resources that are suitable for these uses;
- to assess whether the solar, onshore and offshore wind energy potentials are sufficient to decarbonise the national energy supply by 2050; and
- to identify the opportunities and challenges involving in moving forward.

A GIS-based analysis was conducted with the Renewable Energy Potential under Space Constraint Conditions ([R]E Space) approach (Teske *et al* 2019, 2024a, 2024b, Miyake *et al* 2024), an important component of the One Earth Climate Model (OECM) (Teske 2019). The OECM is an integrated energy assessment model used to develop decarbonisation pathways for sectors, countries, and regions, and also at the global level. Since 2017, the OECM has been applied to more than 50 countries and regions. In this study, [R]E Space was applied to identify areas suitable

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[1] The opposition party is a coalition of the Liberal Party and National Party, with the National Party traditionally representing rural and regional communities.

for the installation of renewable energy in Australia, for the generation of solar, onshore, and offshore wind energy, considering the key resource constraint factors identified in a literature review. The factors constraining solar and onshore wind potentials include land use, slope/topography, protected areas, solar irradiation (direct normal irradiation: DNI), and wind speed. Water depth (bathymetry), marine protected areas, windspeed, and other factors (e.g., ports) are considered the constraint factors for offshore wind potential. The GIS-based spatial analysis was combined with high-resolution mapping of the areas with potential to generate solar, onshore wind, and/or offshore wind energy. The installed capacity and the electricity that could potentially be generated from solar and wind energy were estimated from the land areas and offshore areas within the national executive economic zone (EEZ), which were calculated from the spatial analysis. The results were then compared with our projection of the country's final electricity demand in 2050 by state, obtained from the results of the OECM (Teske *et al* 2023).

2. Methods

2.1. Study area

Australia is a unique country and continent, holding significant advantages offered by its abundant land (7,688,287 km^2) and natural resources (e.g., iron ore, coal, copper, uranium, bauxite, timber), combined with a long coastline (approximately 34,000 km) (Geoscience Australia 2021a). Australia is the sixth largest country, by area, in the world, whereas the country has a relatively small domestic population (27 million in 2024) (Australian Bureau of Statistics 2024), with a national annual electricity demand of 274 TWh (Australian Government 2024b). Australia is a member state of the Group of Twenty (G20), constituted of the world's largest economies, which are responsible for 86% of the global energy demand and 87% of global energy-related CO_2 emissions (Teske *et al* 2023). In 2023, the G20 leaders agreed to triple the global renewable energy capacity by 2030 (India Ministry of Extra Affairs 2023).

Australia has been a significant producer and exporter of fossil fuel to the world. The country was ranked among the top five coal producers (446 million tonnes) (IEA 2023c) and among the top ten natural gas producer (5,452,937 TJ) (IEA 2023b) in 2022. At the same time, Australia has many advantages in solar and wind resources. The continent is located in the southern hemisphere, and receives the highest level of solar irradiation. The total yearly DNI ranges from 334 to 2,980 kilowatt-hours per square meter (kWh/m^2), and the higher end of the range ($>$2,000 $kWh\ m^{-2}$) occurs in the central outback regions of Western Australia, South Australia, the Northern Territory, Queensland, and New South Wales (Solargis and World Bank Group 2019). Solar irradiance is lower in the southern and eastern coastal regions of Tasmania. Instead, these regions are expected to have good wind energy yields, because they are located in areas of high wind speed in the southeast of the continent such as Victoria and Tasmania (Davis *et al* 2023). The wind speed in Australia ranges from 1.7 to 17.3 meter per second (m/s) at a height of 100 m.

The Australian Federal Government legislated an emissions reduction target of 43% by 2030 relative to 2005 levels, and net-zero GHG emissions by 2050 (Climate Change Act 2022), consistent with its international obligations under the Paris Agreement (Parliament of Australia 2022). The legislation was accompanied by a variety of other federal policies and legislation to assist Australia decarbonise, including the Safeguard Mechanism, renewable electricity targets, the Capacity Investment Scheme, and vehicle efficiency standards (Australian Government 2023). Australia is composed of six federated states and two territories, each with its own set of geographic, economic, and political circumstances. Each state faces a different starting point regarding the decarbonisation of electricity, including the composition of its energy sources (and imports), access to the National Electricity Market (NEM) and its transmission infrastructure. Although the motivation to decarbonise the economy and energy system and the progress achieved vary among different jurisdictions, each state and territory has emission targets (table 1).

The two states with the smallest geographic areas have already achieved 100% renewable energy: the Australia Capital Territory (mainly from wind) and Tasmania (mainly from hydro). Another two southern states have set more ambitious targets, to achieve 100% renewables before 2030: South Australia (Government of South Australia 2024) and Victoria (State Government of Victoria 2024). The remaining states include the largest fossil-fuel producers and exporters, including the black coal producers in Queensland and New South Wales and the natural gas producers in Western Australia and the Northern Territory. The transition may be more challenging for these states and territory.

2.2. GIS-based assessment and mapping

In this analysis, renewable energy potential areas were identified with the [R]E Space approach. [R]E Space has been gradually upgraded over the years and has been used in a number of contexts including global regions and individual countries. The spatial assessment of Australia was initially conducted as part of our assessments for the G20 countries (Miyake *et al* 2024).

Table 1. Renewable energy targets of Australian states and territories.

State or territory	Renewable energy target	Emissions reduction target
Australia (Federal Government)	**• 82% by 2030**	**• 43% below 2005 levels by 2030** **• net-zero emissions by 2050**
Australian Capital Territory (ACT Government n.d., n.d.)	• 100% renewable electricity since 2020 • transition away from gas by 2045	**Climate Change and Greenhouse Gas Reduction Act 2010** • 50%–60% by 2025 • 65%–75% by 2030 • 90%–95% by 2040 • net-zero emissions by 2045 (below 1990 levels)
New South Wales (NSW Government 2020, 2023)	• no state-wide targets • 12 GW of renewable electricity generation (wind and solar) by 2030	**The Climate Change (Net Zero Future) Act 2023** • 50% by 2030 • 70% by 2035 • net zero by 2050 (below 2005 levels)
Northern Territory (Northern Territory Government 2021)	• 50% by 2030 (note: the target has been abondoned in early 2025)	• no interim targets • net zero by 2050
Queensland (Queensland Government 2024a, 2024b)	• 50% by 2030 • 70% by 2032 • 80% by 2035	**Clean Economy Jobs Act 2024** • 75% by 2035 • net zero by 2050
South Australia (Government of South Australia 2024)	• 100% net renewable electricity generation by 2027	**South Australia's Net Zero Strategy** • at least 60% (below 2005 levels) by 2030 • net zero by 2050
Tasmania (Tasmanian Government N.D., Point. Advisory 2021)	• 100% renewable electricity after 2020 • 200% renewable electricity by 2040	• at least 60% (below 1990 levels) by 2050
Victoria (State Government of Victoria 2023, 2024)	**Renewable Energy (Jobs and Investment) Act 2017 (Vic)** • 40% by 2025 • 65% and 2.6 GW of storage planned by 2030 • 95% and 6.3 GW of storage planned by 2035 **Offshore wind energy** • at least 2 GW capacity by 2032 • 4 GW by 2035 • 9 GW by 2040	**Victoria's 2025 Emission Reduction Target** • 28%–33% by 2025 • 45%–50% by 2030 • 75%–80% by 2035 • net zero by 2045 (below 2005 levels)
Western Australia (IEA 2023a) (Government of Western Australia 2024)	• no state-wide targets • state-owned coal-fired power stations, under Synergy, will be retired by 2030	• 80% (below 2020 levels) by 2030 (only government emissions) • no state-wide interim targets

The latest version of [R]E Space incorporates a Boolean raster overlay approach, which considers multiple land-resource constraint factors that can affect decisions about the locations of renewable energy projects. Individual criteria were set for each land-resource constraint factor for solar, onshore wind, and offshore wind energy potential areas (tables 2 and 3). Next, the spatial data inputs on different themes associated with these criteria were overlain and combined into a single output raster. The input data and the criteria used for the process differ for solar, onshore wind, and offshore wind, thus generating three different maps of solar, onshore wind, or offshore wind energy potentials. Mapping was performed with the ESRI ArcMap 10.6.1 software and publicly available, global and national spatial data. All areas of renewable energy potential were calculated and visualised with GIS.

The land identified in this assessment will be referred to as 'solar energy potential areas,' 'onshore wind potential areas,', and 'offshore wind potential areas' in this study. To determine actual project locations, these areas will require more detailed assessments incorporating additional geographic, environmental, and socio-economic data within the local context to support effective planning. However, these areas are considered to hold strong technical potential for future renewable energy developments as meeting key criteria outlined in this study.

Table 2. List of land resource constraint factors and criteria used for the analysis of solar and onshore wind energy potential in this study.

Land-resource constraint factors	Assumptions and criteria	Data source
Land use	Land use classes included and eliminated are provided in the appendix for solar energy potential and onshore wind potential.	Catchment Scale Land Use of Australia, update December 2020 (ABARES 2021)
Slope	Slope was calculated from the DEM dataset. Any land with a slope of $>30\%$ was excluded from all scenarios.	SRTM 90m DEM (NASA and CGIAR 2018)
Protected Areas	All protected areas designated in the map (e.g., national parks, wildlife reserves, conservation areas) were excluded from all scenarios.	World Database on Protected Areas (UNEP-WCMC and IUCN 2022)
Solar irradiance (direct normal irradiation: DNI)	Average yearly DNI values $\geqslant$1,000 kWh m^{-2}	Global Solar Atlas (Solargis and World Bank Group 2019)
Wind speeds at a height of 100 m	Wind speeds $\geqslant$5 m s^{-1} at a height of 100 m for onshore wind potential areas	Global Wind Atlas (Davis *et al* 2023)
Distance from electricity transmission lines	Solar and wind potentials in areas $\leqslant$10 km from transmission lines (Scenario 2)	Geoscience Australia (Geoscience Australia 2021b)

2.2.1. Mapping procedures for solar energy potential areas and onshore wind energy potential areas

Prior to this project, a literature review was conducted to identify the land-resource constraint factors used in existing GIS-based assessments of renewable energy potential or land suitability studies for solar energy (n = 42) and onshore wind energy (n = 30) for G20 countries (Supplementary material). Although it was a global literature review, it included two studies of Australia (ROAM Consulting Pty. Ltd 2012, Islam *et al* 2022). In total, 42 studies were reviewed for solar and onshore wind energy (Supplementary data). The review identified the most frequently used land resource constraint factors in these studies such as (1) slope (n = 42), (2) land-use or land-cover class (n = 38), and (3) protected areas (n = 35). Almost all studies also required (4) solar irradiance data (n = 25) to select locations for solar energy projects and (5) windspeed data (n = 23) to select suitable locations for onshore wind energy projects (Miyake *et al* 2024). Therefore, these constraint factors were considered in our spatial analysis for our Scenario 1 maps for both solar and onshore wind energy potentials.

Many studies also considered the distance from urban areas or settlements (n = 35), the distance from (major) roads (n = 24), and/or the distance from electricity transmission lines (n = 23) as additional land-resource constraint factors. In Australia, most of the population is concentrated on the eastern seaboard and the southwest coast of the continent, and transmission lines and cables mainly connect these populated areas. Therefore, this analysis also calculated solar and onshore wind energy potentials in areas $\leqslant$10 km from transmission lines (Scenario 2). The land-resource constraint factors and the criteria used in our analysis are summarised (table 2). For protected areas and slope, the same criteria were used for the maps of both the solar and onshore wind energy potentials. The dataset of the World Database on Protected Area (WDPA) is a comprehensive global database covering both marine and terrestrial protected areas (UNEP-WCMC and IUCN 2022). To ensure that future renewable energy projects are not established in protected areas, WDPA's spatial data were used as an input to exclude these areas from those projects. These data were overlain with the slope dataset to set the upper limit (30%) of the slope for areas upon which renewable energy facilities could be installed and maintained. The slope was calculated with the SRTM 90m Digital Elevation Database (DEM) on GIS (NASA and CGIAR 2018).

The different criteria for suitable land classes were applied to solar and onshore wind projects. Therefore, two separate spatial layers were prepared. In our analysis, the national-scale land use dataset of the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) (Catchment scale land use of Australia) (ABARES 2021) was used as input data to exclude land use classes that are unsuitable for solar and onshore wind projects. This included all land sub-classes under 'nature conservation' and those indicating high conservation values (e.g., wetlands), forest land uses (native, production and plantation forestry), and water bodies. Our analysis also considered urban land classes, given the increasing role of rooftop solar energy in Australia. Conversely, these urban land classes were restricted for onshore wind projects because of safety issues, noise concerns, and other potential impacts.

In our analysis, DNI was used as the indicator of solar irradiance. The availability of DNI data is essential for concentrated solar power (CSP) (Chen *et al* 2022) and concentrated photovoltaic (CPV) systems (Martinez *et al* 2022), which can only convert DNI to electricity. The DNI dataset from the Global Solar Atlas (Solargis and World Bank Group 2019) was used as input data to identify solar potential areas with an average yearly DNI of $\geqslant$1,000 kWh m^{-2}. For onshore wind potential areas, windspeeds at a height of 100 m from the Global Wind Atlas (Davis *et al* 2023) were input in this analysis, with a mean wind speed of $\geqslant$5 m s^{-1}.

The mapping procedures for both maps are described in figure 2. All spatial data were converted to Boolean data, in which a value of 0 indicates 'no potential' and a value of 1 indicates 'potential' for solar or onshore wind energy projects. The following raster calculation formula was applied in GIS to derive solar energy potential areas:

Solar Energy Potential Area (0,1) = Protected areas (0,1) × Slope (0,1) × Land-use (Solar) (0,1) × DNI (0,1)

To derive onshore wind energy potential areas, the following raster calculation formula was applied in GIS:

Onshore Wind Energy Potential Area (0,1) = Protected areas (0,1) × Slope (0,1) × Land-use (Wind) (0,1) × Wind speed (0,1)

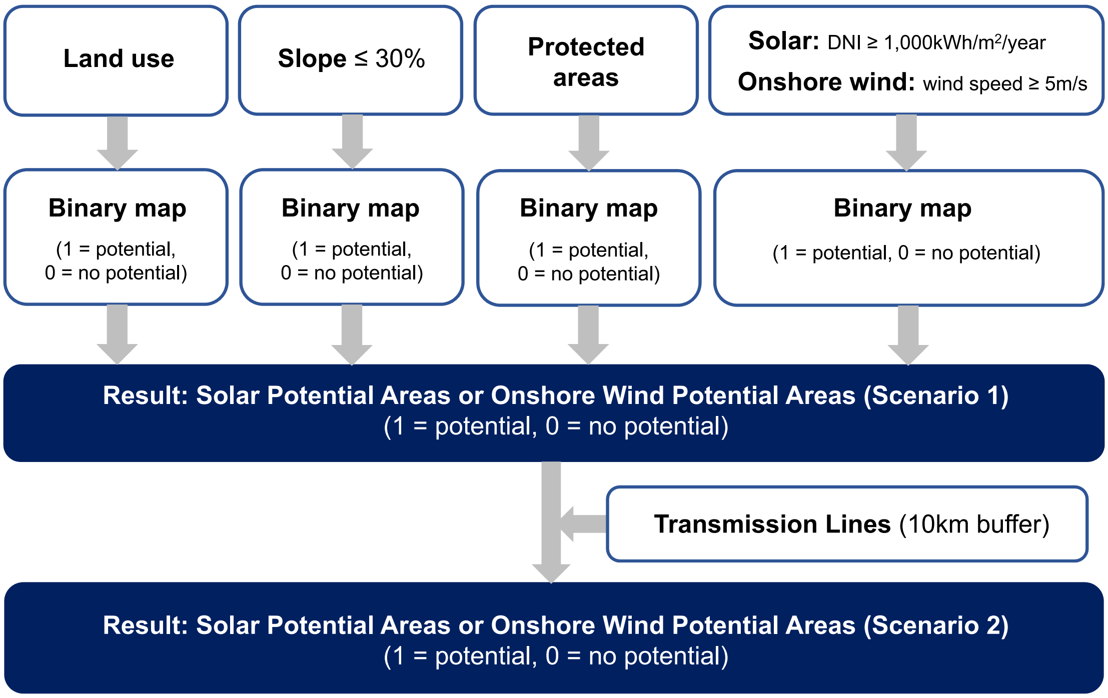

Figure 2. GIS-based mapping procedure for solar energy potential areas and onshore wind energy potential areas.

2.2.2. Mapping procedure for offshore wind potential areas

To identify areas for future offshore wind projects within Australia's exclusive economic zone (EEZ), an offshore wind potential map was also constructed in GIS. The key input data included gridded bathymetry data from the General Bathymetric Chart of the Oceans (GEBCO) (GEBCO Compilation Group 2023), data on marine protected areas from WDPA (UNEP-WCMC and IUCN 2022), and windspeed data at a height of 100 m from the Global Wind Atlas (Davis *et al* 2023) (table 3). Average annual wind speeds of $\geqslant$6.0 m s^{-1} are generally considered commercially viable. The criterion of a mean wind speed of >6 m s^{-1} was used instead of 5 m s^{-1} to ensure the better economic viability of the projects. In our analysis, the maximum water depth restriction applied for bottom-fixed foundations was 50 m (Offshore Scenario 1), and the restriction applied for floating foundations was 500 m (Offshore Scenario 2). These values conform to the range of values applied in the majority of international offshore wind assessment studies (Bosch *et al* 2018, Peters *et al* 2020).

All spatial data were converted to Boolean data and overlain to generate a map of areas of offshore wind potential, and then the same raster calculation formula for onshore wind energy potential area was used to derive offshore wind energy potential areas (figure 3).

2.2.3. Calculation of installed capacity and energy generation potential from land and ocean areas

The installed capacity for renewable energy can depend on various local factors, such as the local treatment of solar irradiation or wind speed and capacity, geographical constraints, downstream loss, and so on (Bosch *et al* 2018). In our analysis, the solar energy potential (GW) was calculated for Australia based on the area (km^2) identified as having solar energy potential, under the assumption that the installed capacity per km^2 was 25 megawatt (MW) on average. This estimation is based on the assumption used by U.S. National Renewable Energy Laboratory (Ong *et al* 2013), which estimates an average utility scale solar PV capacity intensity of 30 MW km^{-2} to 33 MW km^{-2}. Additional space requirements for storage, logistics buildings and access roads were taken into account, which reduced the performance per square kilometre. It was also converted into solar electricity generation potential (TWh/year) under the assumption of 1,100 h a year (h/year). The onshore wind energy potential (GW) was also calculated for Australia based on the identified areas of onshore wind potential in (km^2) and the assumption that the average installed capacity per km^2 was 5 MW. The wind installed capacity density per square kilometre varies significantly between 6.2 and 46.9 MW km^{-2} in Europe (Enevoldsen and Jacobson 2021). For the global analysis, the lower end of the capacity density was chosen. The installed capacity was converted into onshore wind electricity generation potential (TWh/year) using an assumption of a capacity factor of 3,000 h $year^{-1}$ for onshore wind and 3,600 h $year^{-1}$ for offshore wind energy.

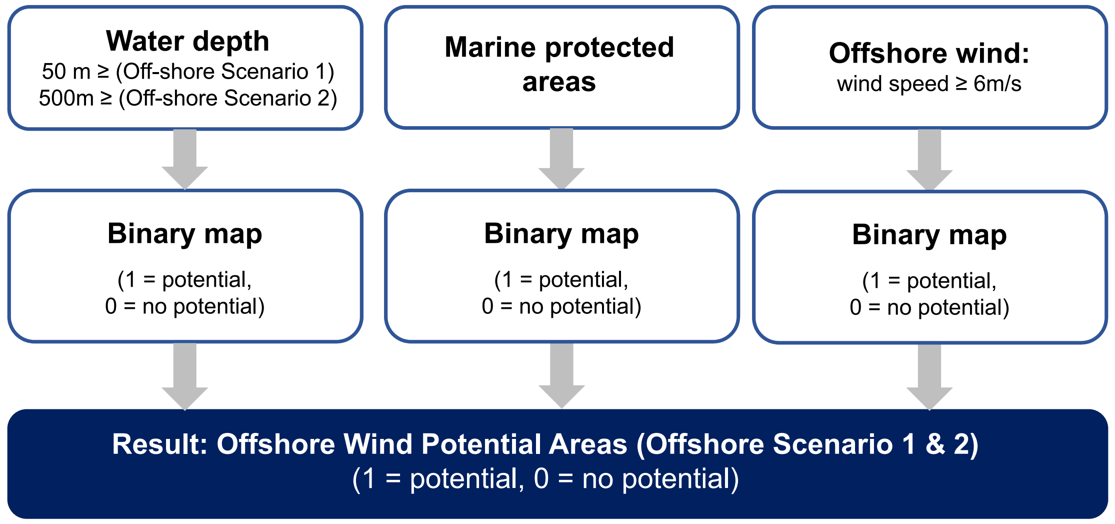

Figure 3. GIS-based mapping procedure for offshore wind energy potential areas.

Table 3. List of resource constraint factors and criteria for the analysis of the areas of offshore wind energy potential in this study.

Resource constraint factors	Assumptions and criteria	Data source
Maritime boundaries	Australia Exclusive Economic Zone (200 nautical miles)	The Pacific Community (SPC) (The Pacific Community (SPC) 2022)
Water depth	Water depth $\leq$50 m for bottom-fixed foundations (Offshore Scenario 1) Water depth $\leq$500 m for floating foundations (Offshore Scenario 2)	GEBCO 2023 Grid (GEBCO Compilation Group 2023)
Marine protected areas	All protected areas designated in the data were excluded from all scenarios.	World Database on Protected Areas (UNEP-WCMC and IUCN 2022)
Wind speeds at a height of 100 m	Wind speeds $\geq$5 m s^{-1} at a height of 100 m for onshore wind potential areas	Global Wind Atlas (Davis *et al* 2023)
Major maritime ports	Port locations and information	Geoscience Australia (Geoscience Australia 2020)

3. Results

3.1. Solar energy potential in Australia

Our results identify exceptional solar energy potential in Australia (tables 4 and 5. Australia has 5.1 million km^2 of area with solar energy potential, equivalent to 67% of the country's land area (figure 4). This land area could potentially provide 128,524 GW of installed capacity and 141,377 TWh $year^{-1}$ of solar electricity. Compared with the projected national electricity demand in 2050 modelled with OECM, Australia should be able to supply over 256 times its projected final national electricity demand in 2050, and only 0.4% of the solar energy potential area should be sufficient to supply the country's projected electricity demand in 2050.

Table 4. Solar energy potential areas in Australia.

State or territory	Solar energy potential area (km^2) (% of land area)	Solar energy potential (GW)	Solar electricity generation potential (TWh/year)
NSW & ACT			
– Scenario 1	658,375 (81.9%)	16,459	18,105
– Scenario 2	137,756 (17.1%)	3,444	3,788
NT			
– Scenario 1	621,277 (46.2%)	15,532	17,085
– Scenario 2	11,545 (0.9%)	289	317
QLD			
– Scenario 1	1,419,857 (82.2%)	35,496	39,046
– Scenario 2	132,412 (7.7%)	3,310	3,641
SA			
– Scenario 1	512,137 (52.1%)	12,803	14,084
– Scenario 2	57,203 (5.8%)	1,430	1,573
TAS			
– Scenario 1	19,134 (28.3%)	478	526
– Scenario 2	10,128 (15.0%)	253	279
VIC			
– Scenario 1	134,222 (59.1%)	3,356	3,691
– Scenario 2	45,922 (20.2%)	1,148	1,263
WA			
– Scenario 1	1,775,960 (70.4%)	44,399	48,839
– Scenario 2	81,251 (3.2%)	2,031	2,234
Australia (total)			
– **Scenario 1**	**5,140,970 (67.0%)**	**128,524**	**141,377**
– **Scenario 2**	**476,217 (6.2%)**	**11,905**	**13,096**

Note: Scenario 2 (Transmission Lines ⩽10 km)

Table 5. Comparison of projected solar electricity generation potential with projected final electricity demand in 2050.

State or territory	Regional projection of electricity demand in 2050 (TWh/year)	Ratio of potential generation to projected demand in 2050	% of solar energy potential area required to supply regional or national electricity demand in 2050
NSW & ACT			
– Scenario 1	176	103	0.97
– Scenario 2		22	4.65
NT			
– Scenario 1	7	2,577	0.04
– Scenario 2		48	2.09
QLD			
– Scenario 1	130	302	0.33
– Scenario 2		28	3.56
SA			
– Scenario 1	33	425	0.24
– Scenario 2		48	2.10
TAS			
– Scenario 1	22	23	4.28
– Scenario 2		12	8.06
VIC			
– Scenario 1	126	29	3.42
– Scenario 2		10	10.00
WA			
– Scenario 1	58	843	0.12
– Scenario 2		39	2.59
Australia (total)			
– **Scenario 1**	**552**	**256**	**0.4**
– **Scenario 2**		**24**	**4.2**

Note: Scenario 2 (Transmission Lines ⩽10 km)

The largest solar energy potential was detected in Western Australia, with more than 1.7 million km^2 (70.4% of the state land area), followed by Queensland, with 1.4 million km^2 (82.2%), New South Wales with 0.66 million km^2 (82.2%), and the Northern Territory with 0.62 million km^2 (46.2%).

With the additional restriction to areas within 10 km of the transmission line network (Solar Scenario 2), our results still confirmed the large solar energy potential in Australia. Under this scenario, the solar potential area drops significantly to 476,217 km^2, equivalent to 6.2% of the country's total land area, which could provide 11,905 GW in installed capacity and 13,096 TWh year^{-1} of solar electricity. This is more than sufficient to meet the projected final national electricity demand in 2050, exceeding it more than 23-fold. The use of only 4.2% of the solar energy potential area would be sufficient to meet the projected electricity demand in 2050.

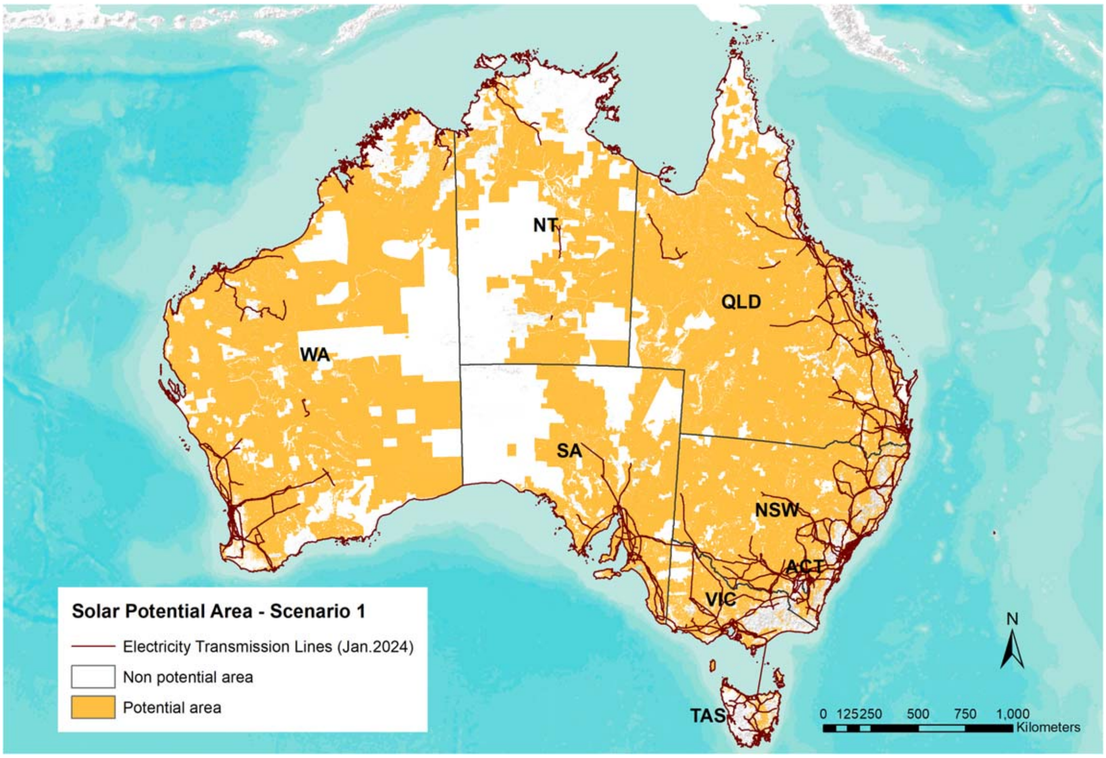

Figure 4. Solar energy potential areas in Australia.

3.2. Onshore wind energy potential in Australia

The results of the onshore wind energy potential study are summarised in table 6, which compared with projected final electricity demand in 2050 (table 7). Australia has 4.8 million km^2 of land with onshore wind energy potential, which is equivalent to 63.2% of the national land area (figure 5). This land has potential to provide 24,254 GW of installed capacity from onshore wind energy projects, generating 72,761 TWh year^{-1} of electricity. This is over 132 times the country's projected national demand in 2050, and only 0.8% of the onshore wind energy potential area could supply Australia's entire projected electricity demand in 2050. The restrictions on project locations mean that the projections of onshore energy potential are usually conservative compared with the projected solar energy potential. However, our results confirm that Australia also has great onshore energy potential, which is more than sufficient to meet the national renewable energy target by 2050.

The largest onshore wind energy potential is found in Western Australia, with more than 1.7 million km^2 (68.0% of the state land area), followed by Queensland with 1.3 million km^2 (76.8%), New South Wales with 0.59 million km^2 (74.7%), and the Northern Territory with 0.57 million km^2 (42.1%).

In Onshore Wind Scenario 2, the area identified with onshore wind energy potential is 401,370 km^2 (equivalent to 5.2% of the land area). This land could accommodate 2,006 GW of installed capacity and generate 6,021 TWh year^{-1} of onshore wind electricity. The electricity generation potential is 11 times the projected final electricity demand in 2050, and 9.2% of this land area could supply the country's entire projected electricity demand in 2050. If onshore wind projects are combined with solar PV systems, the land required for the projects to meet these targets may be reduced significantly.

Table 6. Onshore wind energy potential areas in Australia.

State or territory	Onshore wind energy potential area (km^2) (% of land area)	Onshore wind energy potential (GW)	Onshore wind electricity generation potential (TWh/year)
NSW & ACT			
– Scenario 1	598,291 (74.5%)	2,992	8,974
– Scenario 2	106,622 (13.3%)	534	1,601
NT			
– Scenario 1	566,679 (42.1%)	2,833	8,500
– Scenario 2	6,698 (0.5%)	34	100
QLD			
– Scenario 1	1,326,639 (76.8%)	6,633	19,900
– Scenario 2	109,726 (6.4%)	549	1,646
SA			
– Scenario 1	505,265 (51.4%)	2,526	7,579
– Scenario 2	54,480 (5.5%)	272	817
TAS			
– Scenario 1	16,362 (24.2%)	82	245
– Scenario 2	8,226 (12.2%)	41	123
VIC			
– Scenario 1	121,555 (53.5%)	608	1,823
– Scenario 2	38,874 (17.1%)	194	583
WA			
– Scenario 1	1,715,955 (68.0%)	8,580	25,739
– Scenario 2	76,601 (3.0%)	383	1,149
Australia (total)			
– Scenario 1	**4,850,753 (63.2%)**	**24,254**	**72,761**
– Scenario 2	**401,370 (5.2%)**	**2,006**	**6,021**

Note: Scenario 2 (Transmission Lines ⩽10 km)

Table 7. Comparison of projected onshore wind electricity generation potential with projected final electricity demand in 2050.

State or territory	Regional projection of electricity demand in 2050 (TWh/year)	Ratio of potential generation to projected demand in 2050	% of onshore wind energy potential area required to supply regional or national demand in 2050
NSW & ACT			
– Scenario 1	176	51	1.96
– Scenario 2		9	11.00
NT			
– Scenario 1	7	1,282	0.08
– Scenario 2		15	6.63
QLD			
– Scenario 1	130	154	0.65
– Scenario 2		13	7.87
SA			
– Scenario 1	33	229	0.44
– Scenario 2		25	4.05
TAS			
– Scenario 1	22	11	9.18
– Scenario 2		5	18.28
VIC			
– Scenario 1	126	14	6.93
– Scenario 2		5	21.66
WA			
– Scenario 1	58	444	0.23
– Scenario 2		20	5.04
Australia (total)			
– Scenario 1	**552**	**132**	**0.8**
– Scenario 2		**11**	**9.2**

Note: Scenario 2 (Transmission Lines ⩽10 km)

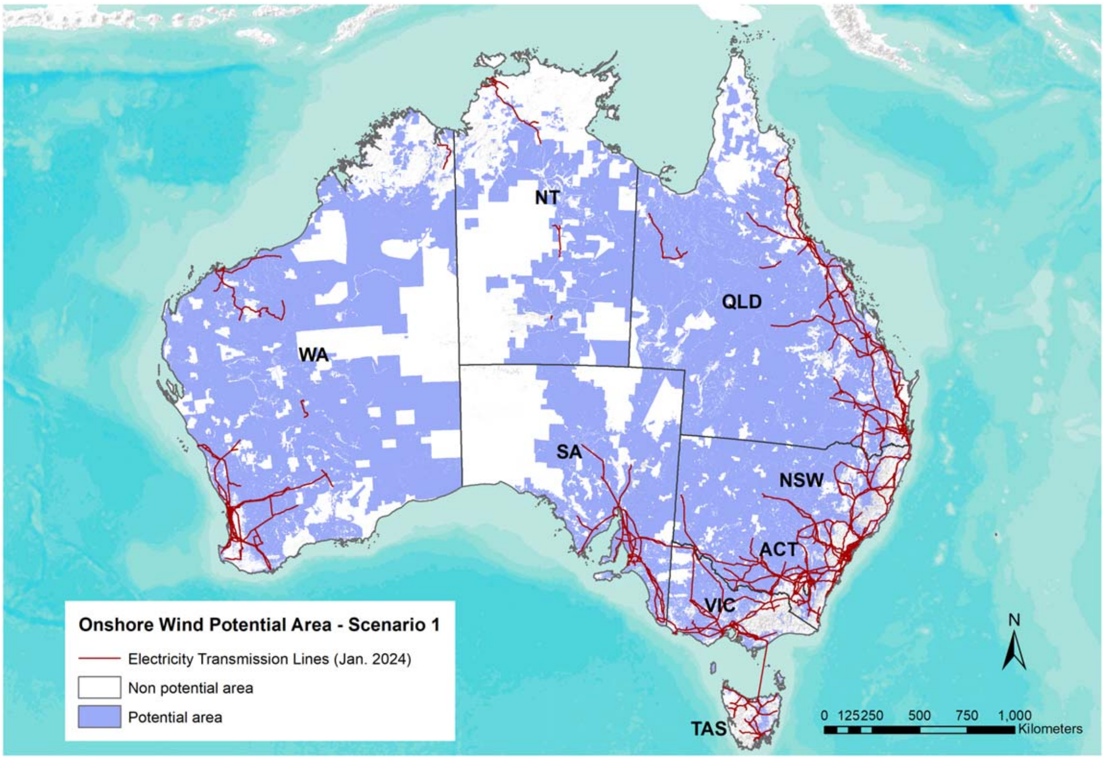

Figure 5. Onshore wind energy potential areas in Australia.

3.3. Offshore wind energy potential in Australia

In this analysis, two scenarios of installed capacity restricted by water depth have been prepared and calculated (table 8). Australia is a continent with a long coastline. In total, 347,578 km^2 were identified as offshore energy potential area in Scenario 1, with water depths up to 50 m (Offshore Scenario 1), which has the potential to provide 1,738 GW of installed capacity from offshore wind energy projects, generating 6,257 TWh year^{-1} of electricity (figure 6). This scenario provides 11 times the predicted energy demand of Australia in 2050. When the use of floating foundations in ocean up to 500 m in depth is assumed (Offshore Scenario 2), the suitable area tripled to 1,063,527 km^2, with potential installed capacity of 5,318 GW and generating 19,145 TWh year^{-1} of electricity (figure 7). This scenario provides 35 times the predicted energy demand of Australia in 2050.

Our analysis and maps also confirm that offshore wind is a suitable energy source for southern states, such as Victoria, Tasmania, and South Australia. These states have more land constraints than other states because the populations are located along coastal areas, where areas of higher wind speed are located.

Table 8. Offshore wind energy potential areas in Australia.

	Australian EEZ		
	Offshore wind energy potential area (km^2)	Offshore wind energy potential (GW)	Offshore wind electricity generation potential (TWh/year)
Offshore Scenario 1 (water depth $\leqslant$50 m)	347,578	1,738	6,257
Offshore Scenario 2 (water depth $\leqslant$500 m)	1,063,527	5,318	19,145

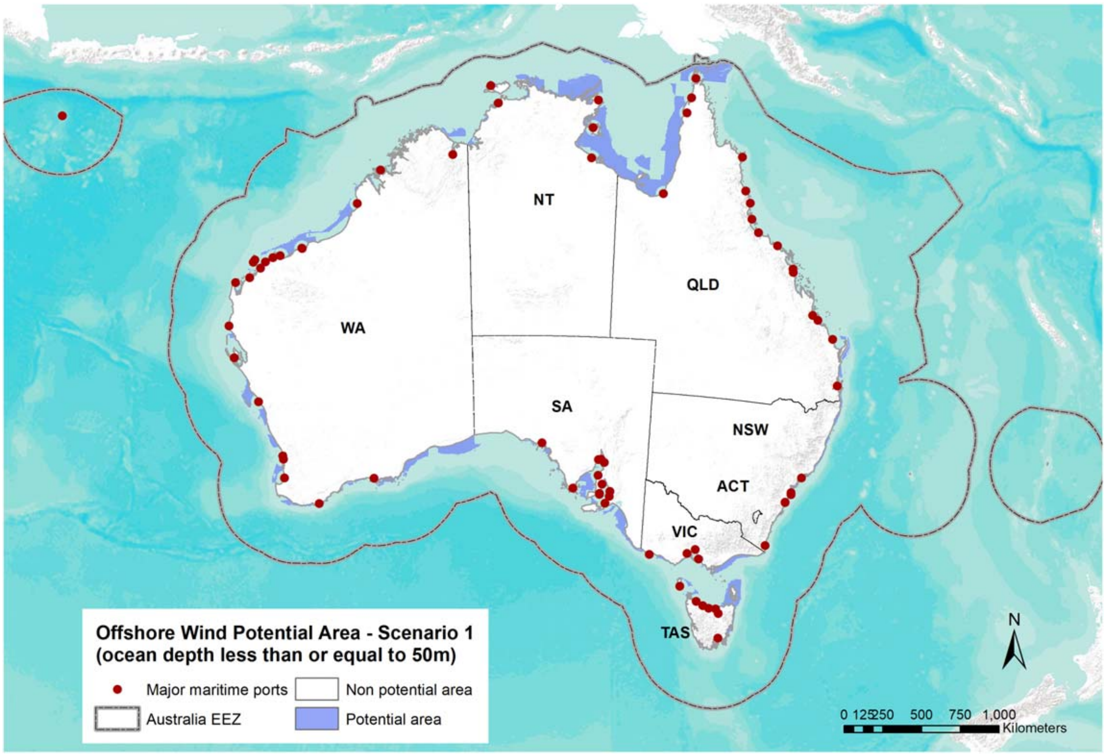

Figure 6. Offshore wind energy potential areas in Australia—Offshore Scenario 1 (ocean depth ⩽50 m).

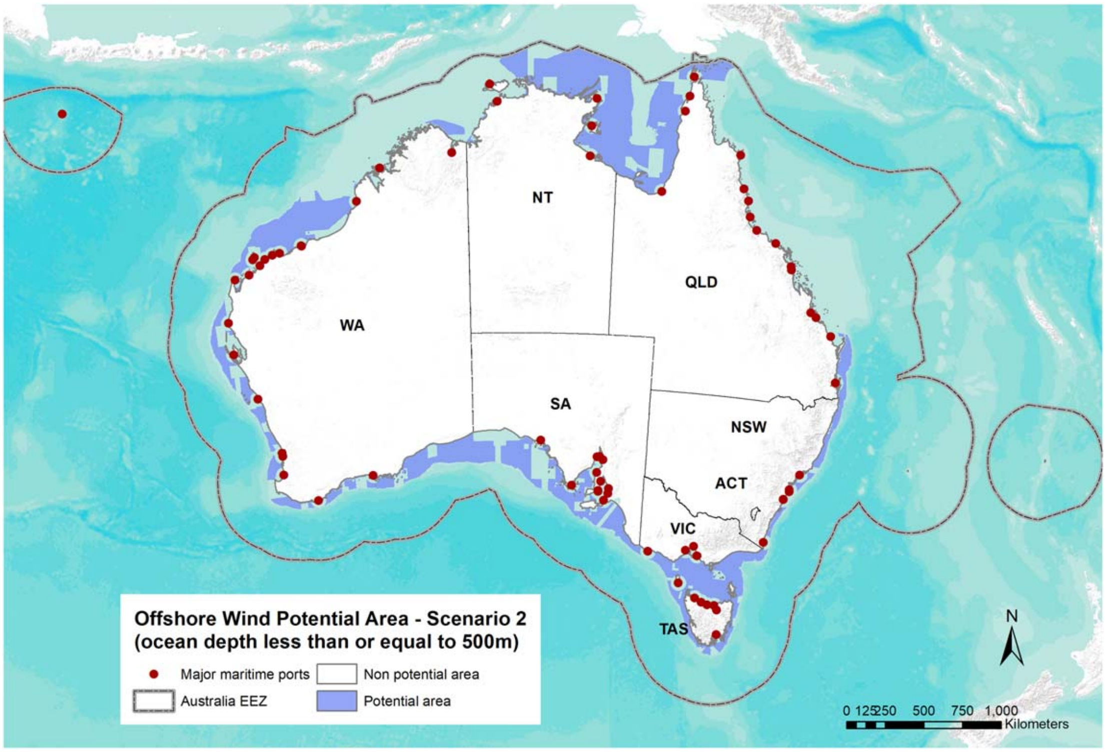

Figure 7. Offshore wind energy potential areas in Australia—Offshore Scenario 2 (ocean depth ⩽500 m).

4. Discussion

4.1. Australia's comparative advantages transitioning to renewable energy

4.1.1. High potentials for solar and wind energy

Our analysis identified over 5.1 million km^2 of land with solar potential or 4.8 million km^2 with onshore wind potential. These findings suggest that utilizing only 0.4% of the solar potential area or 0.8% of the wind potential area alone would be sufficient to meet the country's projected electricity demand in 2050. Furthermore, Australia has a long coastline, a large part of which could be suitable for offshore wind projects. For example, our analysis found that only 2.9% of Australia's offshore wind potential area under Offshore Scenario 2 (water depth $\leqslant$500 m) would be required to meet the country's projected electricity demand in 2050.

This work extends upon a previous study that was part of a global analysis of the G20 countries (Miyake *et al* 2024). Our findings demonstrate that among the G20 countries, Australia has considerable advantages in its solar energy and onshore wind energy potentials (tables 9 and 10). The areas of renewable energy potential identified here are indicative in so far as they provide a high-level assessment of regions with high potential, and a detailed analysis at local and site scale would be required to select relevant sites for project development. The results indicate that the use of only small proportion of the identified renewable energy potential areas in Australia can easily meet the national electricity demand in 2050. This is largely because of the small national population and the low national energy demand compared with those of countries of similar size, such as China and the United States.

Overall, this GIS-based spatial analysis indicates that Australia could be a leader in the global transition to renewable energy, with a real possibility of becoming a 'renewable energy superpower' if the uptake of renewable energy resources is pursued. Our work also shows that Australia has sufficient renewable potential to achieve 100% renewable energy and could meet its net zero targets without the inclusion of nuclear power in the energy mix.

The results also demonstrate that each state is extremely well positioned to achieve its own net zero ambitions, given that each state need only harness a fraction of its solar and wind potential to meet its projected energy demand by 2050. Moreover, Australia as a whole has excellent offshore wind potential, and will only require a fraction of this power to help power its net-zero ambitions. Our results are consistent with a variety of previous studies, which demonstrated that Australia is well positioned to decarbonise its energy system using renewables, including studies undertaken by the Australian Energy Market Operator (AEMO) and other governmental authorities, as well as a variety of academic studies that have demonstrated the feasibility and cost-effectiveness of using 100% renewables (Elliston *et al* 2014, Blakers *et al* 2017, Rispler *et al* 2022).

Table 9. Comparison of the solar energy potentials of G20 countries.

	Solar Potential Area (km^2)	% of country area	Installed potential (GW)	Solar electricity generation potential (TWh/ year)	Final electricity demand in 2050 (TWh/ year)	Ratio of potential generation to the projected demand in 2050	% of Solar Potential Area required to supply the final electricity demand in 2050
G20	33,575,355	42	839,384	923,322	48,859	19	5.3
China	5,151,340	55	128,784	141,662	15,000	9	10.6
Australia	5,140,920	67	128,523	141,375	552	256	0.4
United States	4,810,580	51	120,265	132,291	8,530	16	6.4
Brazil	3,494,390	41	87,360	96,096	1,279	75	1.3
Russia	2,667,510	16	66,688	73,357	1,544	48	2.1
India	2,389,050	76	59,726	65,699	7,451	9	11.3
Canada	2,095,810	21	52,395	57,635	1,137	51	2.0
Argentina	1,797,550	65	44,939	49,433	1,238	144	0.7
Saudi Arabia	1,682,780	87	42,070	46,276	781	59	1.7
EU27	1,376,011	33	34,400	37,840	5,247	7	13.9
Mexico	1,160,220	59	29,006	31,906	697	46	2.2
South Africa	959,713	79	23,993	26,392	446	59	1.7
Türkiye	527,680	68	13,192	14,511	1,223	12	8.4
France[a]	265,645	48	6,641	7,305	848	9	11.6
Indonesia	227,007	12	5,675	6,243	1,525	4	22.8
Italy[a]	158,780	53	3,970	4,366	597	7	13.7
Japan	60,837	16	1,521	1,673	1,647	1	98.5
Germany[a]	57,852	16	1,446	1,591	1,136	1	71.4
South Korea	32,823	33	821	903	975	0.9	—
UK	1,134	0.5	28	31	581	0.1	—

[a] Countries in the European Union (EU27)

It is assumed that the installed capacity per km^2 is 25 MW on average, and the solar electricity generation potential (TWh/year) is calculated under the assumption of a 1,100 h year^{-1} capacity factor.

Table 10. Comparison of the onshore wind energy potentials of G20 countries.

	Onshore wind Area (km^2)	% of country area	Installed potential (GW)	Wind electricity generation potential (TWh/a)	Final electricity demand in 2050 (TWh/ year)	Ratio of potential generation to the projected demand in 2050	% of Wind Potential Area required to supply final electricity demand in 2050
G20	31,128,332	39	155,642	466,925	48,859	10	10.5
Australia	4,850,800	63	24,254	72,762	552	132	0.8
China	4,793,340	51	23,967	71,900	15,000	5	20.9
Russia	4,643,550	27	23,218	69,653	1,544	45	2.2
United States	4,351,580	46	21,758	65,274	8,530	8	13.1
Canada	3,350,930	34	16,755	50,264	1,137	51	2.2
Argentina	1,932,520	70	9,663	28,988	1,238	84	1.2
Brazil	1,682,680	20	8,413	25,240	1,279	20	5.1
Saudi Arabia	1,619,240	84	8,096	24,289	781	31	3.2
EU27	1,326,087	32	6,630	19,891	5,247	4	26.4
India	886,384	28	4,432	13,296	7,451	2	56.0
South Africa	793,516	65	3,968	11,903	446	27	3.7
Mexico	491,606	25	2,458	7,374	697	11	9.4
France[a]	249,782	46	1,249	3,747	848	4	22.6
Türkiye	229,396	29	1,147	3,441	1,223	3	35.5
Germany[a]	139,767	39	699	2,097	1,136	2	54.2
UK	119,854	49	599	1,798	581	3	32.3
Italy[a]	49,812	17	249	747	597	1	79.9
Indonesia	24,890	1	124	373	1,525	0.3	—
Japan	21,340	6	107	320	1,647	0.2	—
South Korea	10,620	11	53	159	975	0.2	—

[a] Countries in EU27

It is assumed that the installed capacity per km^2 is 5 MW on average, and the onshore wind electricity generation potential (TWh/year) is calculated under the assumption of a 3,000 h $year^{-1}$ capacity factor.

4.1.2. Co-benefits: potential solutions for energy security, equity, and reliance, and socio-economic benefits

The advantages of solar and wind energy are often discussed within the context of decarbonisation. However, it is also important to discuss other critical benefits, such as the strengthening of energy security, equity, and reliance, and the local socio-economic benefits for remote and rural communities in Australia. The continent has one of the lowest population densities (three people per km^2) in the world, and the national electricity grid (National Electricity Market) does not cover remote inland areas. The Australian Renewable Energy Agency estimated that around 500,000 people (2% of the population) live in remote areas with no connection to the electricity grid (ARENA 2023). Even when there is access to transmission lines, only low-voltage lines are available to many inland towns. A stable and reliable electricity supply has always been a challenge in remote parts of Australia due to the difficulties in developing electricity infrastructure, its extension and maintenance, outside populated areas. In recent years, the effects of climate change have been felt in Australia, large areas of which are located in either arid or semi-arid climatic zone. The climate is getting tougher each year, with increasing temperatures (exceeding 40 °C in some inland regions) and increasingly frequent drought, floods, bushfires, and extreme weather events in summer (Bureau of Meteorology and CSIRO 2024). The system sometimes suffers blackouts and interruptions in summer (e.g., loss of air-conditioning and refrigeration systems), which could have serious implications for livelihoods, health, and the activities of daily life in remote communities, including Aboriginal communities (Standen *et al* 2022, Mathew *et al* 2025, Norman *et al* 2025a). The limitations of a centralised electricity system that relies on existing grids have been felt by communities that do not live close to the existing infrastructure. Consequently, a distributed energy supply and stand-alone energy systems powered by solar and/or wind and combined with batteries, such as rooftop solar systems and small microgrids, which can power communities, are being proposed and developed across the country, and are expected to play a crucial role in remote communities in Australia (Dwyer *et al* 2023, Wright 2024, Australian Government 2019, Mathew *et al* 2025).

4.2. Current challenges in Australia's energy transition

Despite these findings that Australia is the best-placed member nation of the G20 in terms of decarbonising its energy system and has ample renewable potential to successfully transition to a net-zero economy, there are still challenges. Specifically, Australia's transition to renewables-based energy system remains a point of social and political friction, including opposition from regional communities in areas of renewable energy generation and infrastructure projects. The 'HaveYourSay' survey undertaken by the Australian Government as part of the Community Engagement Review on renewable energy infrastructure developments reflects the dissatisfaction of these regional communities who live near desirable renewable energy sites. Project developers tend to prioritise technical and economic considerations, and thus regional communities who are more accommodated to their traditional regional landscape and agricultural economy are likely to have competing priorities for their region. The survey confirmed high rates of dissatisfaction with project developers among community members:

- '92% of respondents were dissatisfied with the extent to which project developers engaged the local community;
- 85% of respondents were dissatisfied with the explanations provided by project developers in response to their questions;
- 85% of respondents stated that their concerns were not addressed in a timely manner' (Dyer 2024).

Therefore, community dissatisfaction with the engagement processes used by developers is seen as creating a barrier to the large-scale roll-out of renewable energy projects and an environment in which the genuine concerns of individuals can become amplified. Social licence issues arising from these processes extend to both onshore and offshore projects, as well as to the development of infrastructure to support the transition (e.g., new overhead transmission lines, and battery storage). Therefore, the most important piece of the puzzle remaining is the establishment of appropriate regulatory and policy frameworks to ensure that community engagement processes are conducted adequately when new infrastructure is developed.

Without appropriate community engagement processes, hesitancy and resistance to renewable energy infrastructure is likely to propagate across regional areas. The following sections provide details of the challenges and solutions facing the roll-out of developments in renewable energy infrastructure in Australia.

4.2.1. Solar and onshore wind: Competition for agricultural land, and roles of spatial analysis and maps in community engagement

One of the main challenges in energy transition is the competition for land with biodiversity conservation, food production, and other urban and agricultural land uses (Nonhebel 2005, Miyake *et al* 2012, Van De Ven *et al* 2021). The issue has been discussed in a number of studies internationally, including in the United States (Swofford and Slattery 2010, Bidwell 2013, Burch *et al* 2020, Cunningham and Seidman 2024) and Europe (Jackson 2011, Tafarte *et al* 2022, McKinsey and Company 2023). Despite Australia's extensive land resources available for energy infrastructure, the transition may face similar issues to those of other countries regarding the competition for land and resistance to renewable energy developments by communities.

One such example is the rising tension between agricultural communities and renewable energy projects (Gerrard *et al* 2025). Proposals of large-scale solar projects in multiple regions across Australia is a point of contention with some existing landowners in areas ear-marked for development (Taylor 2024, Gerrard *et al* 2025). In 2020–2021, agricultural land accounted for >65% of the total national land area of Australia. Extensive grazing land for sheep and cattle covered in native vegetation accounts for a significant proportion of the total agricultural land (ABARES 2024). These large grazing plots are also of interests for large-scale renewable energy projects. As a result, renewable energy companies and farmers can find themselves in competition, and in some cases, this can escalate into conflict. In particular, rural communities that have previously experienced the impacts of mining and energy projects (e.g., coal seam gas) tend to oppose new energy projects (Taylor 2024). There is widespread dissatisfaction with the extent to which developers of new energy projects engage with the community and with the processes used to address their concerns. Community members can hold an array of concerns on possible impacts on their livelihoods (e.g., farming operations, restriction of activity posed by specific regulations), which may be caused directly or indirectly by the development of a project and the related infrastructure, such as proposed transmission lines, large electricity towers and batteries to support the project. In 2023, AEMO released a map including 10,000 km of high voltage transmission lines which need to be built to support the country's energy transition (ABC News 2023), which has caused strong oppositions from regional communities across the country (Burnett 2023, Norman 2023). Other concerns range from loss of local biodiversity and its habitat (Burnett 2023), uncertainties with the final designs of projects and the proposed placement of infrastructure, changes to the landscape, possible impacts on their property values, and ability to sell plots of land (Daly 2023), and bushfire risk and heat impacts from battery installation (Brown *et al* 2025).

All experience has suggested that effective planning and engagement are critical in success of new renewable energy projects. The responsibility for the planning and development of renewable energy projects is currently allocated to different levels of government in Australia. For example, local governments are responsible for land use planning and approvals for small and mid-scale solar energy projects[2], whereas state governments oversee planning approvals for large-scale solar and most onshore wind energy projects given their expected impacts, as in New South Wales. Because offshore wind projects involve national waters, the Federal Government is responsible for the development and regulation of offshore wind zones. Each guideline specifies the importance of considering local impacts of projects on immediate areas surrounding a project (e.g., Wind Energy Guideline (NSW Government 2024), Large-scale Solar Energy Guideline (NSW Government 2022)). Despite the fact that these guidelines provide a planning framework regarding site selection, environmental impacts, and require the consideration of an array of other matters (including some guidance on community engagement), community members are not feeling adequately consulted or supported by the practices of current developers. Meanwhile, there are innovative initiatives and guidelines for developers to fill the above gaps, which are currently led by not-for-profit organisations such as Australian Renewable Energy Alliance, First Nations Clean Energy Network, and the Community Power Agency (Gerrard *et al* 2025). In fact, the mapping concept and method used in this study was applied in a more recent project, which aimed to inform the local Aboriginal communities in New South Wales about potential sites for renewable energy development. A series of maps were generated for the case study areas to support local decision-making in selecting locations for future renewable energy projects on their landholdings, addressing current climate and energy security challenges the communities are facing (Norman *et al* 2025a, 2025b). This project highlighted that spatial analysis and mapping could play a significant role in initiating conversations with local communities, supporting the engagement process, enabling local input, and guiding informed decision-making in the energy transition of regional Aboriginal communities in Australia.

Lastly, new technical and economic approaches have been examined to create win–win situations for both the agricultural/rural sector and the renewable energy sector, and to reduce the competition for land, such as agrivoltaics and microgrids. Agrivoltaics has greater precedent in the United States, Europe, and Japan than in Australia. The system is designed to generate benefits for farmers by reducing the GHG emissions from agriculture and improving energy security and income diversification. The development of agrivoltaics is slow in Australia and many issues in the current regulatory and policy frameworks remain unresolved (Taylor *et al* 2024), while the potential of agrivoltaics is considered in the context of multiple goals, including helping meet climate, energy, and food demands (Gomez-Casanovas *et al* 2023). Microgrids are another technical advancement which can help avoid construction of additional high voltage transmission lines and large-scale batteries, by producing and managing power at a local level. Thus, providing the potential to mitigate additional land use competition in regions which would otherwise need to be connected to large-scale infrastructure.

4.2.2. Offshore wind: A possible solution to land use competition?

Our findings also highlight Australia's substantial offshore wind energy potential. To date, no offshore wind project has yet come online in Australia, although the technology currently has strong support from governments at both the national and state levels. The Federal Government has currently identified six priority areas for offshore wind along Australia's coastline (Australian Government 2024a), with Australia as a whole attracting more than 15 project proposals (Renew Economy 2025). The offshore wind sector in Australia is only now emerging and thus the path to final investment decisions (FID) was likely to be protracted even for more advanced projects given the work required to reach FID (e.g. licensing, feasibility assessment, environmental impact assessment, transmission & interconnection studies, planning approvals etc). The sector faces some headwinds particularly in relation to projects securing financing, as several projects were relying on backing from fossil fuel companies which have since scaled back their ambitions in this emerging sector to focus on returning value to shareholders through their primary business activity of extracting, processing and selling fossil fuels (Edward 2025). Offshore wind is not without its own technical and financial challenges—especially in the nascent Australian market.

The Minister for Climate Change and Energy undertook a community consultation process for each of the six offshore wind zones. Thousands of responses were received from community groups and organisations, industry associations, trade unions, and non-governmental organizations. Through this process, the priority areas have been adjusted in line with the feedback received. For instance, zones have been moved further from the shoreline, and regions have been adapted to provide shipping lanes and to accommodate other ocean users (e.g., industry, fisheries) (Australian Government 2024e, ABC News 2024). The Minister also declared that

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[2] When a solar energy project has a capital investment value of more than $30 million, or a capital investment value of more than $10 million and is in an environmentally sensitive area of state significance.

'future offshore wind projects must share the space with existing marine users, including First Nations, fishers, shipping, and defence' (Australian Government 2024e).

The community concerns raised and the pushback from some industry groups have raised questions about the suitability of leveraging offshore wind at scale to reduce pressures on the competition for land that arises with onshore renewable energy projects. A study from the Massachusetts region in the United States demonstrated a variety of reasons why community members opposed offshore wind development. The study identified three main community concerns: impacts on marine life and the environment (65% of the sample), aesthetics (51%), impacts on fishing and boating safety (50%) (Firestone and Kempton 2007). Aesthetic impact was considered to be the output with the most likely negative impact (72% of sample) (Firestone and Kempton 2007). Another study from the same region in the USA reported that community members can greatly overestimate the likely environmental impact of the projects compared with existing marine activities (Kempton *et al* 2005). The findings of these US studies can be translated to the Australian context, given that offshore wind was a new development in both regions. The similarities of these regions are reflected by the fact that offshore wind proposals have faced opposition on the same grounds.

It is also important to note there has also been strong community support for offshore wind projects in coastal regions of Australia, mainly due to the creation of jobs and local industries, and locally sourced renewable energy (Stephens and Burfitt 2024). Policy makers and project proponents can leverage existing support as it has been shown that 'local people are more likely to accept these facilities, if they provide clear, tangible socio-economic benefits for their communities and if a balanced, shared use of the sea can be guaranteed in which important local economic sectors can continue to thrive (Frolova *et al* 2022)'. Other studies have demonstrated that early and frequent two-way engagement, alongside addressing specific community concerns with clear and accessible information, can create successful outcomes with stronger project support (Hall and Lazarus 2015).

4.3. Limitations and future works

Our spatial assessment of solar and onshore wind potentials was initially designed and conducted as part of our assessments of G20 countries, in a foundational work to allow comparisons to be made of the renewable energy potentials of different countries (Miyake *et al* 2024). An offshore wind analysis was added to provide a comprehensive picture of the renewable energy potential in Australia. Our maps only present 'indicative' areas based on theoretical and geographical potentials, given geographical and land-resource constraints. Therefore, these maps are not intended to be used to determine where renewable projects can be constructed or as an indication of the areas that should host renewable energy infrastructure developments. The authors fully acknowledge the need for careful consideration of the potential competition for land. In our solar energy potential maps, the areas of possible utility include existing built-up areas to allow for increased rooftop solar PV installations, whereas some land that is already incompatible with such use (i.e., lacks available rooftops) must be excluded from further analyses. Similarly, the areas identified as having renewable energy potential in this study include agricultural land and parts of forested areas, because large plots of flat agricultural land (e.g., extensive grazing land) is also favourable for renewable energy projects in Australia.

The spatial analysis was conducted as an international study, and therefore limitations are identified in terms of its integration with specific challenges Australia's renewable energy roll-out is currently facing. Future analyses could leverage finer-resolution data to support local decisions to address economic, social and environmental concerns, reflecting local contexts. For example, certain economic factors relevant to renewable energy projects were considered in our scenarios, such as proximity to high-voltage transmission lines and minimum wind speed. However, integrating a comprehensive economic analysis in future studies could further refine the commercially viable potential identified in this assessment. The classification and quality of agricultural land in terms of agricultural productivity can be also considered to better select areas for exclusion, and areas in which the integration of agrivoltaics with food production is suitable can be identified. As for environmental and social considerations, areas proximate to high conservation priority must also be excluded from future analyses (e.g., buffer zones), and consideration given to the habitats of local flora and fauna and areas with significant ecological and cultural value, to ensure optimal land-use decisions. These additional spatial layers can be developed by integrating local information and knowledge into future work, such as flooding and bush fire risks, energy infrastructure and network planning, regional planning and land zoning, and land ownership data (including land owned by the Aboriginal communities). There are also significant opportunities to refine our offshore wind potential map, including additional local factors such as sub-sea cables (Bosch *et al* 2018), proximity to shore, shipping routes, vessel movements and density, locations of onshore support works (Johnston *et al* 2025), current effects, distances to infrastructures (ports and substations), cost parameters (Nagababu *et al* 2017) as well as local marine biodiversity and ecosystem data. The finer-scale spatial analysis can be combined with a multi-criterion decision-making tool, such as Analytic Hierarchy Process (AHP), which enable identifying the most suitable project sites for the local needs.

5. Conclusion

Australia aims to rapidly transform its economy to become a 'renewable energy superpower' and to meet its net-zero emissions target by 2050. In this study, a GIS-based spatial analysis was conducted to better understand the renewable energy potentials in Australia using the [R]E Space approach, and to compare them against the projected national and state energy demands in 2050, obtained with the OECM (Teske 2019). This analysis aims to inform a wide range of international and Australian stakeholders of our findings to accelerate this ongoing transition.

Our results indicate that Australia could be a leader in this global transition to renewable energy, with the real possibility of becoming a 'renewable energy superpower' if the uptake of renewable energy resources is pursued. Specifically, our analysis identified over 5.1 million km^2 of land with solar energy potential and 4.8 million km^2 with onshore wind energy potential. These findings suggest that the solar energy potential is 256 times greater than the 2050 energy demand and that the onshore wind energy potential is 132 times that demand. This indicates that utilizing only 0.4% of the solar potential area or 0.8% of the wind potential area will be sufficient to meet the country's projected electricity demand in 2050. Large offshore wind energy potentials were also identified for Australia, with an area of 347,578 km^2 available for one proposed scenario (water depths $\leqslant$50 m), which is 11 times greater than the predicted national energy demand in 2050.

In Australia, where the development and maintenance of the energy infrastructure are challenging in weakly populated small inland towns and remote areas, renewable energy and related technologies could provide significant benefits to remote and rural communities, enhancing energy security, reliability, independence, equity, and socio-economic opportunities. However, challenges related to the larger deployment of renewable energy infrastructure may be similar to those found in other countries. These include growing tension and community resistance to new projects due to competition for land for large onshore projects and concerns about the possible impacts of infrastructure. Therefore, the changes that will be decisive in enabling a successful transition are the promotion of emerging technologies to mitigate any potential impacts and land-use competition; and the rapid development of regulatory and policy reforms in planning and community engagement processes, to leverage existing support for renewable energy.

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Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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