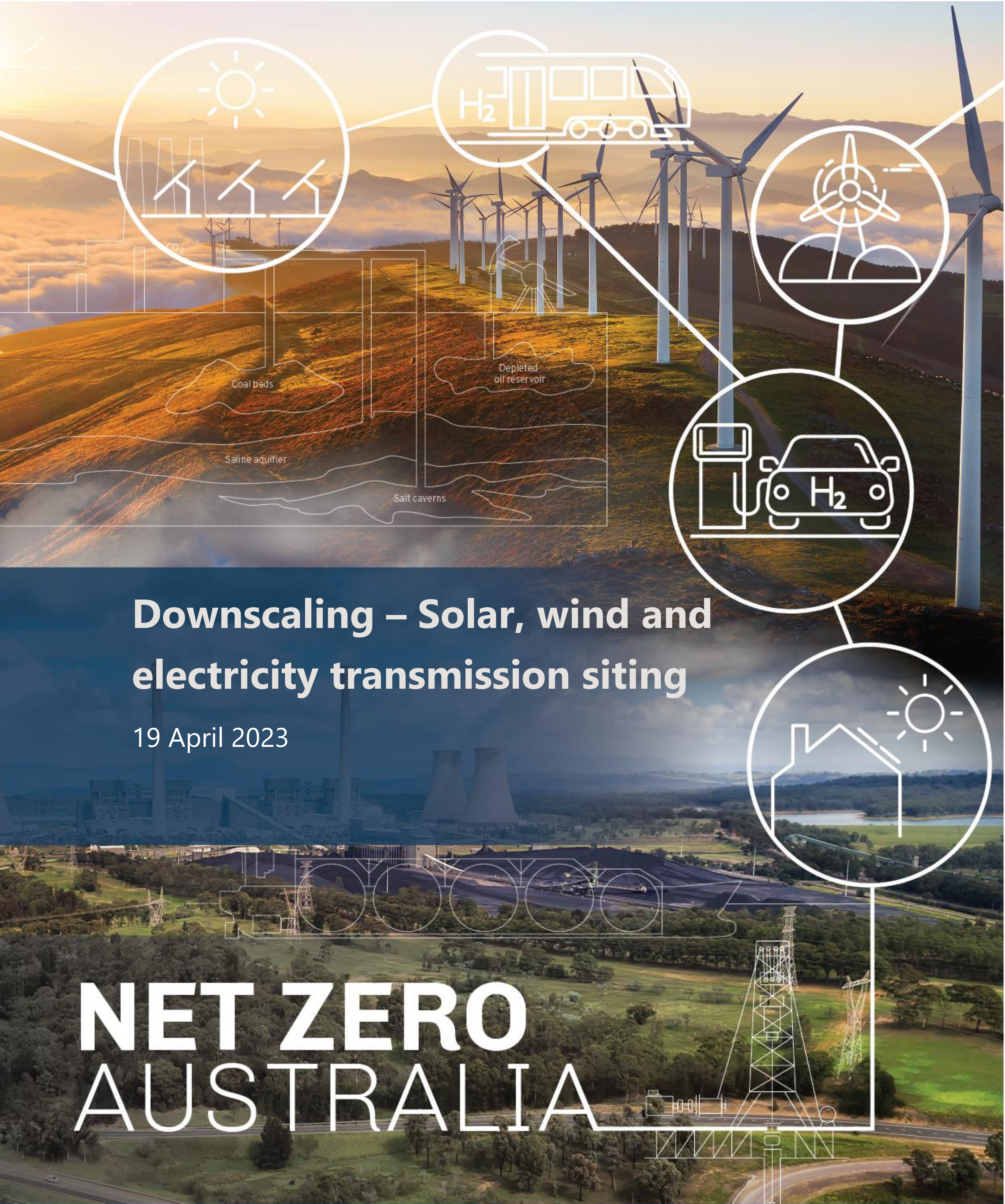

Downscaling – Solar, wind and electricity transmission siting

19 April 2023

NET ZERO
AUSTRALIA

THE UNIVERSITY OF MELBOURNE
PRINCETON UNIVERSITY
THE UNIVERSITY OF QUEENSLAND AUSTRALIA
CREATE CHANGE
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The Net Zero Australia (NZAu) project is a collaborative partnership between the University of Melbourne, The University of Queensland, Princeton University and management consultancy Nous Group. The study examines pathways and detailed infrastructure requirements by which Australia can transition to net zero emissions, and be a major exporter of low emission energy and products.

Net Zero Australia

Downscaling – Solar, wind & electricity transmission siting

19 April 2023

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Contents

1 Introduction

The Net Zero Australia (NZAu) project is informed by the Net Zero America (NZA) project where over 3 TW of variable renewable energy (VRE) projects were sited in the project's 'middle of the road' scenario, and the US transmission grid grew by ~3x its current total capacity [1]. Therefore, it was assumed from the outset of NZAu that large quantities of variable renewable energy (VRE) – in the form of solar PV and wind projects – and electricity transmission lines would be needed to make any net-zero transition in Australia feasible.

Several detailed downscaling steps were taken to inform the NZAu balancing model. These steps are covered in the *Methods, Assumptions, Scenarios & Sensitivities* (MASS) [2] document and include the generation of renewable energy availability traces, and the processes of explicitly siting and determining the relevant characteristics (including cost parameters) of all possible variable renewable energy (VRE) and transmission projects that can be used by the model. This document does not cover the capital costs of VRE and transmission infrastructure. A discussion of the capital needed for the transition can be found in the *Downscaling – Capital Mobilization* document.

This document covers VRE and electricity transmission results for NZAu's core scenarios. The core scenarios discussed in this document are the high electrification (E+), slow electrification (E–), 100% renewables (RE+), renewables constrained (RE–), and the onshoring (ONS) scenarios. A detailed description of each of these scenarios can be found in the MASS document [2].

Three of the NZAu scenarios (E+, RE+, E–) see 3 TW of VRE capacity installed with lesser amounts in the ONS (~2.2 TW) and RE– (~1.5 TW) scenarios. Solar PV capacity represents the majority VRE share in all scenarios, with onshore wind seeing modest capacity growth in early years of the transition followed by a loss of VRE share in later years as solar PV costs drop well below wind costs in all regions of Australia. Offshore wind is the least utilized VRE technology in four of five scenarios (with < 60 GW of installed capacity) but reaches over 400 GW of installed capacity – representing over a quarter of all installed VRE capacity – in the RE– scenario.

Electricity transmission is needed to transfer electricity from VRE installations to load destinations in both export and domestic zones. Over 370,000 GW-km of transmission capacity is added to existing transmission capacity by 2060 in all scenarios but the ONS scenario which only adds 235,000 GW-km capacity. Placing these unprecedented builds in the context of an Australian high voltage transmission system estimated to be roughly 28,000 GW-km in 2020 - the domestic portion of the build peaks at 2.9x the 2020 total (~80,000 GW-km) in 2050 in the E+ scenario, while the export zone focused transmission build expands to 10x the 2020 total (~293,000 GW-km) by 2060, representing ~80% of the total build. The E+ 2050 domestic build of 2.9x the 2020 total Australian system can be compared with the NZA E+ 2050 domestic build that was 3.1x the estimated GW-km capacity of the USA's 2020 transmission network [1].

The scale and ambition of VRE and transmission builds for all NZAu scenarios are unprecedented in Australia.

2 Modelling results for VRE and electricity transmission lines at national scale

Figure 1 presents the cumulative installed capacities of the utility-scale wind and solar PV technologies included in the net-zero transition at a national level in GW by scenario and year. Figure 1 indicates that solar PV is the utility-scale variable renewable energy (VRE) resource most used in all NZAu core scenarios, with installed capacities in 2060 ranging from just under 1 TW in the RE– scenario to over 3 TW in the RE+ scenario. Offshore wind is least utilized VRE technology in 2060 in the E+ scenario with 47 GW of installed capacity but sees 420 GW installed in the RE– scenario. Onshore wind installations are more constant across all scenarios in Figure 1, ranging between a minimum installed capacity of 71 GW in 2060 (down from 105 GW in 2035) in the ONS scenario to a maximum of 113 GW in 2060 (down from 150 GW in 2040) in the RE+ scenario. The installed capacity of onshore wind peaks in 2040 in all scenarios in Figure 1 as the price of solar PV technology falls below the price of onshore wind during the final 20 years of the transition.

Figure 1 | The cumulative installed capacities of the utility-scale wind and solar PV technologies included in the net-zero transition at a national level in GW by scenario and year

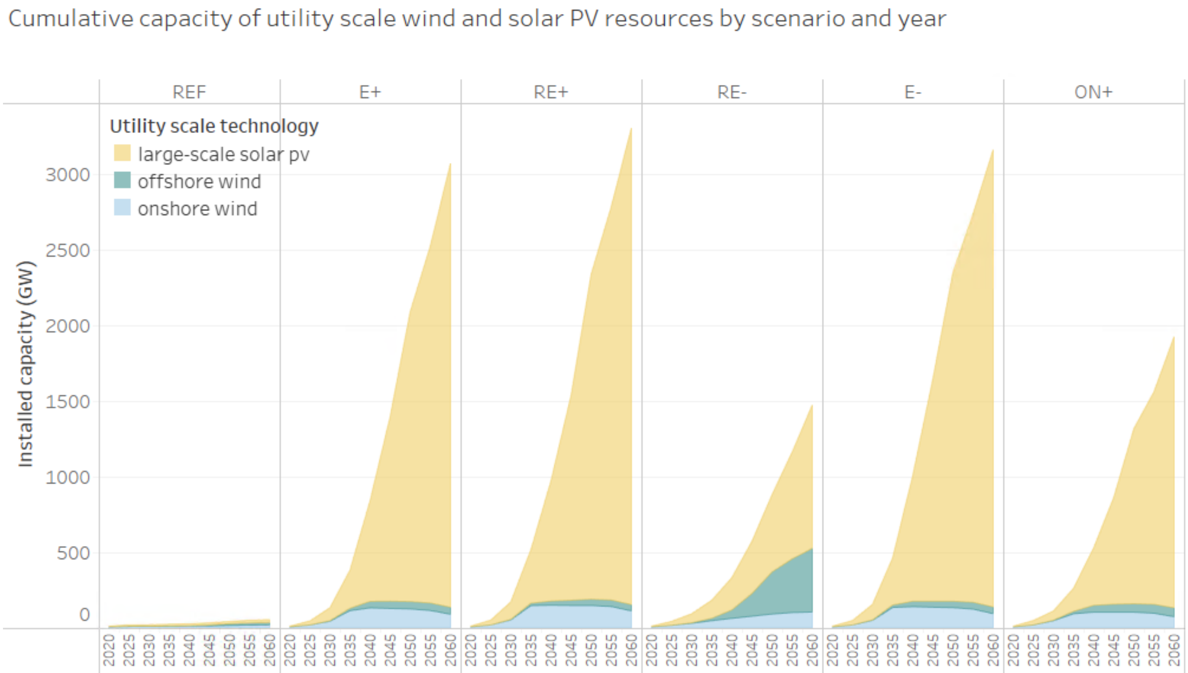


Figure 2 presents the cumulative installed capacities (in GW) of the utility-scale wind and solar PV technologies included in domestic regions of the NZAu model, by scenario and year. Figure 2 requires a caveated understanding, as Victoria does not have a dedicated export zone in the RIO model, and clean fuels produced for export from Victoria are driven by energy sources in domestic regions of Australia. An indication of Victoria's share of clean export markets can be gathered from Figure 3 which shows GW of ammonia exports by scenario and year, from the six exporting state/territories included in NZAu modelling [2].

Figure 2 | The cumulative capacities of the utility-scale wind and solar PV technologies (in GW) installed in domestic regions of the NZAu model, by scenario and year

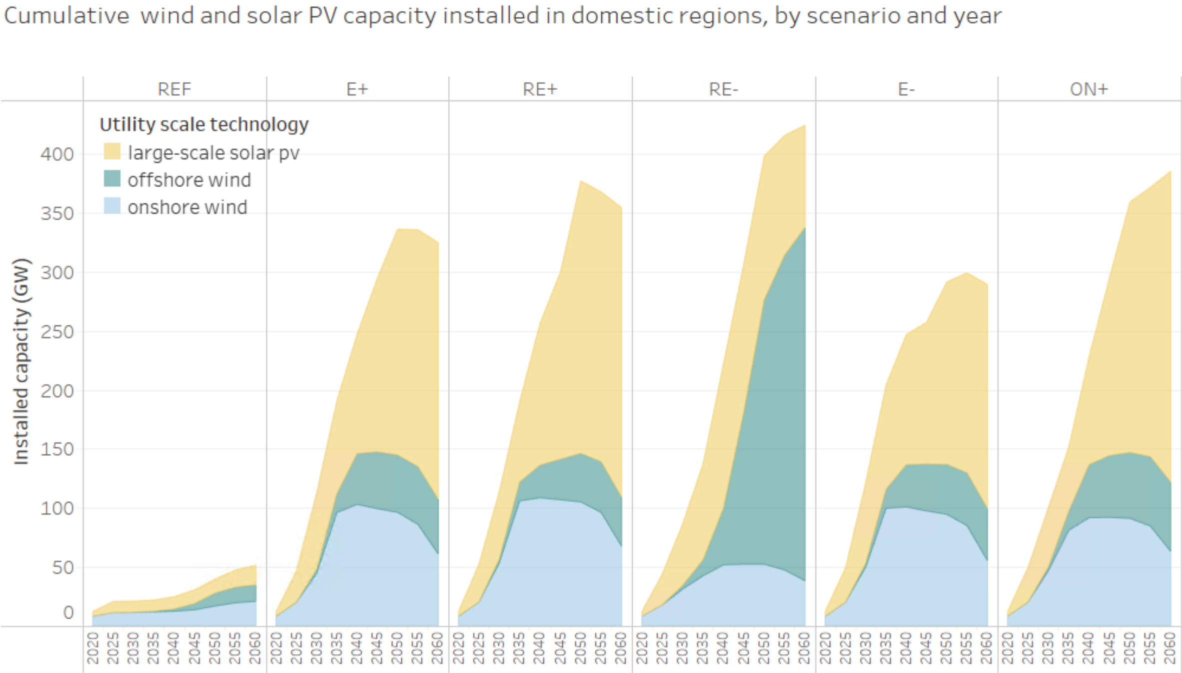


Figure 3 | Ammonia exports in GW by scenario and year, from the exporting state/territories included in NZAu modelling

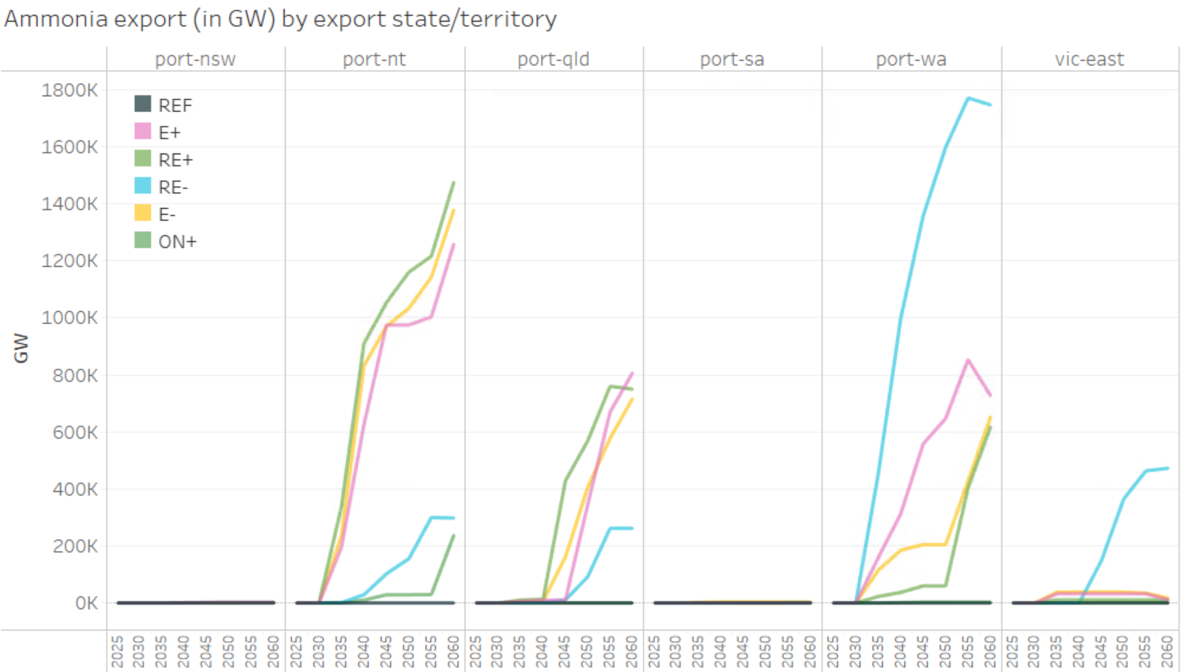


Figure 2 indicates that solar PV is the VRE with the most installed capacity in domestic zones in all NZAu core scenarios but the RE– scenario which sees offshore wind capacity more than tripling the solar PV capacity installed in domestic regions (and nearly 8x the onshore wind capacity). In all other core scenarios, the domestic balance swings in the other direction in Figure 2, with installed solar PV capacity more than doubling the combined capacity of onshore and offshore wind in each scenario. It can be inferred from Figure 3 that a portion of the VRE installed in the RE– scenario in Figure 2 has been installed to support the increased role of exports from Victoria in that scenario (mapping in a later section will indicate which technologies likely play the central role in supporting exports from Victoria). Figure 3 also suggests that in all core scenarios but RE–, exports from Victoria are a minor driver on the domestic build shown in Figure 2.

Figure 4 presents the cumulative capacities of the utility-scale wind and solar PV technologies (in GW) installed in export regions of the NZAu model, by scenario and year. The caveat included with Figure 2 extends to Figure 4, suggesting that while VRE capacity serving domestic markets will be overstated due to the inclusion of VRE supporting exports from Victoria, VRE capacity serving export markets will be understated for the same reason.

Figure 4 | The cumulative capacities of the utility-scale wind and solar PV technologies (in GW) installed in export regions of the NZAu model, by scenario and year

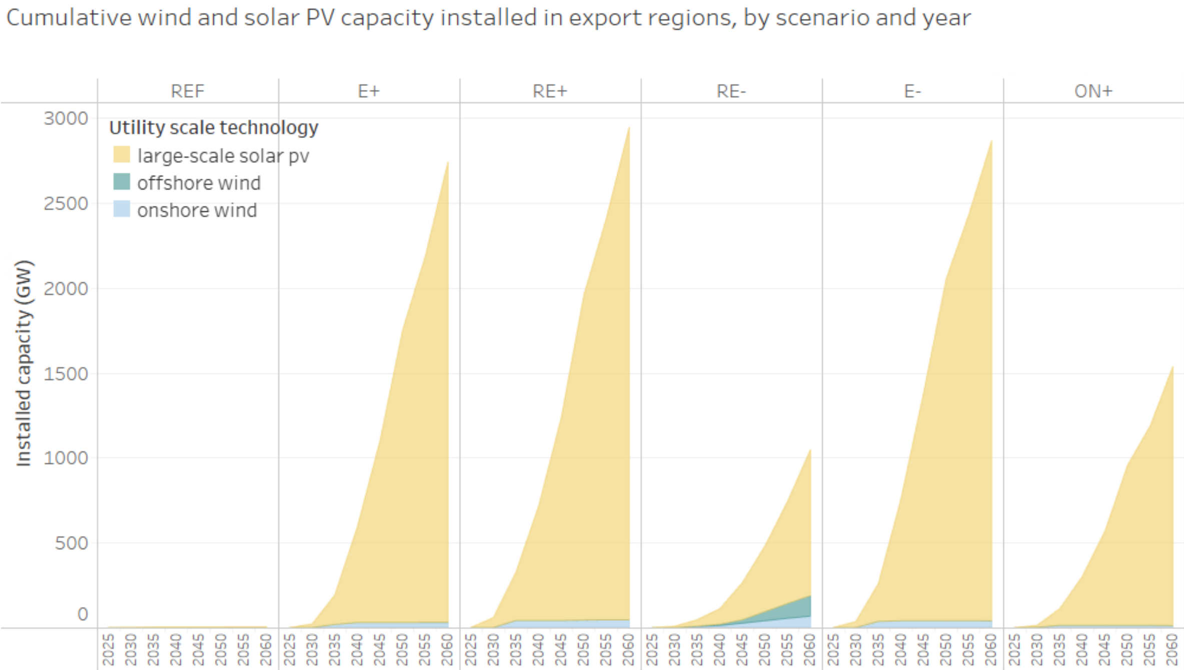


Figure 4 indicates that solar PV is the utility-scale VRE resource most used to energize export markets in all NZAu core scenarios, with installed capacities in export zones in 2060 ranging from 860 GW in in the RE– scenario to 2,900 GW in the RE+ scenario. Figure 4 also highlights the relative difference in installed capacities of VRE between domestic and export regions with over 8x the capacity of VRE installed in export regions in 2060 in the E+ scenario than was installed in domestic regions in the same year. This ratio is similar for the RE+ and E– scenarios but falls to ~2.5x and 4x in the RE– and ONS scenarios.

Figure 5 presents the cumulative inter-regional transmission capacity installed in export and domestic regions (in GW), by scenario and year. The installed capacities of spur lines and bulk transmission (connecting spur lines to load centres) are not tracked by the NZAu balancing model and will be determined as part of a later section detailing siting and mapping of electricity transmission.

Figure 5 | The cumulative installed capacity of inter-regional transmission at a national level in GW by scenario and year, with domestic/export split

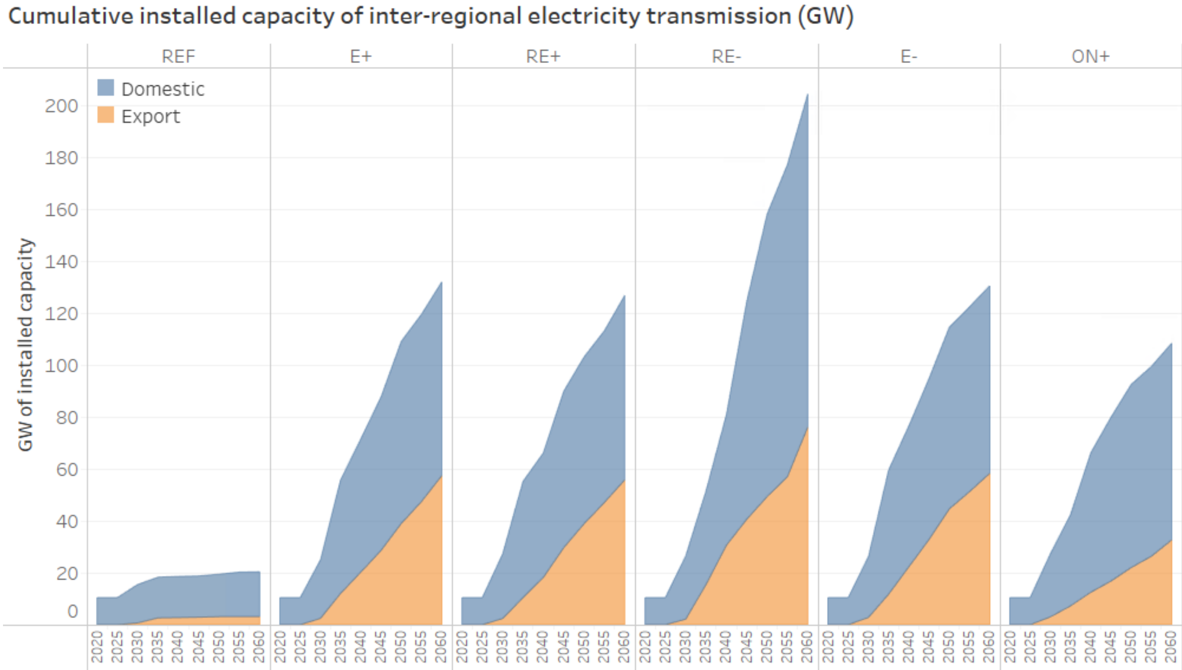


Figure 5 indicates that the total combined capacity of the inter-regional transmission lines serving domestic markets is greater than the total combined capacity of the transmission lines built to enable clean energy exports in export regions. This appears counterintuitive given the relative difference in the size of installed VRE capacities between the export and domestic markets. However, the relative compactness and independence of individual export zones is outweighed by the wider spatial distribution and greater number of interdependent connections involved in enabling a reliable domestic electricity grid – with a high penetration of VRE – in later years of the transition. The spatial underpinnings and implications of Figure 5 will be unpacked and explored in a later section showing transition maps. Figure 5 shows the largest domestic and export inter-regional transmission builds occurring in the RE– scenario. The second largest domestic build occurs in conjunction with the smallest export build in Figure 5 in the ONS scenario in which energy resources serve domestic rather than overseas steel and aluminium industries.

3 Modelling results for VRE and electricity transmission lines by state/territory

Figure 6 and Figure 7 present the cumulative capacities of solar PV (in GW) installed in domestic and export regions respectively, showing state/territory capacities by scenario and year. Figure 6 indicates that all modelled state/territories but Tasmania (TAS) have installed at least 8 GW of solar PV capacity in domestic regions by 2060 under all scenarios. Figure 6 also shows that for all but the RE– scenario, NSW, QLD, and WA all see at least 20 GW of solar PV capacity installed in domestic regions by 2060. The RE– scenario has the lowest overall capacity of solar PV, with installed capacities in QLD, NSW, VIC and WA all shrinking in comparison to other scenarios and installed capacity in NT growing (quite dramatically) when compared to other scenarios. Figure 7 indicates that almost all installed capacity of solar PV in export regions is situated in WA, NT, and QLD across all scenarios.

Figure 6 | The cumulative capacities of utility-scale solar PV technologies installed in domestic regions (in GW), by scenario, year and state/territory

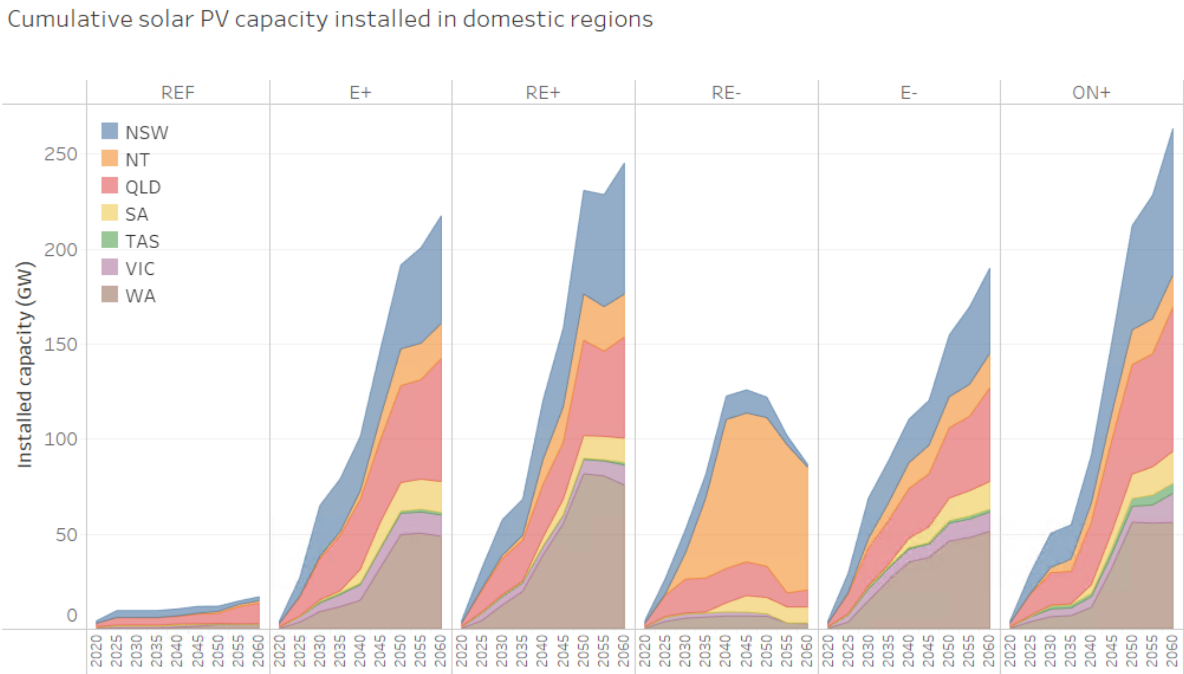


Figure 7 | The cumulative capacities of utility-scale solar PV technologies installed in export regions (in GW), by scenario, year and state/territory

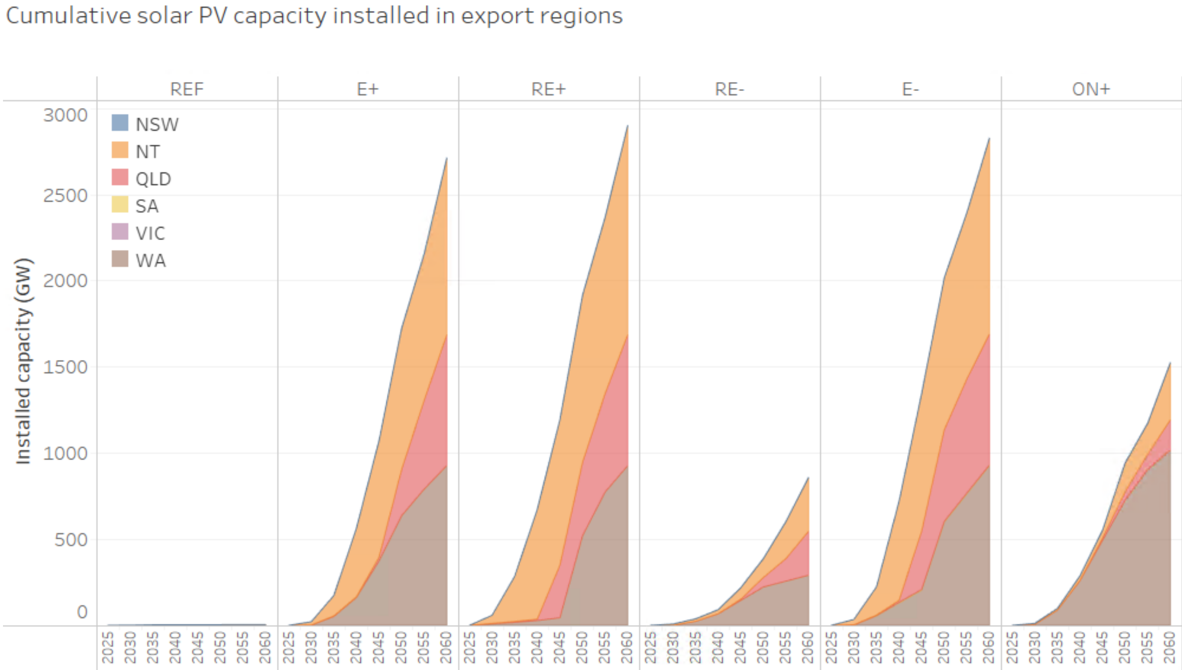


Figure 8 and Figure 9 present the cumulative capacity of onshore wind (in GW) installed in domestic and export regions respectively, showing state/territory capacities by scenario and year. Figure 8 indicates that the domestic installed capacity of onshore wind peaks in 2040 for all modelled state/territories and all scenarios (except the REF). In no scenario does TAS see an installed domestic onshore wind capacity of greater than 1 GW. Figure 9 shows the capacities of onshore wind installed in export regions being built almost entirely in WA, the NT and QLD. The regional ratios of installed capacities are reasonably consistent in the E+, RE+ and E– scenarios, with the major increase in WA's relative installed capacity in the RE– scenario and a major decrease in the NT's and QLD's relative installed capacities occurring in both the RE– and ONS scenarios. The allocation of new iron and steel and aluminium industry is expected to be a major influence on these changes in the ONS scenario.

Figure 8 | The cumulative capacity of onshore wind (in GW) installed in domestic regions, showing state/territory capacities by scenario and year

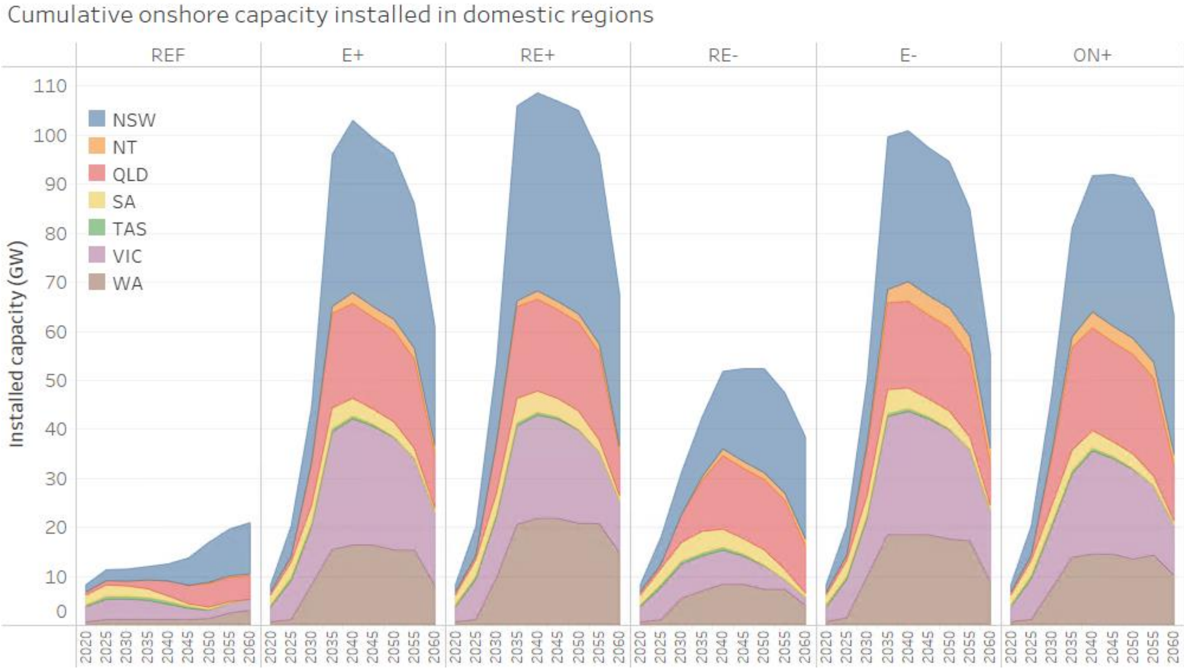


Figure 9 | The cumulative capacity of onshore wind (in GW) installed in export regions, showing state/territory capacities by scenario and year

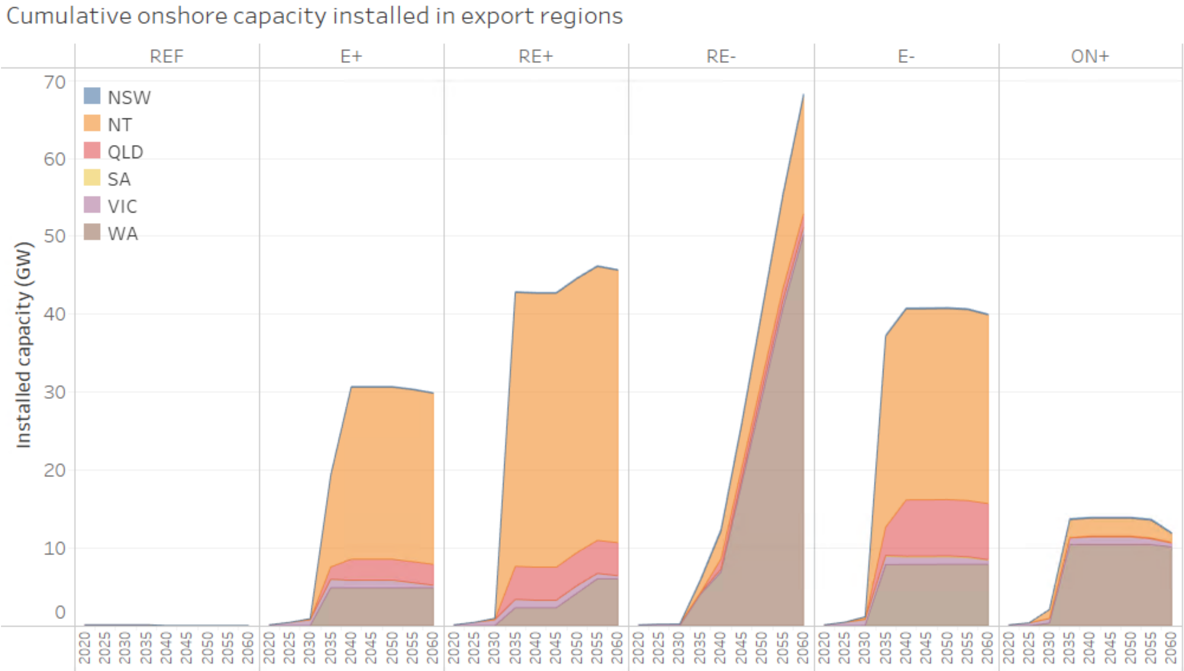


Figure 10 and Figure 11 present the cumulative capacity of offshore wind (in GW) installed in domestic and export regions respectively, showing state/territory capacities by scenario and year. Figure 10 indicates that across all scenarios VIC, QLD and WA all have at least 4 GW of offshore wind capacity installed in domestic regions by 2060, with the most marked increase in offshore wind for all regions occurring in the RE– scenario. Figure 10 shows VIC playing a consistent host to offshore wind capacity with at least 20 GW sited in all scenarios, and nearly 140 GW sited in the RE– scenario. Figure 11 shows the installed capacities of offshore wind in export regions being almost entirely non-existent, with the exception of the RE– scenario which sees over 120 GW of offshore wind built to support exports in WA. The location of ammonia exports shown in Figure 3 is suggestive that a large portion of offshore wind capacity sites in domestic regions of VIC and TAS in the RE– scenario are connected to the marked increase of the export of clean fuels from VIC in that scenario.

Figure 10 | The cumulative capacity of offshore wind (in GW) installed in domestic regions, showing state/territory capacities by scenario and year

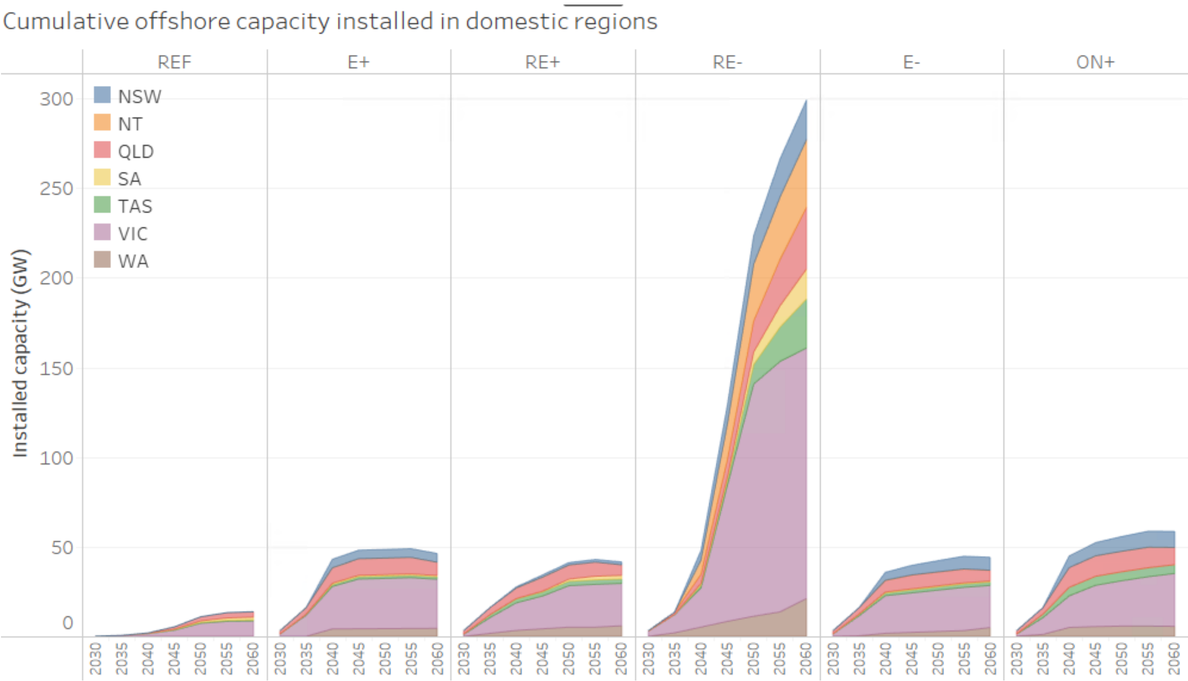
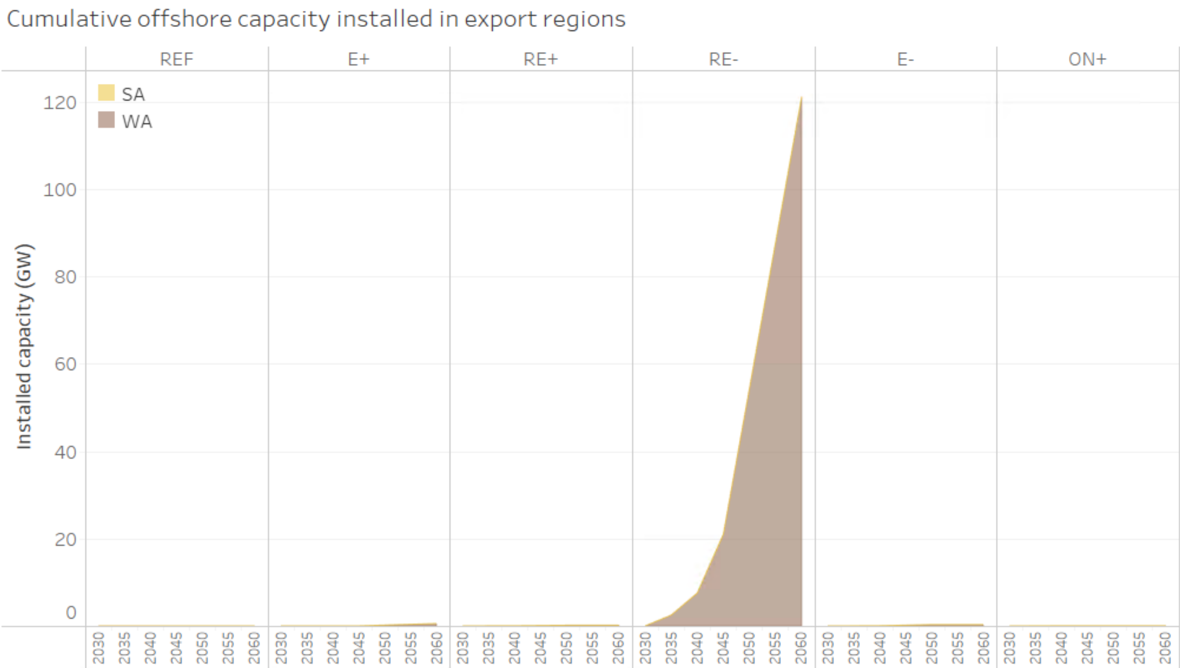


Figure 11 | The cumulative capacity of offshore wind (in GW) installed in export regions, showing state/territory capacities by scenario and year



4 Selection, mapping, and characterisation of VRE and transmission lines

The downscaling described in this section covers the disaggregation of the installed capacities of VRE and transmission shown in Figure 1 and Figure 5 into individually mapped project areas (with relevant transmission to load) shown by scenario and five-year time step. Downscaling steps include:

1. The least-cost selection and mapping of projects needed to reach the cumulative installed capacities of solar PV, onshore wind, and offshore wind for each region, scenario, and five-year time step 2025 (see Table 20 in the Appendix for the list of existing and potential projects drawn on by the model in 2020 or 2025);
2. The mapping of the spur and bulk transmission lines to transmit electricity from each VRE project to a load destination; and
3. The mapping of inter-regional transmission used to transfer electricity between regions, and from electrolysis nodes to export ports;
4. Characterisation of the transition in five-year time steps.

4.1 VRE and the transmission lines needed to get power from VRE projects to regional load destinations

The NZAu balancing model selects the installed capacities of VRE resources shown in Figure 6 through Figure 11 from a number of representative candidate projects generated from a supply curve of all VRE resources available in a region [2]. This process is described in detail in the supplementary material included with Wu et al. [3] and results in the regionally representative VRE projects – described by capital cost, fixed and variable operation and maintenance costs, interconnection cost, efficiency, maximum capacity factor, levelized cost of capital (LCC), and zonal potential – detailed in the *NZAu Modelling Inputs Catalogue*.

General rules used in selection and mapping steps include:

1. Any candidate project area with a more than 10% overlap with an existing VRE project is removed from the candidate project pool until the project is retired, at which point it is made available with the regional project pool.
2. On the retirement of a project purpose-built for the net-zero transition, the project area is placed back into (in appropriate LCOE order) the project siting queue.
3. If the location of an existing project is not publicly available [4]–[10] then the location of the projects is approximated.
4. Transmission line options between a VRE project and possible load destinations are determined using VRE resource availability at each load location (determined using least-cost path algorithms [2]) and the total population of each load location. It should be understood that:
    a. The populations of load destinations are used to limit the installed capacity of transmission lines terminating at load destinations with small populations (denoted as bulk destinations/lines hereafter) and increase the installed capacity of transmission lines terminating at load destinations with large populations (denoted as sink destinations/lines hereafter).
    b. Supply curve methods [2] explicitly consider load centres containing 81% of Australia's population (~20 million people) for direct connection to new VRE resources Australian populations lacking a direct VRE supply in each scenario are expected to be able to access clean electricity via:
        i. the transfer capacity of existing transmission networks,

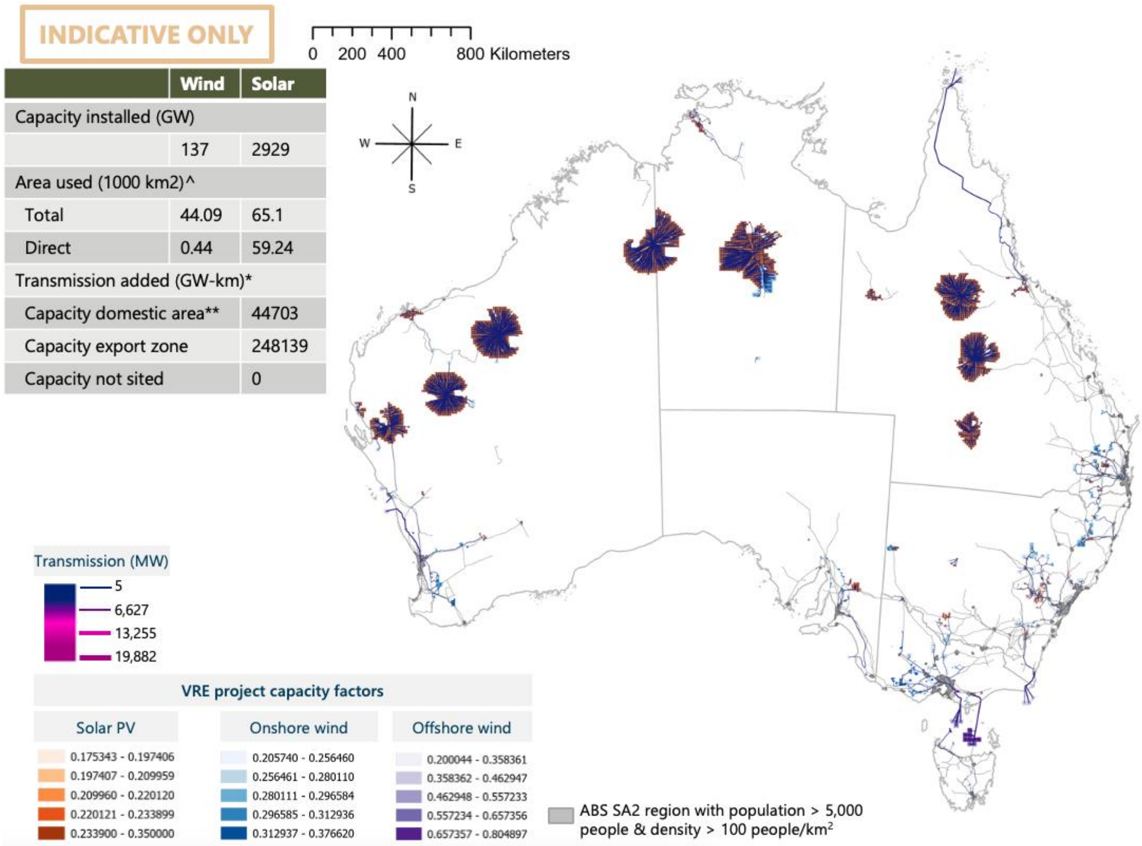
ii. synergetic new connections to inter-regional and existing transmission corridors in cases when those corridors run through or close-by load destinations,

iii. regional/federal appropriation and re-routing of sink transmission lines to reach locations not directly connected to VRE in NZAu downscaling, and

iv. the extensive tariff-driven distribution upgrades specified in RIO when locations not directly connected to VRE are near destinations connected directly to VRE.

Figure 12 shows the results of selecting, siting/retiring, and mapping utility scale VRE projects (and connected transmission lines, except for inter-regional transmission lines) for the E+ scenario in 2060.

Figure 12 | VRE and transmission map for the E+ scenario in 2060



The following map notes apply to Figure 12 and all maps in this document:

- (^) Area totals reported on maps include marine areas. Solar PV project areas shown in map cover the entire candidate area considered for a project, of which only 20% will be used on final siting of physical infrastructure. Depicting solar PV projects 5x larger than total areas listed in the map tables aids in making smaller projects visible on maps and underscores a flexibility for accounting for local contexts in determining the final siting for projects. Area totals do not include the land used by the transmission lines connecting projects to loads. The direct areas listed are 91% and 1% of total areas for solar and wind respectively [1]. The minimum project sizes for depiction on maps are 5 MW for solar, 50MW for onshore wind, and 100MW for offshore wind.

- (*) Transmission expansions are mapped to follow existing rights of way for existing TX > 132kV, national roads, railroads, pipelines; paths are indicative not definitive. All transmission lines between projects and loads are mapped. However, inter-regional transmission expansions of any length that are below 500 MW are not mapped. Neither are inter-regional transmission lines of greater than 1000 km in length and less than 1 GW; greater than 1500 km in length and less than 2 GW, or greater than 2000 km in length and less than 3 GW. NZAu notes that an empirically based method for setting thresholds like these is needed, but guidance was lacking from NZA [1], and as Australia does not have transmission lines at this scale, arbitrary thresholds were chosen. All transmission expansions, except for spur lines, are built five years before the VRE projects that they serve. Transmission totals in the map tables are split between domestic areas (which may or may not serve exports in the SE of Australia, export zones which have been built only to serve clean exports, and a running tally of transmission the transmission capacity that is not sited because it falls below the thresholds set out above.

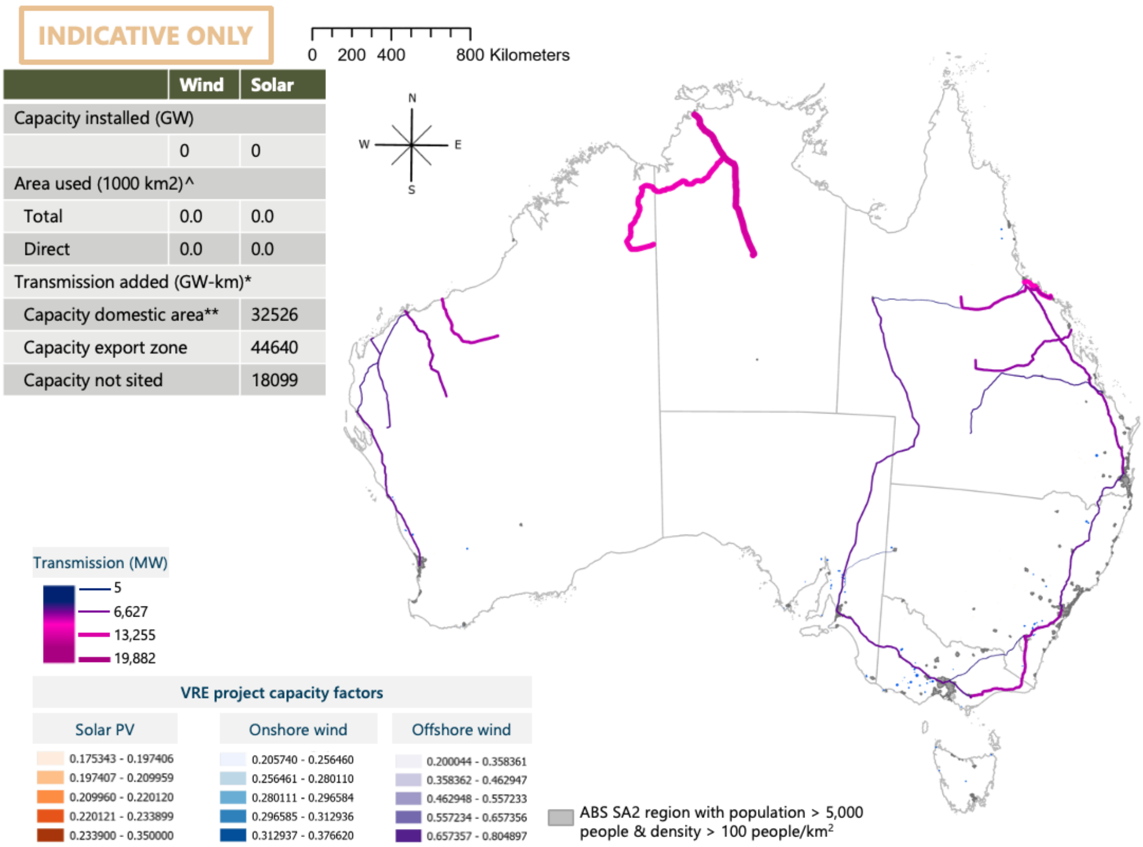
- (**) An estimation of the transmission capacity for TX > 132 kV in 2020 is 28,000 GW-km, which covers ~46,600 km of transmission, and is detailed in an Appendix of this document. All domestic capacity totals listed in maps after 2020 (e.g. 2025) only report transmission capacity that is additional to this base number.

Return to Figure 13 (inter-regional lines), Figure 14 (E+ 2060), Figure 15 (RE+ 2060), Figure 16 (RE– 2060), Figure 17 (E– 2060), Figure 18 (ONS 2060), Figure 19 (REF 2060), Figure 21 (2060 land use indigenous estate), Figure 22 (2060 land use farmland), Figure 23 (2060 land use tenure), or Figure 26 (2060 land use Key Biodiversity Areas).

4.2 Inter-regional transmission lines

The NZAu balancing model uses explicitly specified inter-regional transmission lines (by route, capacity, voltage, length [2]) to transfer electricity between regions, and from electrolysis nodes to export ports where electricity intensive export industry is located (e.g. ammonia production). Inter-regional transmission line capacities for the E+ scenario are shown for 2060 in Figure 13.

Figure 13 | Inter-regional transmission map for the E+ scenario in 2060

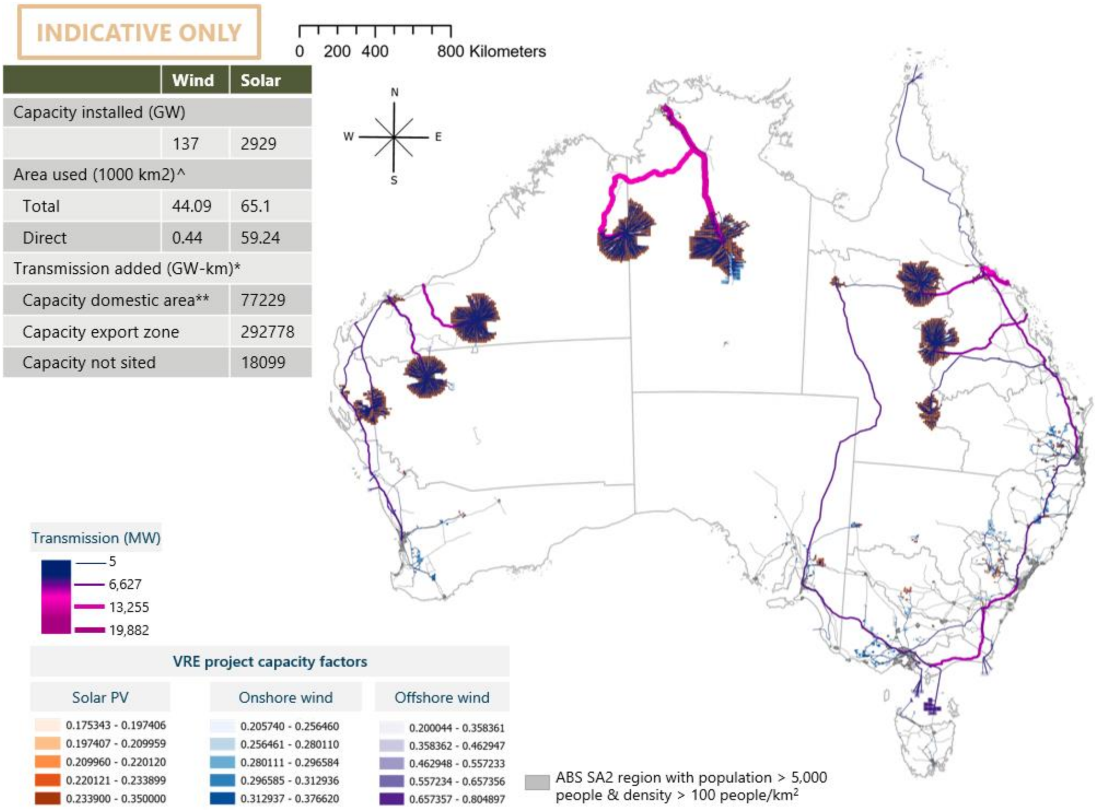


See Map Notes below Figure 12, with links below those notes to return to this Figure.

4.3 Electricity transitions by 2060 for all scenarios

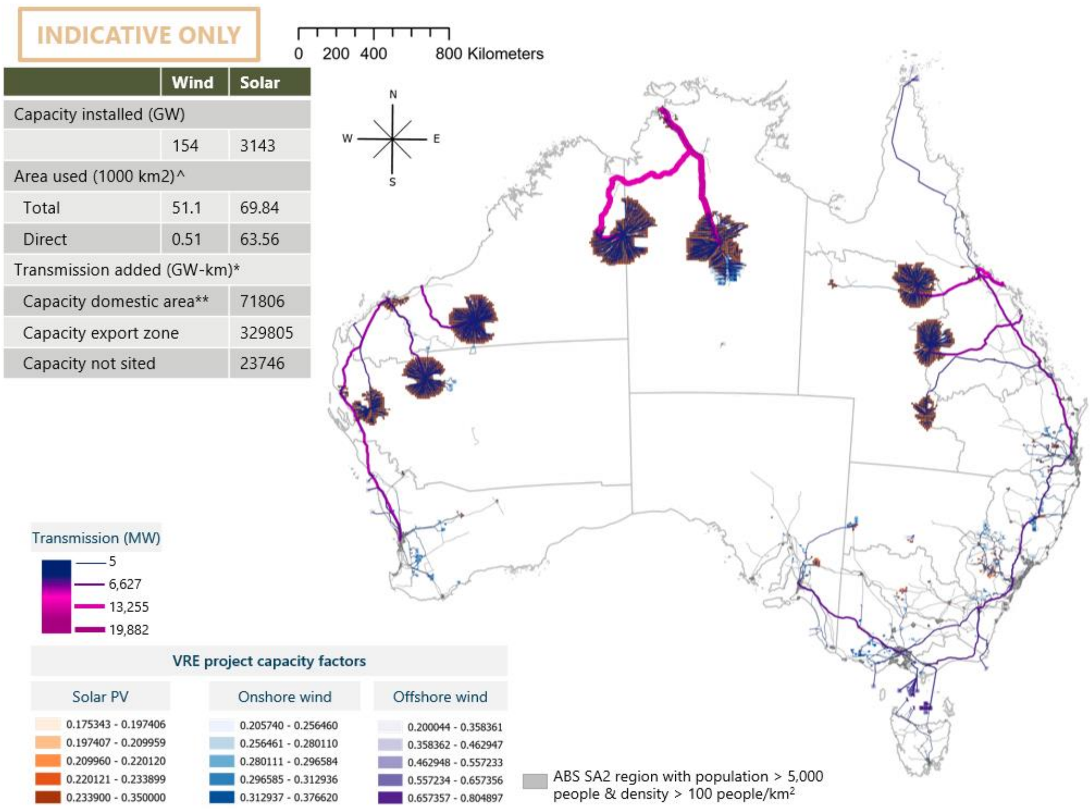
Maps for the final year of the electricity transition for all scenarios are shown in Figure 14 through Figure 19. Electricity transition map series from 2020 to 2060 for all core scenarios can be found in the [Appendix.](#)

Figure 14 | VRE and transmission maps for the E+ scenario in 2060



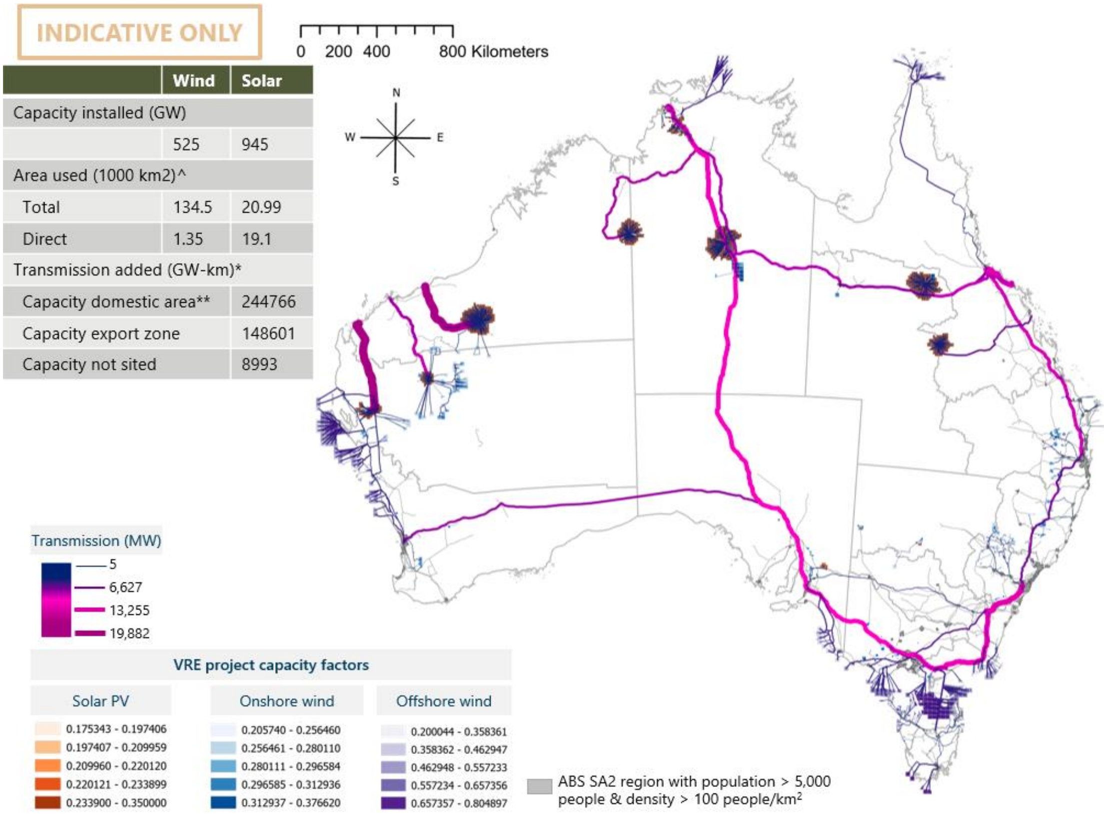
See Map Notes below Figure 12, with links below those notes to return to this Figure.

Figure 15 | VRE and transmission maps for the RE+ scenario in 2060



See Map Notes below Figure 12, with links below those notes to return to this Figure.

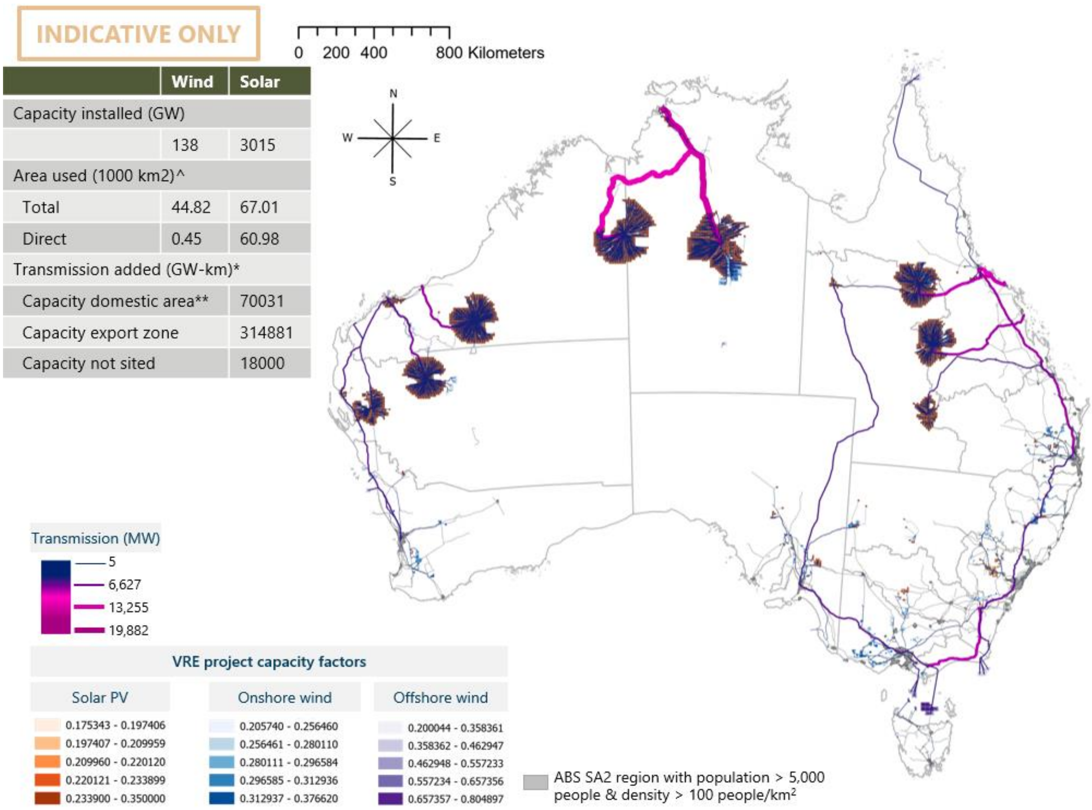
Figure 16 | VRE and transmission maps for the RE– scenario in 2060



	Wind	Solar
Capacity installed (GW)		
	525	945
Area used (1000 km2)^		
Total	134.5	20.99
Direct	1.35	19.1
Transmission added (GW-km)*		
Capacity domestic area**		244766
Capacity export zone		148601
Capacity not sited		8993

See Map Notes below Figure 12, with links below those notes to return to this Figure.

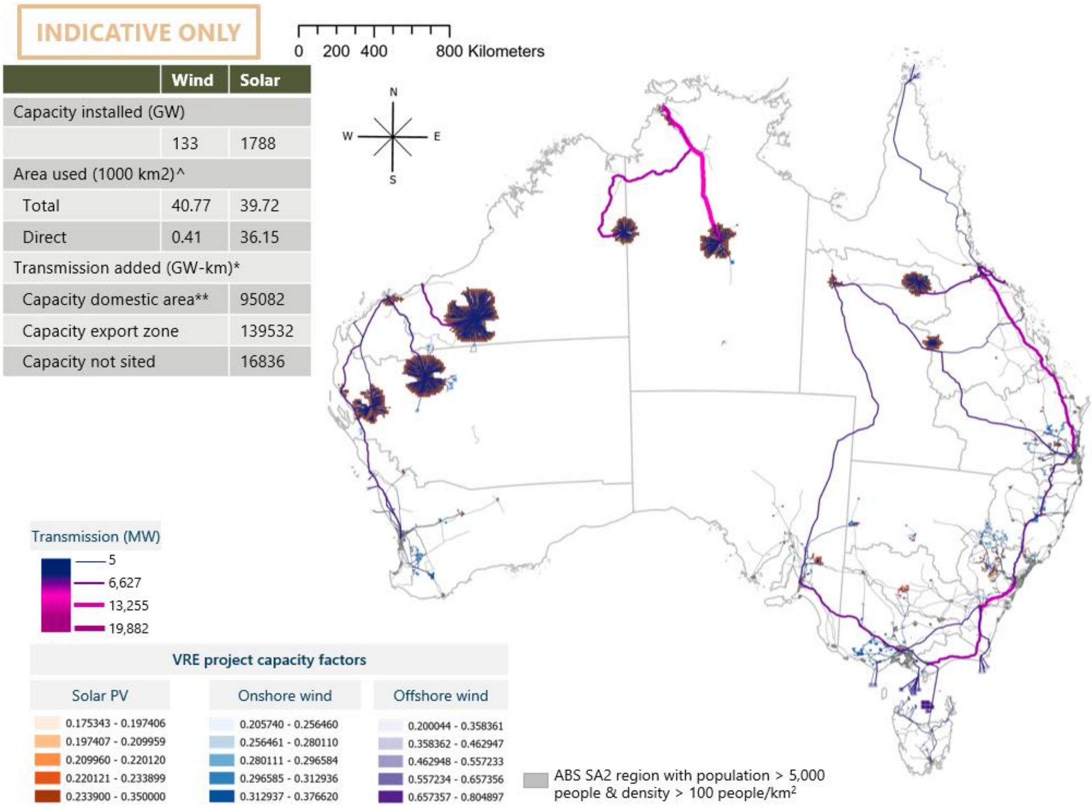
Figure 17 | VRE and transmission maps for the E– scenario in 2060



	Wind	Solar
Capacity installed (GW)		
	138	3015
Area used (1000 km2)^		
Total	44.82	67.01
Direct	0.45	60.98
Transmission added (GW-km)*		
Capacity domestic area**		70031
Capacity export zone		314881
Capacity not sited		18000

See Map Notes below Figure 12, with links below those notes to return to this Figure.

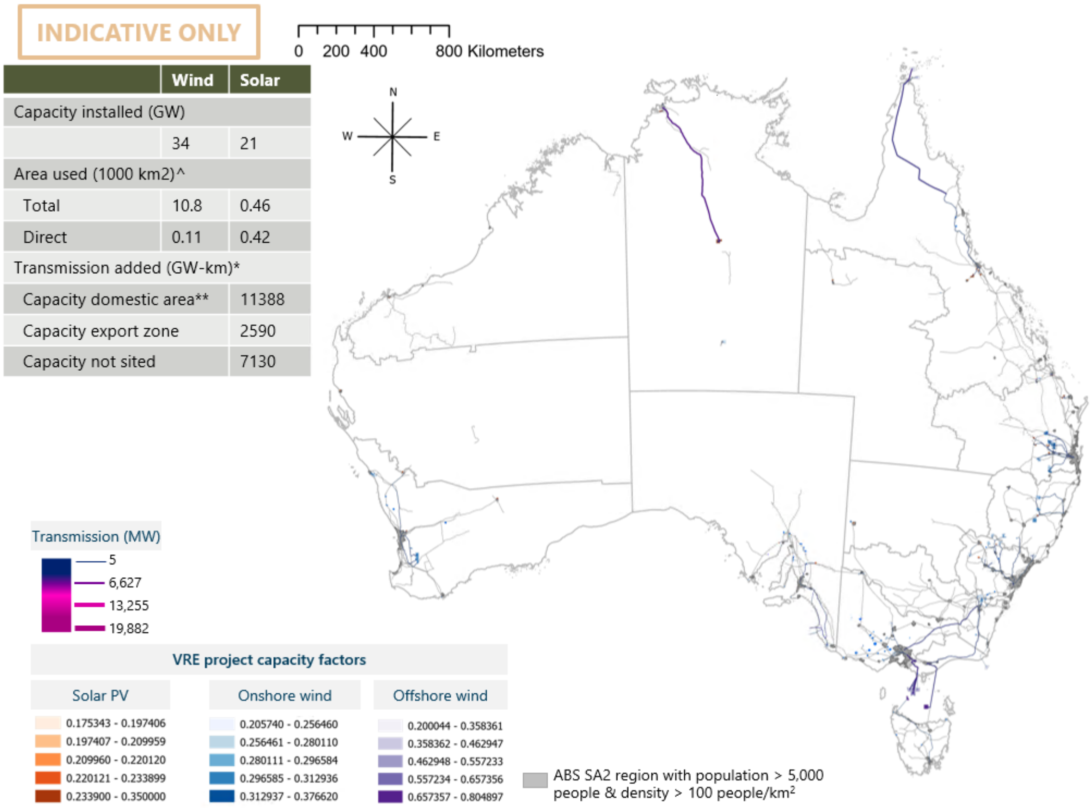
Figure 18 | VRE and transmission maps for the ONS scenario in 2060



	Wind	Solar
Capacity installed (GW)		
	133	1788
Area used (1000 km2)^		
Total	40.77	39.72
Direct	0.41	36.15
Transmission added (GW-km)*		
Capacity domestic area**		95082
Capacity export zone		139532
Capacity not sited		16836

See Map Notes below Figure 12, with links below those notes to return to this Figure.

Figure 19 | VRE and transmission maps for the REF scenario in 2060



	Wind	Solar
Capacity installed (GW)		
	34	21
Area used (1000 km2)^		
Total	10.8	0.46
Direct	0.11	0.42
Transmission added (GW-km)*		
Capacity domestic area**	11388	
Capacity export zone	2590	
Capacity not sited	7130	

See Map Notes below Figure 12, with links below those notes to return to this Figure.

The spatial representation of scenarios in 2060 looks similar for the E+, RE+, E–, and ONS scenarios (Figure 14, Figure 15, Figure 17, and Figure 18 respectively), with only the RE+ scenario missing the outback QLD to SA connection shown in the other three scenarios. In this case that corridor is not mapped and added to the 'Capacity not sited' total in the map table as the corridor, which stretches 1,800 km and has a maximum rating of 1.4 GW in 2060 in the RE+ scenario. This falls below the NZAu mapping threshold of 2 GW for a 1,500 – 2,000 km line. Connections run along the eastern and western seaboards in all four scenarios, with NT having its own self-contained connections.

The VRE and electricity transmission line build for the RE– scenario in 2060 (Figure 16) illustrates the spatial and network impacts of the decision constraining onshore renewable build rates while placing no such constraints on offshore wind. Figure 16 depicts less solar PV projects in WA, QLD and the NT, expanded or new offshore wind builds in all states/territories of Australia but NSW, and large new transmission corridors between the WA and SA and the NT and its eastern and southern neighbors (NT and SA). The REF scenario shown in Figure 19 indicates the growing but minimal needs of a grid that has not focused on low carbon resources while also agreeing to the export of clean electricity from the NT via an undersea electricity cable.

5 Land-use impact analyses of indigenous estate, farmland, land tenure, and biodiversity

The land-use impact analyses included in this report cover indigenous estate, farmland, land tenure, and biodiversity. Each land-use impact analyses includes the following steps:

1. Select the available GIS layer to use for the analysis and access data at highest spatial resolution available to the public – usually specified using a meter (m) value.
   a. **Indigenous Estate** – raster with 100 m cell size [11]
   b. **Farmland** – raster 250 m cell size [12]
   c. **Land tenure** – raster with 250 m cell size [13]
   d. **Biodiversity** – feature layer with default spatial resolution of < 1m [14]
2. For each core scenario and selected model year (2030 and 2060), generate a version of VRE and electricity transmission infrastructure that includes project areas.
   a. Solar PV projects – full area used for project siting
   b. Wind projects – full area used for project siting
   c. Transmission projects – the right-of-way widths applied to the transmission lines used in modelling [2] are listed in Table 1. Subsea right-of-way widths are modelled as 40m for all options.
3. Pro-rate transmission project rights-of-way (ROWs) according to project type and transmission line capacity.
   a. Spur lines and inter-regional transmission projects: pro-rate the footprint using the ratio of the transmission line capacity required by a project in a specific model year and scenario to the maximum carrying capacity of the line specified in Table 1. For example, a spur line built to serve a 125 MW VRE project is built as a 132kV double circuit line and then assigned a ROW width of 125MW/250MW * 35 meters = 17.5 meters. This follows the pro-rating method used in the transmission costing for in supply curve modelling [2], and was employed in downscaling as lower voltage transmission options serving smaller projects (<250 MW) were not explicitly included in modelling.
   b. Bulk transmission projects: the project ROW is not pro-rated. Current modelling methods are limited to stacking new transmission lines on top of one another, rather than aggregating the footprint into a new corridor with the combined carrying capacity of all overlapping transmission lines. This shortfall in modelling methods is marked for improvement in future research and will likely lead to some underestimation of the impact of transmission in corridors with more than one overlapping transmission line. It also leads to an inability to systematically site and size all the new substations constructed to support expanding transmission infrastructure, the footprints of which have not been included in the land-use analysis.
   c. In the case of transmission projects that exceed the largest AC or DC options available, an appropriate multiple of the largest transmission ROW is assigned based on a corridor's estimated total capacity (e.g. a 6,000 MW DC corridor will have a ROW that is 2 x a 3,000 MW corridor's ROW).
4. Convert the infrastructure footprint into a raster with a 10m cell size, using the Polygon to Raster conversion tool [15] in ArcGIS Pro. Also convert any analysis layers provided as a feature layer to a 10 m cell size. This additional step was taken rather than just using the internal polygon to raster conversion in the next step to improve control of the conversion to raster (better assignment of category to the cell), and to speed up processing time during the next step.
5. Run the Tabulate Area Tool [16] available with ArcGIS Pro to determine the footprint of each selected NZAu infrastructure type in the selected categories of the layer being analysed.

6. Calculate the **total** and **direct areas** of project footprints on different categories of the map layer under assessment. See Figure 20 for a visual representation of **total** and **direct areas** of the project footprints of solar PV and onshore wind projects. To following adjustments are made to the aggregate land area of each project type:
    a. Utility solar PV projects:
        i. Total footprint = 20% of the full candidate project area used for siting;
        ii. Direct footprint = 91% of total footprint [1].
    b. Wind projects:
        i. Total footprint = 100% of full candidate project area used for siting;
        ii. Direct project footprint = 1% of total footprint [1].
    c. Transmission project impacts
        i. Total and direct footprints are 100% of full project area estimated after prior pro-rating step(s).
7. Report infrastructure impacts in terms of both the **total** and **direct area** impacted in kilometres squared (km^2) and as percentages of the areas covered by each relevant category of the map layer under assessment.

Note that the Total and Direct areas presented in this section are a small overestimate of the areas of the actual modelled capacities of solar and wind projects, due to the presence of a number of partial project builds (less than the full rated build of the candidate project area). The land footprint impact of the modelling choosing not to build a project up to the full rated capacity of the land area is minor and can be observed in the final installed project power densities for the E+ scenario of 44.8, 2.5, and 3.8 MW/km^2 respectively for solar PV, onshore wind, and offshore wind (compared with the candidate project area maximum project power densities of 45, 2.7 and 4.4 MW/km^2).

Figure 20 Visual explanation of the total and direct project footprints used onshore in NZAu

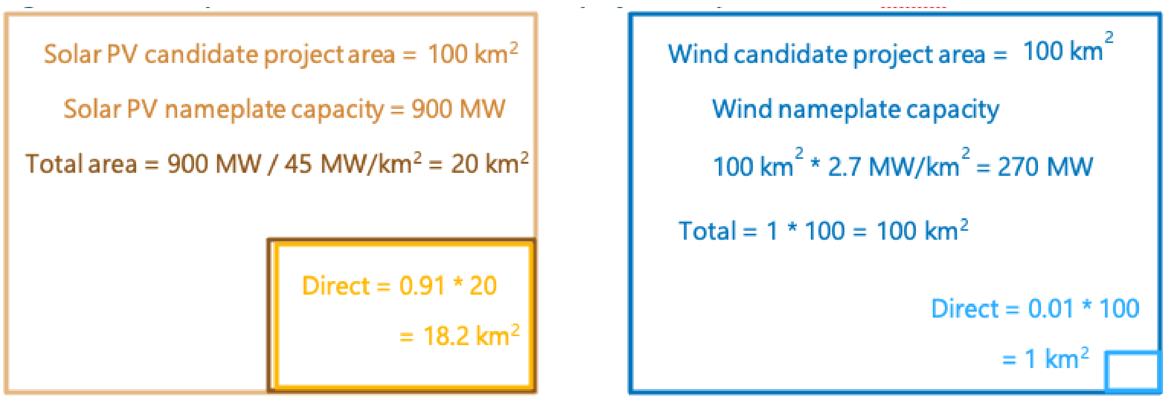


Table 1 | Transmission right-of-way widths applied to transmission corridors

Description	AC/DC	Location	kV	Circuits	Capacity (MW)	ROW (m)
132 kV double	AC	Overhead	132	2	250	35 [17]
275 kV single	AC	Overhead	275	1	400	55 [17]
330 kV single	AC	Overhead	330	1	600	58 [17]
275 kV double	AC	Overhead	275	2	950	50 [17]

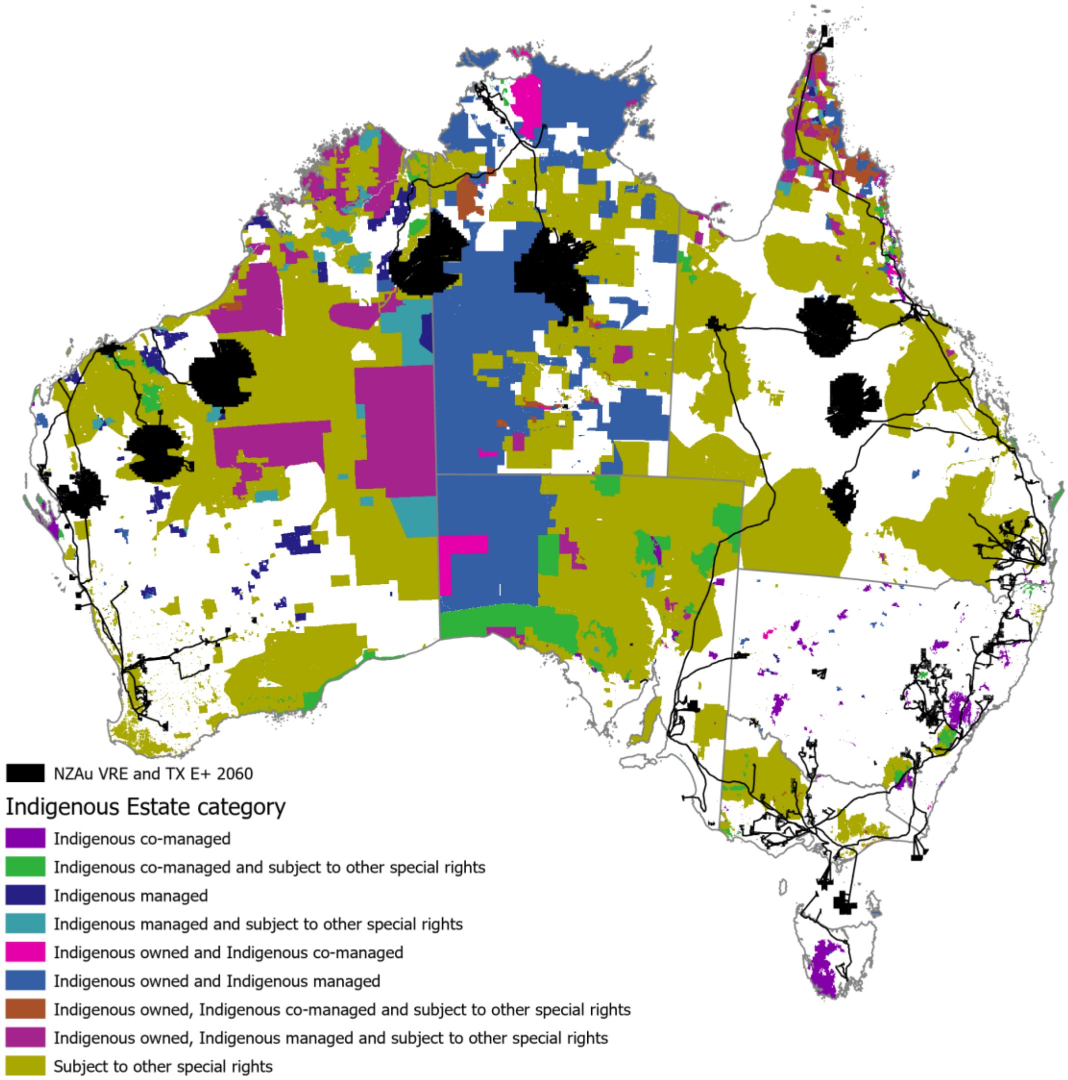
330 kV double	AC	Overhead	330	2	1200	53 [17]
500 kV double	AC	Overhead	500	2	3040	60 [17]
500 kV twin	DC	Overhead	500	2	3000	61 [3]
500 kV single monopole	DC	Subsea	500	1	385	40
500 kV twin monopole (750)	DC	Subsea	500	2	750	40
500 kV twin monopole (1500)	DC	Subsea	500	2	1500	40

5.1 Indigenous Estate

Figure 21 shows an overlay of NZAu infrastructure in the E+ scenario through 2060 on the Indigenous Estate [11]. The indigenous estate categories tracked in Figure 21 cover the following attributes, whose text has been copied verbatim from the source [11], with emphasis added by NZAu:

- **Indigenous owned**: freehold land or forest that is owned by Indigenous communities, or land or forest for which ownership is vested through other mechanisms
- **Indigenous managed**: land or forest that is managed by Indigenous communities
- **Indigenous co-managed**: land or forest that has formal, legally binding agreements in place to include input from Indigenous people in the process of developing and implementing a management plan
- **Other special rights**: land or forest subject to native title determinations, registered Indigenous Land Use Agreements, and legislated special cultural use provisions.

Figure 21 | Overlay of NZAu infrastructure in the E+ scenario through 2060 on the Indigenous Estate



Results for the indigenous estate land use analysis are provided for total project areas in km_2 in Table 2; and in percentages of each NZAu infrastructure type in Table 3. Results for the indigenous estate [11] land use analysis are provided for direct project areas in km_2 in Table 4; and in percentages of each NZAu infrastructure type in Table 5.

Table 2 | Results for the indigenous estate impact analysis (total Area km_2)

Category	Solar PV	Wind On	Wind Off	TX	Total
Indigenous co-managed	-	-	-	17	17
Indigenous co-managed & subject to other special rights	-	-	-	16	16
Indigenous managed	724	-	-	151	875
Indigenous managed & subject to other special rights	789	147	-	146	1,083
Indigenous owned & co-managed	-	-	-	6	6

Category	Solar PV	Wind On	Wind Off	TX	Total
Indigenous owned & managed	9,924	5,615	-	1,099	16,638
Indigenous owned & co-managed & w/ other special rights	-	-	-	6	6
Indigenous owned & managed & w/ other special rights	567	47	-	202	815
Subject to other special rights	19,709	9,825	-	2,652	32,186
Total	31,713	15,634	-	4,295	51,642

Table 3 | Results for the indigenous estate impact analysis (total Area %)

Category	Solar PV	Wind On	Wind Off	TX	Total
Indigenous co-managed	0.00%	0.00%	-	0.40%	0.03%
Indigenous co-managed & subject to other special rights	0.00%	0.00%	-	0.37%	0.03%
Indigenous managed	2.28%	0.00%	-	3.52%	1.69%
Indigenous managed & subject to other special rights	2.49%	0.94%	-	3.40%	2.10%
Indigenous owned & co-managed	0.00%	0.00%	-	0.14%	0.01%
Indigenous owned & managed	31.29%	35.92%	-	25.59%	32.22%
Indigenous owned & co-managed & w/ other special rights	0.00%	0.00%	-	0.14%	0.01%
Indigenous owned & managed & w/ other special rights	1.79%	0.30%	-	4.70%	1.58%
With other special rights	62.15%	62.84%	-	61.75%	62.33%
Total	61.41%	30.27%	-	8.32%	100.00%

Table 4 | Results for the indigenous estate impact analysis (direct area km_2)

Category	Solar PV	Wind On	Wind Off	TX	Total
Indigenous co-managed	0	0	-	17	17
Indigenous co-managed & subject to other special rights	0	0	-	16	16
Indigenous managed	659	0	-	151	810
Indigenous managed & subject to other special rights	718	1	-	146	866
Indigenous owned & co-managed	0	0	-	6	6
Indigenous owned & managed	9,031	56	-	1,099	10,186
Indigenous owned & co-managed & w/ other special rights	0	0	-	6	6

Category	Solar PV	Wind On	Wind Off	TX	Total
Indigenous owned & managed & w/ other special rights	516	0	-	202	718
Subject to other special rights	17,935	98	-	2,652	20,686
Total	28,859	155	-	4,295	33,311

Table 5 | Results for the indigenous estate impact analysis (direct area %)

Category	Solar PV	Wind On	Wind Off	TX	Total
Indigenous co-managed	0.00%	0.00%	-	0.40%	0.05%
Indigenous co-managed & subject to other special rights	0.00%	0.00%	-	0.37%	0.05%
Indigenous managed	2.28%	0.00%	-	3.52%	2.43%
Indigenous managed & subject to other special rights	2.49%	0.65%	-	3.40%	2.60%
Indigenous owned & co-managed	0.00%	0.00%	-	0.14%	0.02%
Indigenous owned & managed	31.29%	36.13%	-	25.59%	30.58%
Indigenous owned & co-managed & w/ other special rights	0.00%	0.00%	-	0.14%	0.02%
Indigenous owned & managed & w/ other special rights	1.79%	0.00%	-	4.70%	2.16%
With other special rights	62.15%	63.23%	-	61.75%	62.10%
Total	86.64%	0.47%	-	12.89%	100.00%

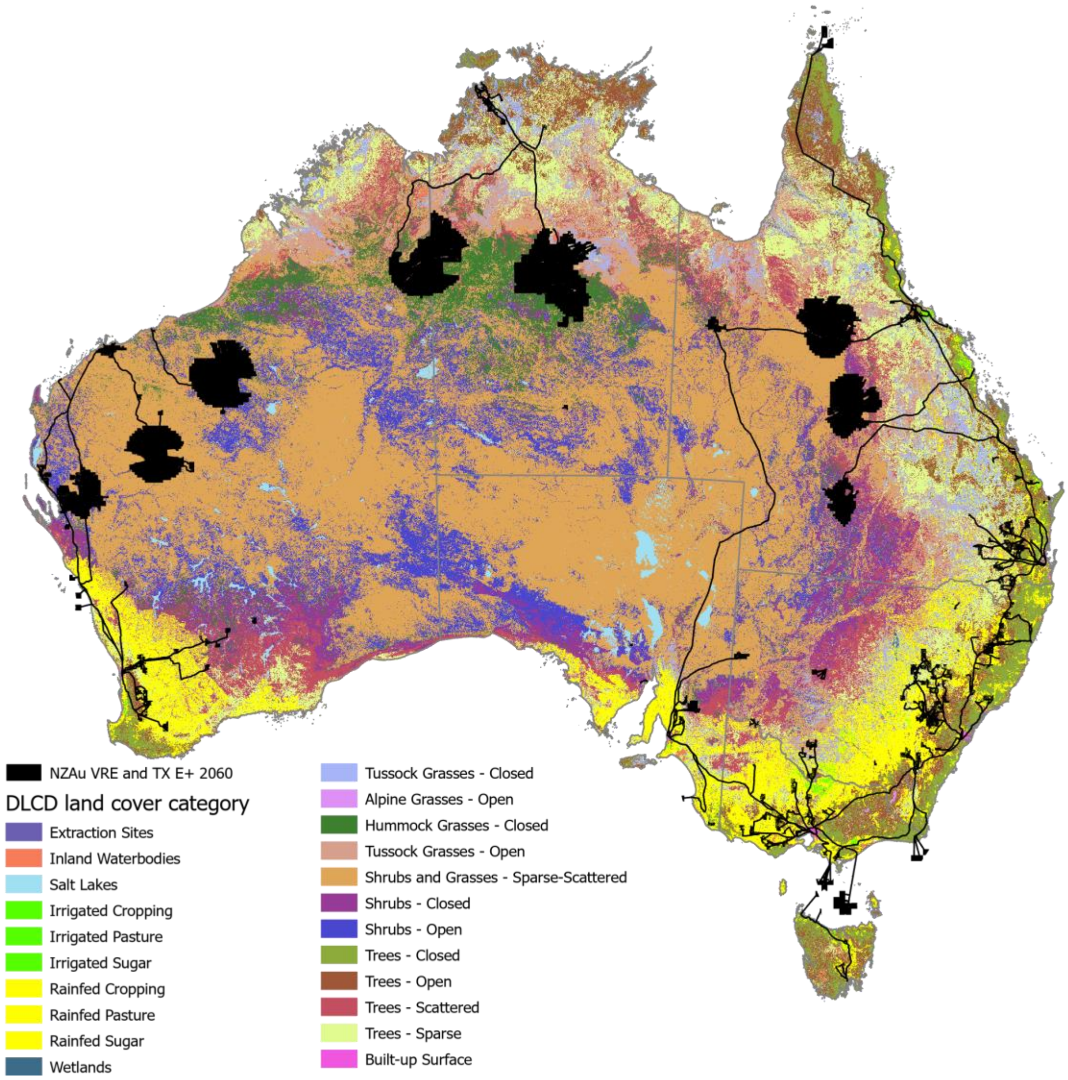
Table 2 indicates that despite its relatively more compact power density, solar PV projects cover double the combined total land area of wind projects sited on indigenous categories, and over seven times the land area traversed by transmission lines. If the comparison considers the combined direct land area in Table 3 rather than the total land area, the ratio stays nearly the same for transmission — solar PV has 6.7x the transmission footprint — but solar PV is understood to have over 185x the direct footprint of wind sites.

All Tables in this section indicate that offshore areas are not included in the Indigenous Estate layer, and thus the impact of offshore wind sites on indigenous estate is not accounted for [18], [19]. An inspection of all Tables in this section also indicates that the modelling decision to prefer existing transmission corridors when siting new transmission leads to impacts on all tracked categories of indigenous estate – many of which are free of impact from the VRE project sites.

5.2 Farmland (and all other land use categories)

Figure 22 shows an overlay of NZAu infrastructure in the E+ scenario through 2060 on the farm categories included in the Dynamic Land Cover Dataset (DLCD) used in the analysis [12]. The irrigated and rainfed farm categories tracked in Figure 22 include: Irrigated cropping, irrigated pasture, irrigated sugar, rainfed cropping, rainfed pasture, and rainfed sugar. All other categories are as labelled on the map, noting that NZAu has added offshore areas to the map not included in the original dataset to track the overlay of offshore wind on offshore areas.

Figure 22 | Overlay of NZAu infrastructure in the E+ scenario through 2060 on Farmland (and all other land cover categories)



Results for the farmland impact analysis are provided for total project areas in km^2 in Table 6; and in percentages of each NZAu infrastructure type in Table 7. Results for the farmland impact analysis are provided for direct project areas in km^2 in Table 8; and in percentages of each NZAu infrastructure type in Table 9. The last row in each table provides the summed total for just farmland categories.

Table 6 | Results for the farmland impact analysis (total area km_2)

Category	Solar PV	Wind On	Wind Off	TX	Total
Extraction sites	0	0	0	4	4
Inland waterbodies	0	0	0	6	6
Salt lakes	0	0	0	3	3
Irrigated cropping	0	0	0	14	14
Irrigated pasture	0	0	0	4	4
Irrigated sugar	0	0	0	10	10
Rainfed cropping	0	6,025	0	174	6,199
Rainfed pasture	1,020	14,957	0	598	16,574
Rainfed sugar	0	0	0	1	1
Wetlands	0	0	0	10	10
Tussock grasses - closed	1,026	2,156	0	254	3,436
Hummock grasses - closed	12,053	4,832	0	1,551	18,435
Tussock grasses - open	3,492	764	0	373	4,629
Shrubs and Grasses - Sparse-Scattered	30,725	5,603	0	3,840	40,168
Shrubs - closed	4,011	1,107	0	431	5,549
Shrubs - open	4,023	507	0	408	4,937
Trees - closed	48	833	0	171	1,052
Trees - open	637	3,546	0	327	4,510
Trees - scattered	4,736	1,506	0	341	6,582
Trees - sparse	2,093	5,426	0	477	7,996
Built-up Surface	0	0	0	52	52
Offshore	0	1	12318	88	12,406
Total	63,864	47,263	12,318	9,137	13,2577
Farmland (Irrigated cropping to rainfed sugar)	1,020	20,982	0	801	22,802

Table 7 | Results for the farmland impact analysis (total area %)

Category	Solar PV	Wind On	Wind Off	TX	Total
Extraction Sites	0	0	0	0.05	0
Inland Waterbodies	0	0	0	0.06	0
Salt Lakes	0	0	0	0.03	0
Irrigated Cropping	0	0	0	0.16	0.01
Irrigated Pasture	0	0	0	0.05	0
Irrigated Sugar	0	0	0	0.11	0.01
Rainfed Cropping	0	12.75	0	1.9	4.68
Rainfed Pasture	1.6	31.65	0	6.54	12.5
Rainfed Sugar	0	0	0	0.01	0
Wetlands	0	0	0	0.11	0.01
Tussock Grasses - Closed	1.61	4.56	0	2.78	2.59
Hummock Grasses - Closed	18.87	10.22	0	16.97	13.9
Tussock Grasses - Open	5.47	1.62	0	4.08	3.49
Shrubs and Grasses - Sparse-Scattered	48.11	11.86	0	42.02	30.3
Shrubs - Closed	6.28	2.34	0	4.71	4.19
Shrubs - Open	6.3	1.07	0	4.46	3.72
Trees - Closed	0.08	1.76	0	1.88	0.79
Trees - Open	1	7.5	0	3.58	3.4
Trees - Scattered	7.42	3.19	0	3.74	4.96
Trees - Sparse	3.28	11.48	0	5.22	6.03
Built-up Surface	0	0	0	0.57	0.04
Offshore	0	0	100	0.96	9.36
Total	48.17	35.65	9.29	6.89	100
Farmland (Irrigated cropping to Rainfed sugar)	1.6	44.4	0	8.77	17.2

Table 8 | Results for the farmland impact analysis (direct area km_2)

Category	Solar PV	Wind On	Wind Off	TX	Total
Extraction Sites	0	0	0	4	4
Inland Waterbodies	0	0	0	6	6
Salt Lakes	0	0	0	3	3
Irrigated Cropping	0	0	0	14	14
Irrigated Pasture	0	0	0	4	4
Irrigated Sugar	0	0	0	10	10
Rainfed Cropping	0	60	0	174	234
Rainfed Pasture	928	150	0	598	1,676
Rainfed Sugar	0	0	0	1	1
Wetlands	0	0	0	10	10
Tussock Grasses - Closed	933	22	0	254	1,209
Hummock Grasses - Closed	10,968	48	0	1,551	12,567
Tussock Grasses - Open	3,177	8	0	373	3,558
Shrubs and Grasses - Sparse-Scattered	27,960	56	0	3,840	31,856
Shrubs - Closed	3,650	11	0	431	4,092
Shrubs - Open	3,661	5	0	408	4,074
Trees - Closed	44	8	0	171	223
Trees - Open	580	35	0	327	942
Trees - Scattered	4,309	15	0	341	4,666
Trees - Sparse	1,905	54	0	477	2,436
Built-up Surface	0	0	0	52	52
Offshore	0	0	123	88	211
Total	58,115	472	123	9,137	67,848
Farmland (Irrigated cropping to Rainfed sugar)	928	210	0	801	1,939

Table 9 | Results for the farmland impact analysis (direct area %)

Category	Solar PV	Wind On	Wind Off	TX	Total
Extraction Sites	0	0	0	0.05	0.01
Inland Waterbodies	0	0	0	0.06	0.01
Salt Lakes	0	0	0	0.03	0
Irrigated Cropping	0	0	0	0.16	0.02
Irrigated Pasture	0	0	0	0.05	0.01
Irrigated Sugar	0	0	0	0.11	0.02
Rainfed Cropping	0	12.75	0	1.9	0.35
Rainfed Pasture	1.6	31.65	0	6.54	2.47
Rainfed Sugar	0	0	0	0.01	0
Wetlands	0	0	0	0.11	0.02
Tussock Grasses - Closed	1.61	4.56	0	2.78	1.78
Hummock Grasses - Closed	18.87	10.22	0	16.97	18.52
Tussock Grasses - Open	5.47	1.62	0	4.08	5.24
Shrubs and Grasses - Sparse-Scattered	48.11	11.86	0	42.02	46.95
Shrubs - Closed	6.28	2.34	0	4.71	6.03
Shrubs - Open	6.3	1.07	0	4.46	6
Trees - Closed	0.08	1.76	0	1.88	0.33
Trees - Open	1	7.5	0	3.58	1.39
Trees - Scattered	7.42	3.19	0	3.74	6.88
Trees - Sparse	3.28	11.48	0	5.22	3.59
Built-up Surface	0	0	0	0.57	0.08
Offshore	0	0	100	0.96	0.31
Total	85.65	0.7	0.18	13.47	100
Farmland (Irrigated cropping to Rainfed sugar)	1.6	44.4	0	8.77	2.87

Table 6 indicates that no VRE projects appear on irrigated lands – which was due to intentional exclusions after consultation with project stakeholders. For the same reason, Table 6 indicates that solar PV projects were also not allowed on any rainfed cropping land, while wind projects were allowed on all rainfed farmland types. The main user of total land area when considering farm types is wind as indicated by Table 6. However, when considering direct land area impacts in Table 8, solar PV shows the greatest combined impacts when adding across all farm cover categories, followed by transmission lines (~14% less direct area then solar PV) and then wind projects (~88% less direct area then solar PV). As mentioned in the prior section, the impacts of transmission lines register in all farm categories – despite an effort to minimize transmission lines on irrigated categories – due to a modelling decision to push new transmission into existing corridors [2].

5.3 Land tenure

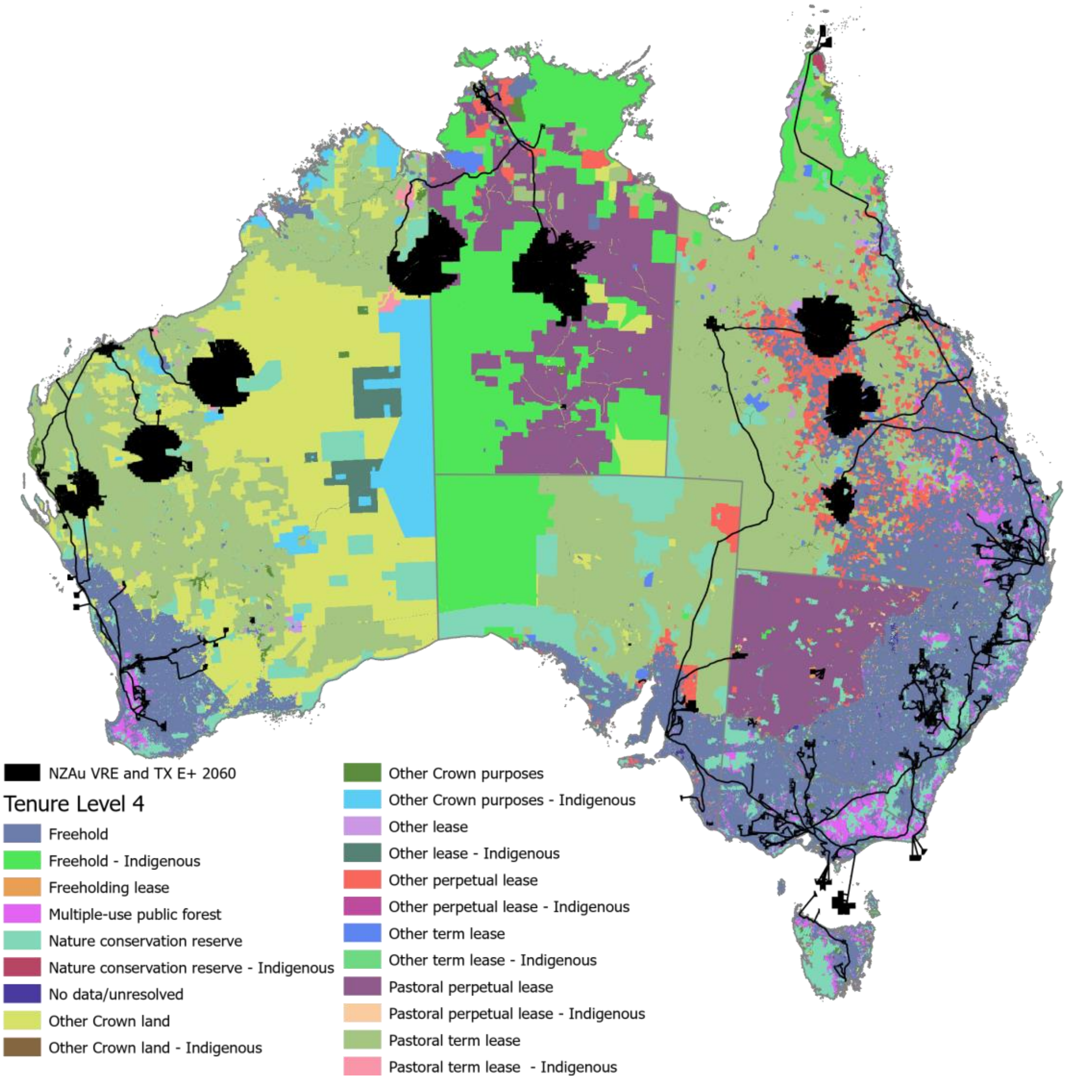
Figure 23 shows an overlay of NZAu infrastructure in the E+ scenario through 2060 on the land tenure categories included in the ABARES land tenure layer used in the analysis [13]. The land tenure categories tracked in Figure 23 are the "Tenure Level 4" categories listed in Table 10, which have been copied verbatim from the metadata provided with the land tenure layer.

Table 10 | "Tenure Level 4" categories (sorted alphabetically, but copied verbatim from the metadata provided with the land tenure layer [13])

Description	Meaning
No data/unresolved	No data/unresolved tenure. Captures areas where there is no tenure data or conflicting data sources; includes water features with unallocated tenure. [NZAu has added the 'offshore' category included in the tenure map to no data/unresolved as they have a roughly 1 km^2 crossover with offshore infrastructure and a few confusing but minor crossovers with onshore infrastructure].
Freehold	Land title holder has the power to sell, lease, licence and mortgage the land. Minerals and petroleum remain property of the Crown. All dealings are subject to compliance to planning and environmental laws, including the protection of heritage and sacred sites. May include freehold land purchased by Aboriginal land trusts through the open market.
Freehold - Indigenous	Land granted to an Aboriginal land trust as freehold. The power to sell, lease and licence the land varies with jurisdiction legislation. Minerals and petroleum rights and acquisition powers of the Crown varies between jurisdictions.
Freeholding lease	Crown leasehold land where a lessee is in the process of transferring lease to freehold with instalments.
Multiple-use public forest	Crown land set aside for multiple-use forest values such as wood harvesting, recreation, and environmental protection, includes state forests and timber reserves.
Nature conservation reserve	Crown land set aside for conservation purposes. Includes heritage reserves where specified.
Nature conservation reserve - Indigenous	Crown land vested or reserved to an Indigenous lands trust and set aside for conservation purposes. Includes heritage reserves where specified.

Description	Meaning
Other Crown land	Crown land unallocated to a purpose or purposes.
Other Crown land - Indigenous	Unallocated Crown land held by an Indigenous land trust.
Other Crown purposes	Crown land set aside for all other purposes including, water, infrastructure, institutional, defence and other undefined reserves; or lands vested to, acquired, or purchased by the Crown or its authorised entities to deliver essential services
Other Crown purposes - Indigenous	Crown land vested or reserved to an Indigenous land trust for the benefit of the Indigenous.
Other lease	Crown leasehold land where the purpose is specified as other or undefined.
Other lease - Indigenous	Crown leasehold land where the purpose is specified as other or undefined and held by an Indigenous land trust.
Other perpetual lease	Crown leasehold land granted in perpetuity to an entity for non-pastoral or non-specified purposes.
Other perpetual lease - Indigenous	Crown leasehold land granted in perpetuity to an Indigenous land trust for non-pastoral or non-specified purposes.
Other term lease	Crown leasehold land granted to an entity for a specified term of years for non-pastoral or non-specified purposes.
Other term lease - Indigenous	Crown leasehold land granted to an Indigenous land trust for a specified term of years for non-pastoral or non-specified purposes.
Pastoral perpetual lease	Crown leasehold land granted in perpetuity to an entity for primarily pastoral purposes
Pastoral term lease	Crown leasehold land granted for a specified term of years to an entity for primarily pastoral purposes.
Pastoral term lease - Indigenous	Crown leasehold land granted for a specified term of years to an Indigenous land trust for primarily pastoral purposes.

Figure 23 | Overlay of NZAu infrastructure in the E+ scenario through 2060 on land tenure categories



Results for the land tenure analysis are provided for total project areas in km_2 in Table 11; and in percentages of each NZAu infrastructure type in Table 12. Results for the land tenure analysis are provided for direct project areas in km_2 in Table 13; and in percentages of each NZAu infrastructure type in Table 14. A “No data/unresolved” category has been added to all following tables to cover onshore areas missing or unresolved in the land tenure map.

Table 11 | Results for the land tenure impact analysis (total area km_2)

Category	Solar PV	Wind On	Wind Off	TX	Total
Freehold	7,776	31,832	-	1,982	41,591
Freehold - Indigenous	9,310	5,679	-	1,116	16,105
Freeholding lease	319	383	-	36	738
Multiple-use public forest	0	33	-	76	109
Nature conservation reserve	380	6	-	129	514

Category	Solar PV	Wind On	Wind Off	TX	Total
Other Crown land	8,237	1,944	-	901	11,083
Other Crown purposes	631	228	-	153	1,013
Other Crown purposes - Indigenous	6	0	-	4	10
Other lease	229	84	-	41	355
Other lease - Indigenous	1	0	-	0	1
Other perpetual lease	5,521	612	-	591	6,725
Other term lease	99	20	-	59	178
Other term lease - Indigenous	0	0	-	0	0
Pastoral perpetual lease	7,201	3,432	-	796	11,429
Pastoral perpetual lease - Indigenous	0	0	-	0	0
Pastoral term lease	23,866	2,995	-	3,128	29,989
Pastoral term lease - Indigenous	273	0	-	37	310
Total	**63,861**	**47,261**	**-**	**9,052**	**12,0179**

Table 12 | Results for the land tenure impact analysis (total area %)

Category	Solar PV	Wind On	Wind Off	TX	Total
Freehold	12.18	67.35	-	21.9	34.61
Freehold - Indigenous	14.58	12.02	-	12.33	13.4
Freeholding lease	0.5	0.81	-	0.4	0.61
Multiple-use public forest	0	0.07	-	0.84	0.09
Nature conservation reserve	0.59	0.01	-	1.42	0.43
Other Crown land	12.9	4.11	-	9.95	9.22
Other Crown purposes	0.99	0.48	-	1.69	0.84
Other Crown purposes - Indigenous	0.01	0	-	0.04	0.01
Other lease	0.36	0.18	-	0.46	0.3
Other lease - Indigenous	0	0	-	0	0
Other perpetual lease	8.65	1.3	-	6.53	5.6
Other term lease	0.15	0.04	-	0.65	0.15
Other term lease - Indigenous	0	0	-	0	0
Pastoral perpetual lease	11.28	7.26	-	8.79	9.51
Pastoral perpetual lease - Indigenous	0	0	-	0	0
Pastoral term lease	37.37	6.34	-	34.55	24.95
Pastoral term lease - Indigenous	0.43	0	-	0.41	0.26

Category	Solar PV	Wind On	Wind Off	TX	Total
Total	53.14	39.33	-	7.53	100

Table 13 | Results for the land tenure impact analysis (direct area km_2)

Category	Solar PV	Wind On	Wind Off	TX	Total
Freehold	11	0	-	3	15
Freehold - Indigenous	7,077	318	-	1,982	9,377
Freeholding lease	8,472	57	-	1,116	9,645
Multiple-use public forest	345	0	-	129	474
Nature conservation reserve	1	0	-	0	1
Other Crown land	5	0	-	4	9
Other Crown purposes	0	0	-	76	77
Other Crown purposes - Indigenous	574	2	-	153	730
Other lease	0	0	-	0	0
Other lease - Indigenous	209	1	-	41	251
Other perpetual lease	0	0	-	0	0
Other term lease	249	0	-	37	286
Other term lease - Indigenous	90	0	-	59	149
Pastoral perpetual lease	290	4	-	36	330
Pastoral perpetual lease - Indigenous	6,553	34	-	796	7,384
Pastoral term lease	5,024	6	-	591	5,622
Pastoral term lease - Indigenous	21,718	30	-	3,128	24,876
Total	**7,495**	**19**	**-**	**901**	**8,415**

Table 14 | Results for the land tenure impact analysis (direct area %)

Category	Solar PV	Wind On	Wind Off	TX	Total
Freehold	12.18	67.35	0	21.9	13.86
Freehold - Indigenous	14.58	12.02	0	12.33	14.26
Freeholding lease	0.5	0.81	0	0.4	0.49
Multiple-use public forest	0	0.07	0	0.84	0.11
Nature conservation reserve	0.59	0.01	0	1.42	0.7
Other Crown land	12.9	4.11	60.87	9.95	12.44
Other Crown purposes	0.99	0.48	0	1.69	1.08

Category	Solar PV	Wind On	Wind Off	TX	Total
Other Crown purposes - Indigenous	0.01	0	0	0.04	0.01
Other lease	0.36	0.18	0	0.46	0.37
Other lease - Indigenous	0	0	0	0	0
Other perpetual lease	8.65	1.3	0	6.53	8.31
Other term lease	0.15	0.04	0	0.65	0.22
Other term lease - Indigenous	0	0	0	0	0
Pastoral perpetual lease	11.28	7.26	0	8.79	10.92
Pastoral perpetual lease - Indigenous	0	0	0	0	0
Pastoral term lease	37.37	6.34	0	34.55	36.78
Pastoral term lease - Indigenous	0.43	0	0	0.41	0.42
Total	**85.92**	**0.7**	**0**	**13.38**	**100**

Table 11 indicates that for the E+ scenario, roughly 49% of the NZAu infrastructure sits on freehold land, with 40% on leased land, and the remaining 10% being sited on un-leased crown lands. Interestingly, Table 11 suggests that utility solar PV is more likely to be sited on *Pastoral term & perpetual lease*, while wind generation assets are predominantly sited on *Freehold* land. The presence of solar PV and wind projects on the categories "Multiple-use public forest" and "Nature conservation reserve" in Table 11 and Table 12 suggests a misalignment between the exclusion layers used and the tenure layer for this analysis. The misalignment represents a potential limitation on interpretation of results and the identification of the source of the misalignment should be included in future work emanating from the study. At the same time, the presence of transmission projects in these and nearly all categories of land tenure, is unsurprising given a modelling preference for new transmission to following existing transmission corridors.

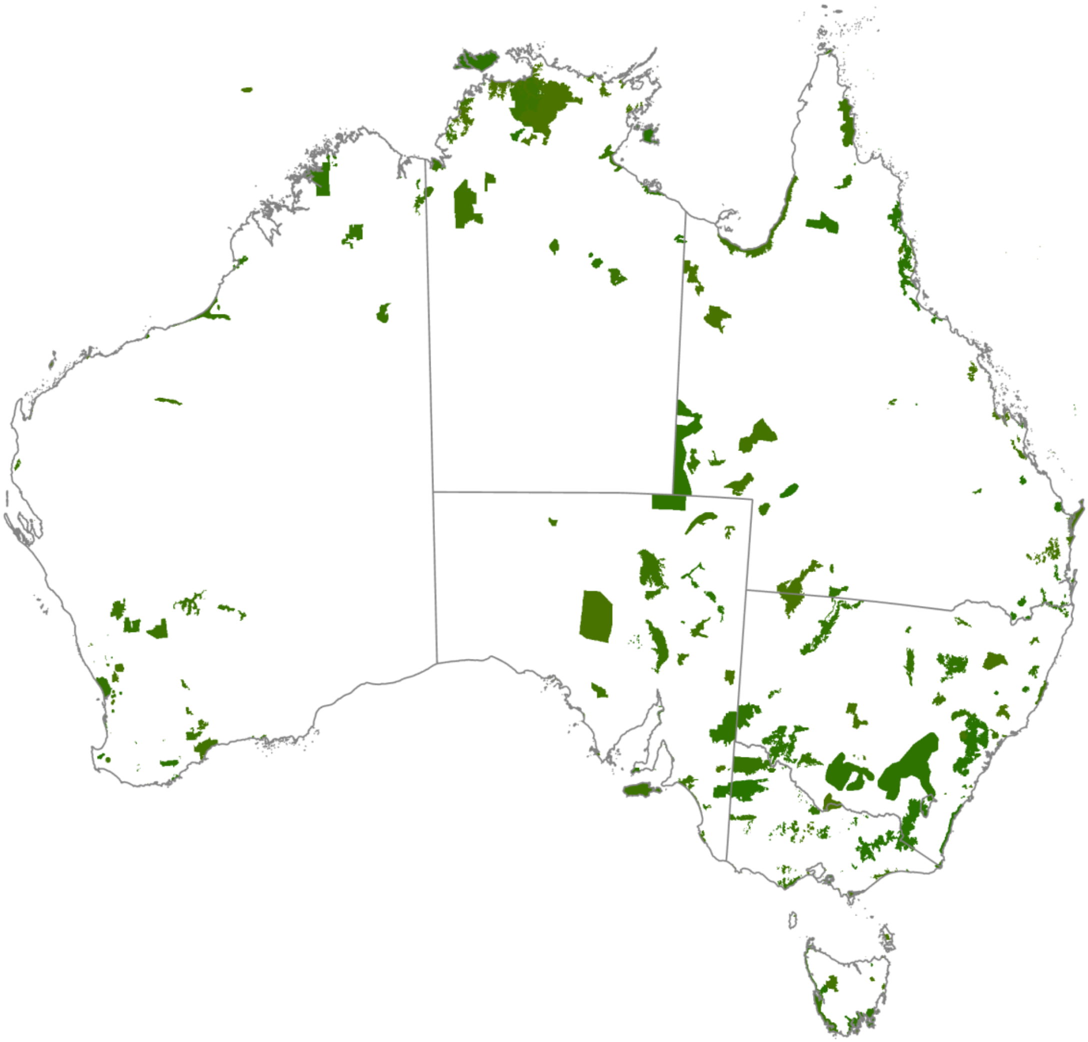
5.4 Biodiversity

At a minimum, a combined approach to safeguarding biological diversity in Australia includes avoiding development in protected areas (PA), key biodiversity areas (KBA), and Australia's last remaining intact bioregions [20]. While work remains to be done to ensure comprehensive coverage of all those areas in a single GIS layer — while also laying out processes to update layers as concerns and threats emerge over time — the following GIS layers have been selected to use in considering NZAu infrastructure footprint impacts on biological diversity in Australia. The Kunming-Montreal Global Biodiversity Framework (GBF) [21] has recently been signed off by Convention for Biological Diversity (CBD) signatory nations – of which Australia is one [22], [23]. The selected layers below are considered against the Global Biodiversity Framework (GBF) targets and connected national efforts. The analyses do not include PA as PA are already included in NZAu exclusion layers and no crossovers with PA are expected outside of existing transmission corridors.

1. Key Biodiversity Areas (see Figure 24)
    a. Key Biodiversity Areas [14]
        i. Target 1, 3, & 4 of GBF [21]
        ii. Jurisdiction – Commonwealth of Australia via the Key Biodiversity National Coordination Group
        iii. Protection status - Varies
        iv. Includes 330 distinct KBAs covering 448,288 km^2, or 5.83 % of Australia’s continuous land area
        v. Provided resolution: < 1m

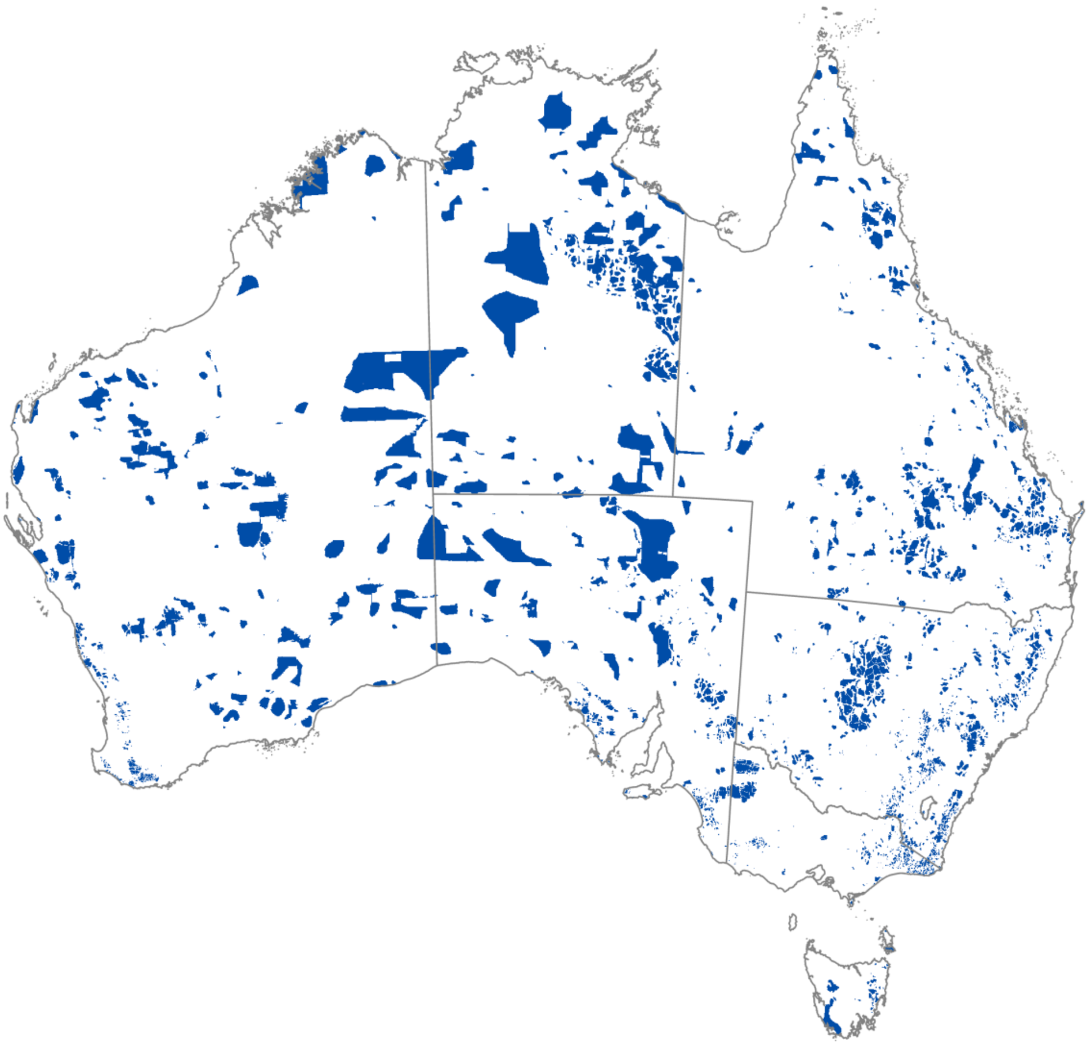
vi. Version used: 2022

Figure 24 | Key Biodiversity Areas



2. Intact Bioregions (see Figure 25)
    a. Intact bioregions [24]
        i. CBD mechanism alignment – inputs into International KBA Criteria C mapping guidelines for intact ecosystems working group, and efforts to align to CBD Kunming-Montreal Framework, in particular goals (Goal A), and targets (1, 2, 12)
        ii. Jurisdiction – Commonwealth of Australia via the Key Biodiversity National Coordination Group
        iii. Protection status – Varies
        iv. Covers 1,001,897 km^2 or 13.03 % of Australia's continuous land area
        v. Provided resolution: 1300 m
        vi. Version used: 2023

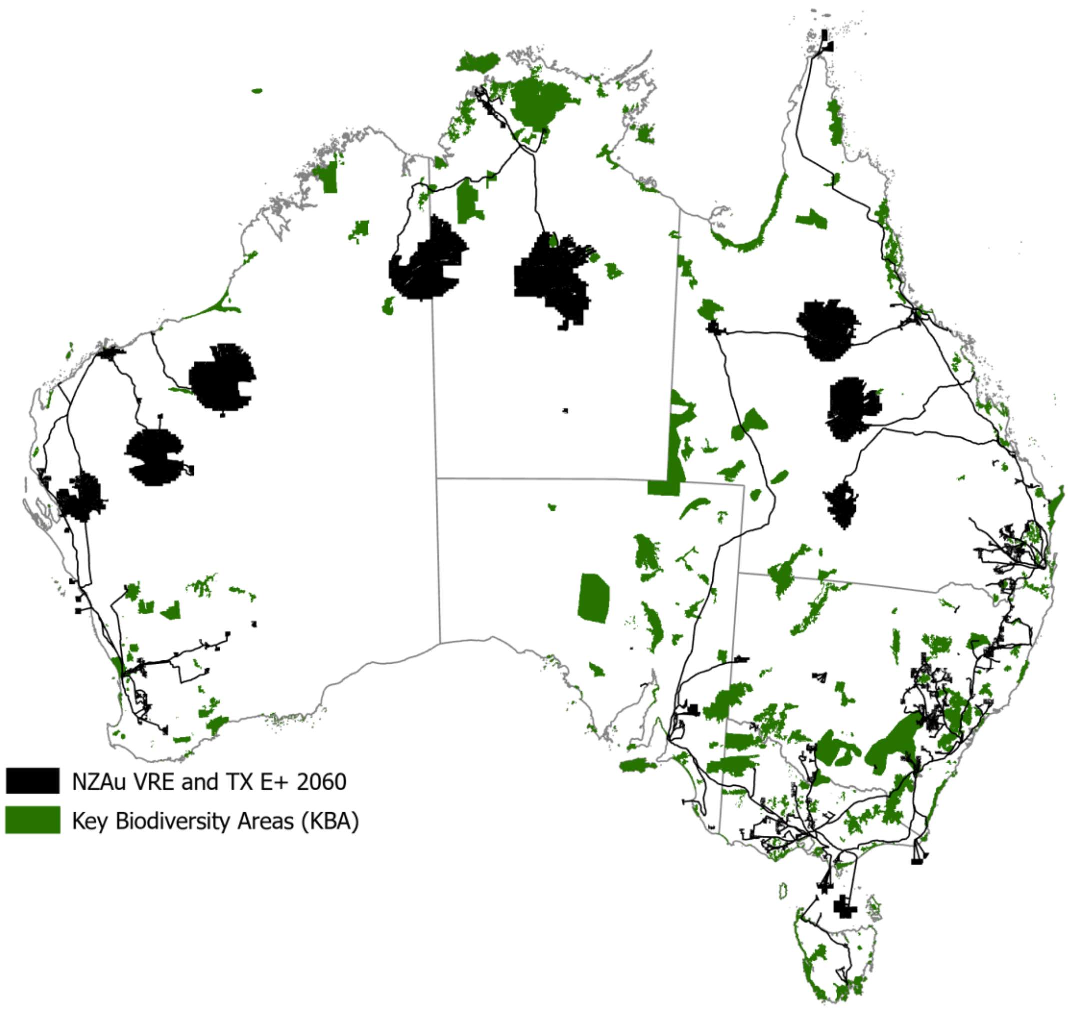
Figure 25 | Intact Bioregions



5.4.1 Key Biodiversity Areas (KBA)

Figure 26 shows an overlay of NZAu infrastructure in the E+ scenario through 2060 on the areas contained in the biodiversity layer selected for the analysis [14].

Figure 26 | Overlay of NZAu infrastructure in the E+ scenario through 2060 on areas contained in the biodiversity layer selected for the analysis



Results for the biodiversity impact analysis are provided for total project areas in km_2 in Table 15; and in percentages of each Key Biodiversity Area (KBA) in Table 16. Results for the biodiversity impact analysis are provided for direct project areas in km^2 in Table 17; and in percentages of each KBA in Table 18. Note that the percentage results of this section differ from the others in reporting %s of each KBA rather than percentages of each NZAu infrastructure type. If a KBA is listed in the following Tables but has a total area that rounds to zero, it is still included in the Tables to indicate an adjacent project or small crossover with the KBA. Estimations of percentage of the KBA area occur before rounding of total and direct area impacts occur.

Table 15 | Results for the KBA analysis (total area km_2)

KBA	Solar PV	Wind On	TX	Total
Adelaide and Mary River Floodplains	0	0	0	0
Arnhem Plateau	0	221	1	222
Australian Alps	0	0	4	4
Barmah-Millewa	0	197	6	202
Bendigo Box-Ironbark Region	0	0	0	0
Bowling Green Bay National Park	0	0	1	1
Buckley River	41	0	2	43
Bundarra-Barraba	2	37	3	42
Bunya Mountains and Yarraman	0	0	2	2
Capertee Valley	0	0	0	0
Coastal Wet Tropics	0	0	0	0
Conondale Range	0	0	0	0
Coomallo	0	0	0	0
D'Aguilar	0	0	1	1
Dampier Saltworks	0	0	0	0
Diamantina and Astrebla Grasslands	0	0	2	2
Extension of Girraween	0	0	1	1
Extension of Labertouche Creek B.R.	0	0	0	0
Fitzroy Floodplain and Delta	0	0	1	1
Fortescue Marshes	1	0	0	1
Gammon Ranges and Arkaroola	0	0	1	1
Gibraltar Range	0	0	1	1
Gidgegannup	1	0	0	1
Gippsland Lakes	0	0	0	0
Goonoo	0	34	0	35
Great Sandy Strait	0	0	0	0
Greater Blue Mountains	0	0	10	10
Gregory National Park	0	0	12	12
Gulf St Vincent	0	0	0	0
Hanging Rock and associated hydrobasin	0	22	0	22
Hunter Estuary	0	0	0	0
Karara and Lochada	0	0	0	0
Keep River	0	0	8	8

KBA	Solar PV	Wind On	TX	Total
Lake Corangamite Complex	0	0	0	0
Lake Galilee	2	0	0	2
Lake Macquarie	0	0	0	0
Lake Woods	17	0	1	18
Little Desert	0	0	0	0
Lockerbie Scrub	0	0	2	2
Lower Brodribb River	0	0	0	0
Moora	0	0	0	0
Morehead River	0	0	2	2
Moreton Bay and Pumicestone Passage	0	0	0	0
Mudgee-Wollar	4	0	4	8
Mundaring-Kalamunda	0	0	1	1
New England	0	0	0	0
North-west Tasmanian Coast	0	0	1	1
Northern Swan Coastal Plain	0	0	11	11
Ord Irrigation Area	0	0	1	1
Paluma	0	0	0	0
Richmond Woodlands	0	0	2	2
Riverina Plains	23	0	1	24
Robbins Passage and Boullanger Bay	0	0	0	0
Rushworth Box-Ironbark Region	0	5	0	5
Scenic Rim	0	0	0	0
South-east Tasmania	0	0	1	1
South-west Slopes of NSW	136	733	31	900
St Arnaud Box-Ironbark Region	0	0	0	0
Tarrabool Lake-Eva Downs Swamp System	0	0	1	1
The Lakes (Western Australia)	0	0	1	1
Traprock	0	178	1	179
Ulladulla to Merimbula	0	0	2	2
Wooroonooran	0	0	3	3
Yinberrie Hills	0	0	11	11
Total	**227**	**1,427**	**133**	**1,787**

Table 16 | Results for the KBA analysis (total area % of each KBA area)

KBA	Solar PV	Wind On	TX	Total
Adelaide and Mary River Floodplains	0	0	0	0
Arnhem Plateau	0	1.04	0	1.05
Australian Alps	0	0	0.03	0.03
Barmah-Millewa	0	7.45	0.22	7.67
Bendigo Box-Ironbark Region	0	0	0.02	0.02
Bowling Green Bay National Park	0	0	0.16	0.16
Buckley River	0.84	0	0.05	0.89
Bundarra-Barraba	0.05	1.05	0.07	1.18
Bunya Mountains and Yarraman	0	0	0.39	0.39
Capertee Valley	0.06	0	0	0.06
Coastal Wet Tropics	0	0	0	0
Conondale Range	0	0	0.03	0.03
Coomallo	0	0	0.6	0.6
D'Aguilar	0	0	0.19	0.19
Dampier Saltworks	0.08	0	0.69	0.77
Diamantina and Astrebla Grasslands	0	0	0.03	0.03
Extension of Girraween	0	0	0.44	0.44
Extension of Labertouche Creek B.R.	0	0	1.8	1.8
Fitzroy Floodplain and Delta	0	0	0.07	0.07
Fortescue Marshes	0.15	0	0	0.15
Gammon Ranges and Arkaroola	0	0	0.03	0.03
Gibraltar Range	0	0	0.33	0.33
Gidgegannup	3.06	0	0.74	3.8
Gippsland Lakes	0	0	0.01	0.01
Goonoo	0	3.28	0.01	3.29
Great Sandy Strait	0	0	0	0
Greater Blue Mountains	0	0	0.1	0.1
Gregory National Park	0	0	0.09	0.09
Gulf St Vincent	0	0	0.04	0.04
Hanging Rock and associated hydrobasin	0	14.26	0.07	14.33
Hunter Estuary	0	0	0.13	0.13
Karara and Lochada	0	0	0.01	0.01
Keep River	0	0	0.85	0.85

KBA	Solar PV	Wind On	TX	Total
Lake Corangamite Complex	0	0	0.03	0.03
Lake Galilee	0.67	0	0	0.67
Lake Macquarie	0	0	0.11	0.11
Lake Woods	1.37	0	0.09	1.47
Little Desert	0	0	0.02	0.02
Lockerbie Scrub	0	0	1.48	1.48
Lower Brodribb River	0	0	0.47	0.47
Moora	0	0	1.79	1.79
Morehead River	0	0	0.17	0.17
Moreton Bay and Pumicestone Passage	0	0	0	0
Mudgee-Wollar	0.23	0	0.24	0.47
Mundaring-Kalamunda	0	0	0.5	0.5
New England	0	0	0	0
North-west Tasmanian Coast	0	0	0.02	0.02
Northern Swan Coastal Plain	0	0	0.45	0.45
Ord Irrigation Area	0	0	0.43	0.43
Paluma	0	0	0.02	0.02
Richmond Woodlands	0	0	0.66	0.66
Riverina Plains	0.21	0	0.01	0.22
Robbins Passage and Boullanger Bay	0	0	0.03	0.03
Rushworth Box-Ironbark Region	0	0.99	0.07	1.06
Scenic Rim	0	0	0.03	0.03
South-east Tasmania	0	0	0.05	0.05
South-west Slopes of NSW	0.53	2.83	0.12	3.48
St Arnaud Box-Ironbark Region	0	0	0	0
Tarrabool Lake-Eva Downs Swamp System	0	0	0.07	0.07
The Lakes (Western Australia)	0	0	0.68	0.68
Traprock	0	27.77	0.13	27.9
Ulladulla to Merimbula	0	0	0.07	0.07
Wooroonooran	0	0	0.06	0.06
Yinberrie Hills	0	0	1.1	1.1

Table 17 | Results for the KBA analysis (direct area km^2)

KBA	Solar PV	Wind On	TX	Total
Adelaide and Mary River Floodplains	0	0	0	0
Arnhem Plateau	0	2	1	3
Australian Alps	0	0	4	4
Barmah-Millewa	0	2	6	8
Bendigo Box-Ironbark Region	0	0	0	0
Bowling Green Bay National Park	0	0	1	1
Buckley River	37	0	2	39
Bundarra-Barraba	2	0	3	5
Bunya Mountains and Yarraman	0	0	2	2
Capertee Valley	0	0	0	0
Coastal Wet Tropics	0	0	0	0
Conondale Range	0	0	0	0
Coomallo	0	0	0	0
D'Aguilar	0	0	1	1
Dampier Saltworks	0	0	0	0
Diamantina and Astrebla Grasslands	0	0	2	2
Extension of Girraween	0	0	1	1
Extension of Labertouche Creek B.R.	0	0	0	0
Fitzroy Floodplain and Delta	0	0	1	1
Fortescue Marshes	1	0	0	1
Gammon Ranges and Arkaroola	0	0	1	1
Gibraltar Range	0	0	1	1
Gidgegannup	1	0	0	1
Gippsland Lakes	0	0	0	0
Goonoo	0	0	0	0
Great Sandy Strait	0	0	0	0
Greater Blue Mountains	0	0	10	10
Gregory National Park	0	0	12	12
Gulf St Vincent	0	0	0	0
Hanging Rock and associated hydrobasin	0	0	0	0
Hunter Estuary	0	0	0	0
Karara and Lochada	0	0	0	0
Keep River	0	0	8	8

KBA	Solar PV	Wind On	TX	Total
Lake Corangamite Complex	0	0	0	0
Lake Galilee	2	0	0	2
Lake Macquarie	0	0	0	0
Lake Woods	15	0	1	17
Little Desert	0	0	0	0
Lockerbie Scrub	0	0	2	2
Lower Brodribb River	0	0	0	0
Moora	0	0	0	0
Morehead River	0	0	2	2
Moreton Bay and Pumicestone Passage	0	0	0	0
Mudgee-Wollar	3	0	4	7
Mundaring-Kalamunda	0	0	1	1
New England	0	0	0	0
North-west Tasmanian Coast	0	0	1	1
Northern Swan Coastal Plain	0	0	11	11
Ord Irrigation Area	0	0	1	1
Paluma	0	0	0	0
Richmond Woodlands	0	0	2	2
Riverina Plains	21	0	1	22
Robbins Passage and Boullanger Bay	0	0	0	0
Rushworth Box-Ironbark Region	0	0	0	0
Scenic Rim	0	0	0	0
South-east Tasmania	0	0	1	1
South-west Slopes of NSW	124	7	31	163
St Arnaud Box-Ironbark Region	0	0	0	0
Tarrabool Lake-Eva Downs Swamp System	0	0	1	1
The Lakes (Western Australia)	0	0	1	1
Traprock	0	2	1	3
Ulladulla to Merimbula	0	0	2	2
Wooroonooran	0	0	3	3
Yinberrie Hills	0	0	11	11
Total	**206**	**13**	**133**	**354**

Table 18 | Results for the KBA analysis (direct area % of each KBA area)

KBA	Solar PV	Wind On	TX	Total
Adelaide and Mary River Floodplains	0	0	0	0
Arnhem Plateau	0	0.01	0	0.01
Australian Alps	0	0	0.03	0.03
Barmah-Millewa	0	0.07	0.22	0.3
Bendigo Box-Ironbark Region	0	0	0.02	0.02
Bowling Green Bay National Park	0	0	0.16	0.16
Buckley River	0.77	0	0.05	0.81
Bundarra-Barraba	0.05	0.01	0.07	0.13
Bunya Mountains and Yarraman	0	0	0.39	0.39
Capertee Valley	0.06	0	0	0.06
Coastal Wet Tropics	0	0	0	0
Conondale Range	0	0	0.03	0.03
Coomallo	0	0	0.6	0.6
D'Aguilar	0	0	0.19	0.19
Dampier Saltworks	0.07	0	0.69	0.76
Diamantina and Astrebla Grasslands	0	0	0.03	0.03
Extension of Girraween	0	0	0.44	0.44
Extension of Labertouche Creek B.R.	0	0	1.8	1.8
Fitzroy Floodplain and Delta	0	0	0.07	0.07
Fortescue Marshes	0.14	0	0	0.14
Gammon Ranges and Arkaroola	0	0	0.03	0.03
Gibraltar Range	0	0	0.33	0.33
Gidgegannup	2.78	0	0.74	3.52
Gippsland Lakes	0	0	0.01	0.01
Goonoo	0	0.03	0.01	0.04
Great Sandy Strait	0	0	0	0
Greater Blue Mountains	0	0	0.1	0.1
Gregory National Park	0	0	0.09	0.09
Gulf St Vincent	0	0	0.04	0.04
Hanging Rock and associated hydrobasin	0	0.14	0.07	0.21
Hunter Estuary	0	0	0.13	0.13
Karara and Lochada	0	0	0.01	0.01
Keep River	0	0	0.85	0.85

Lake Corangamite Complex	0	0	0.03	0.03
Lake Galilee	0.61	0	0	0.61
Lake Macquarie	0	0	0.11	0.11
Lake Woods	1.25	0	0.09	1.34
Little Desert	0	0	0.02	0.02
Lockerbie Scrub	0	0	1.48	1.48
Lower Brodribb River	0	0	0.47	0.47
Moora	0	0	1.79	1.79
Morehead River	0	0	0.17	0.17
Moreton Bay and Pumicestone Passage	0	0	0	0
Mudgee-Wollar	0.21	0	0.24	0.45
Mundaring-Kalamunda	0	0	0.5	0.5
New England	0	0	0	0
North-west Tasmanian Coast	0	0	0.02	0.02
Northern Swan Coastal Plain	0	0	0.45	0.45
Ord Irrigation Area	0	0	0.43	0.43
Paluma	0	0	0.02	0.02
Richmond Woodlands	0	0	0.66	0.66
Riverina Plains	0.19	0	0.01	0.2
Robbins Passage and Boullanger Bay	0	0	0.03	0.03
Rushworth Box-Ironbark Region	0	0.01	0.07	0.08
Scenic Rim	0	0	0.03	0.03
South-east Tasmania	0	0	0.05	0.05
South-west Slopes of NSW	0.48	0.03	0.12	0.63
St Arnaud Box-Ironbark Region	0	0	0	0
Tarrabool Lake-Eva Downs Swamp System	0	0	0.07	0.07
The Lakes (Western Australia)	0	0	0.68	0.68
Traprock	0	0.28	0.13	0.4
Ulladulla to Merimbula	0	0	0.07	0.07
Wooroonooran	0	0	0.06	0.06
Yinberrie Hills	0	0	1.1	1.1

Table 15 indicates that NZAu infrastructure in 2060 in the E+ scenario infringes on 64 KBA, with infrastructure covering up to 1 km^2 of 40 KBA and 10 km^2 or more of 14 KBA. Table 16 indicates that NZAu infrastructure in 2060 in the E+ scenario only covers more than 1% of a KBA's total area in the case of 14 KBAs. A simultaneous inspection of Table 15 and Table 16 suggest that while nine of the 14 KBAs having more than a 1% crossover with NZAu infrastructure in Table 16 are also in the top 14 largest crossover areas in Table 15, total area crossover is not necessarily a good indicator of the percentage of each KBA that is occupied by NZAu infrastructure. Figure 27 places the total area from Table 15 and total area percentage from Table 16 — for each KBA with NZAu infrastructure covering more than 1% of a KBA's total area — into the same plot.

Figure 27 | Potential total KBA impact area in km^2 and as a % of each KBA's total area (for any KBA with a potential impact on more than 1% of its total area)

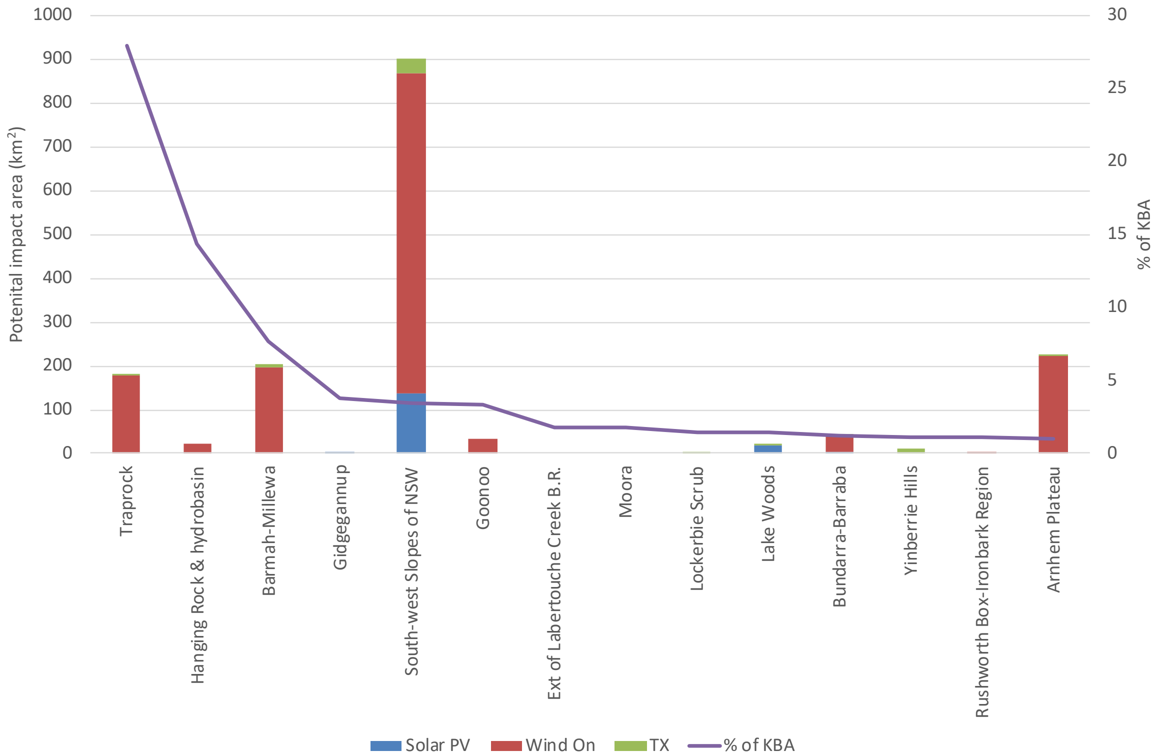


Figure 27 shows that while the KBA with the largest total area crossover with NZAu infrastructure in 2060 in the E+ scenario is the "South-west Slopes of NSW" (900 km^2), the total crossover area only amounts to 3.5% of the KBA's total area of 25,869 km^2. As a percentage of KBA area, Figure 27 shows that there are four KBAs with higher percentages of total area crossover: "Taprock" (27.9%), "Hanging Rock and associated hydrobasin" (14.3%), "Barmah-Millewa" (7.7%), and "Gidgegannup" (3.8%).

When considering direct area impacts in Table 17 and Table 18, wind projects diminish in contribution to direct footprints on KBAs and contribute no area to the six KBAs with more than a 1% direct area crossover with NZAu infrastructure in 2060 in the E+ scenario. For the 34 KBAs that only report a crossover with transmission infrastructure in Table 15 and Table 17, many of those crossovers are expected to arise from a modelling decision to preference existing transmission corridors – wherever they may travel – rather than route around exclusion zones.

5.4.2 Intact Bioregions

Figure 28 shows an overlay of NZAu infrastructure in the E+ scenario through 2060 on the areas contained in the intact bioregions layer selected for the analysis. Results for the intact bioregions impact analysis are provided for total and direct project areas in km_2 and as percentages of total and direct infrastructure area in Table 19.

Figure 28 | Overlay of NZAu infrastructure in the E+ scenario through 2060 on areas contained in the intact bioregions layer selected for the analysis

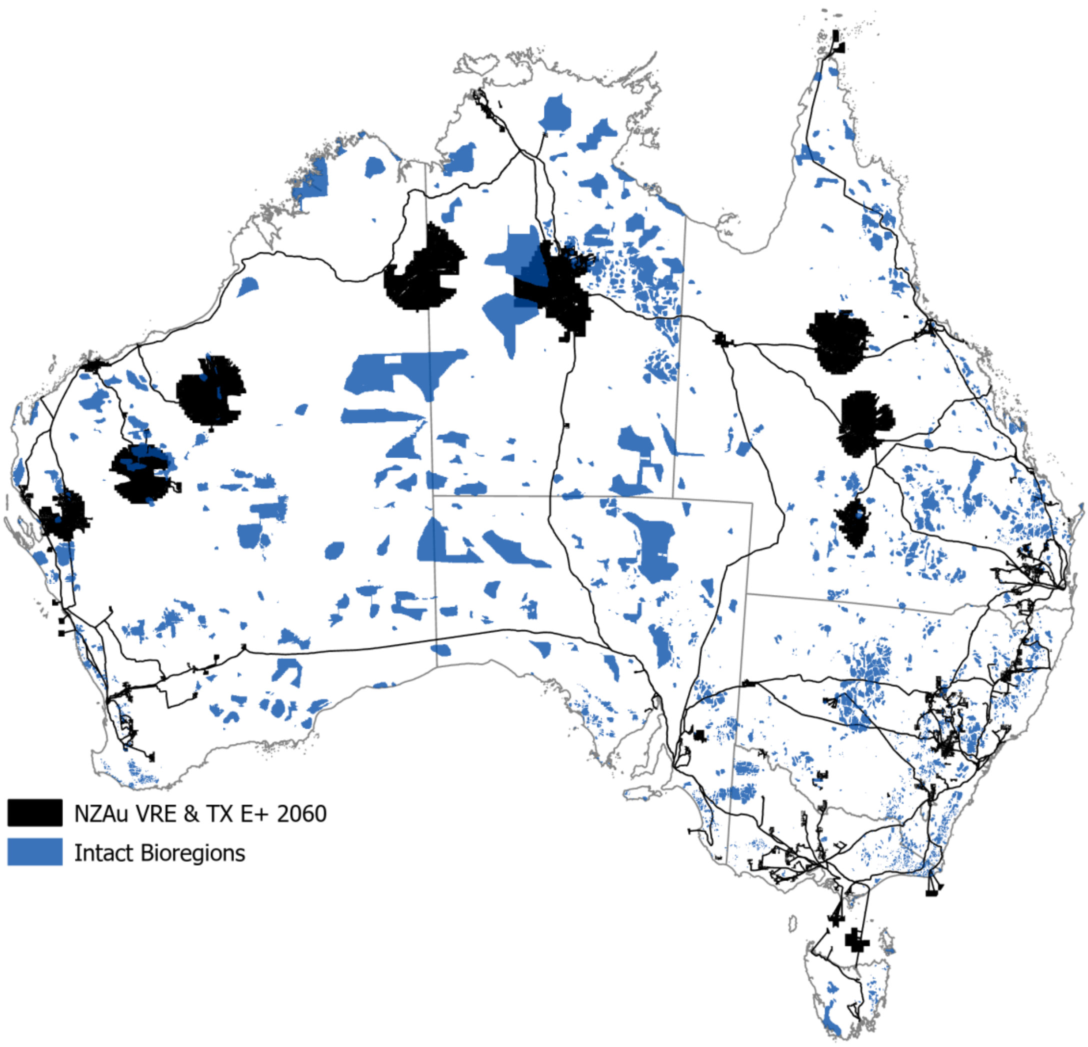


Table 19 | Results for the intact bioregions analysis

Intact bioregions analyses	Solar PV	Wind On	Wind Off	TX	Total
Total area km^2	4,850	1,522	0	489	6,862
Total area %	7.6	3.22	0	5.41	5.71
Direct area km^2	4,414	15	0	489	4,918
Direct area %	7.6	3.22	0	5.41	7.27

Figure 28 shows that most of the impacted bioregions in the E+ scenario are in the NT and WA export areas. Table 19 indicates the total NZAu infrastructure area that impacts intact bioregions is 6,862 km^2 or 6 % of the total NZAu VRE and transmission and infrastructure build. Table 19 also indicates that solar PV projects are likely to have the greatest impact on intact bioregions, followed by wind projects and then transmission corridors. A comparison of Table 15 with Table 19 shows that NZAu infrastructure overlaps a total area of intact bioregions that is ~4x larger than the overlap with KBA.

Appendices

Appendix A: VRE projects treated as existing in NZAu modelling

Table 20 lists the VRE projects selected to be modelled as existing in NZAu. These projects are included in modelling in the first model year after they are listed as becoming operational in Table 20. The projects in Table 20 are then retired no later than the first model year that occurs 30 years after they become operational (e.g. a VRE project put into service in 2023, becomes operational in the model in 2025 and is retired in 2055. Projects in italics in Table 20 were found during data collection — often in earlier versions of referenced documentation [5], [6], [10], [25] — and were included in modelling as a way to partially account for projects that were expected to be added to existing generator lists after the data collection period ended.

Table 20 | VRE projects selected to be modelled as existing in NZAu

Facility	Technology	Capacity (MW)	Operational
Adelaide Desalination	Solar	13.72	2023
Albany	Wind	21.6	2001
Ambrisolar 1	Solar	0.96	2020
Aramara Solar Farm	Solar	101.4	2023
Ararat	Wind	240	2017
Badgingarra	Wind	130	2019
Badgingarra	Solar	17.5	2020
Bald Hills	Wind	106.6	2015
Bango 973	Wind	159	2021
Bango 999	Wind	84.8	2022
Bannerton	Solar	100	2019
Batchelor 1	Solar	10	2021
Batchelor 2	Solar	10	2021
Beros Road	Wind	9.252	2021
Berrybank	Wind	180.6	2021
Beryl	Solar	98.4	2019
Bluegrass Solar Farm	Solar	148	2023
Boco Rock	Wind	113	2015
Bodangora	Wind	113.19	2019
Bolivar WWTP	Solar	11	2023
Bomen	Solar	121	2020
Bremer Bay	Wind	0.6	2004
Broken Hill	Solar	53	2015
Bulgana Green Power Hub	Wind	204.4	2020
Bungala One	Solar	135	2018

Facility	Technology	Capacity (MW)	Operational
Bungala Two	Solar	135	2019
Canunda	Wind	46	2005
Capital	Wind	140.7	2010
Cathedral Rocks	Wind	66	2007
Cattle Hill	Wind	144	2021
Challicum Hills	Wind	52.5	2003
Cherry Tree	Wind	57.6	2020
Childers	Solar	55.87	2019
Christies Beach WWTP	Solar	5	2023
Clare	Solar	110.4	2018
Clements Gap	Wind	56.7	2010
Clermont	Solar	92.5	2019
Cohuna	Solar	31.103	2021
Coleambally	Solar	150.3	2019
Collector	Wind	226.8	2021
Collgar	Wind	206	2011
Collinsville	Solar	42.5	2018
Columboola Solar Farm	Solar	217.25	2023
Coopers Gap	Wind	452.89	2020
Corowa	Solar	35.992	2022
Crookwell 2	Wind	96.04	2019
Crowlands	Wind	79.95	2020
Crudine Ridge	Wind	138	2021
Cullerin Range	Wind	30	2009
Darling Downs	Solar	121	2018
Darlington Point	Solar	274.968	2020
Darwin RAAF	Solar	3.2	2022
Daydream	Solar	167.75	2019
Denmark	Wind	1.44	2013
Dundonnell	Wind	336	2020
Edenvale Solar Park	Solar	146	2024
Elaine	Wind	83.6	2019
Emerald	Solar	72	2019
Emu Downs	Wind	80	2006
Emu Downs	Solar	20	2018
Finley	Solar	162.36	2019

Facility	Technology	Capacity (MW)	Operational
Gangarri	Solar	162	2022
Gannawarra	Solar	55	2018
Glenrowan West	Solar	132	2021
Goonumbla	Solar	69.75	2020
Granville Harbour	Wind	111.6	2021
Grasmere	Wind	13.8	2012
Greenough River Stage 1	Solar	10	2012
Greenough River Stage 2	Solar	30	2020
Gullen Range	Solar	10	2018
Gullen Range Stage 1	Wind	165.5	2014
Gullen Range Wind Farm 2	Wind	110.67	2022
Gunnedah	Solar	110	2022
Gunning	Wind	46.5	2011
North Brown Hill	Wind	132.3	2011
The Bluff	Wind	52.5	2012
Hallett Stage 1	Wind	94.5	2007
Hallett Stage 2	Wind	71.4	2009
Hamilton	Solar	57.5	2019
Happy Valley	Solar	8	2023
Haughton	Solar	132.597	2020
Hayman	Solar	57.75	2020
Hillston Sun	Solar	85	2023
Hornsdale Stage 1	Wind	102.4	2016
Hornsdale Stage 2	Wind	102.4	2017
Hornsdale Stage 3	Wind	112	2017
Hughenden	Solar	18	2022
Jemalong	Solar	55	2022
Junee	Solar	36.014	2022
Kaban Green Power Hub - Wind Farm	Wind	149.8	2023
Kalbarri	Wind	1.6	2009
Karadoc	Solar	102.98	2019
Karakin	Wind	5	2013
Katherine	Solar	25	2021
Kennedy Energy Park	Solar	15	2023
Kennedy Energy Park	Wind	43.2	2023
Kiamal	Solar	199.95	2021

Facility	Technology	Capacity (MW)	Operational
Kiata	Wind	31.05	2018
Kidston	Solar	50	2018
Lake Bonney 1	Wind	80.5	2005
Lake Bonney 2	Wind	159	2008
Lake Bonney 3	Wind	39	2011
Lilyvale	Solar	118.4	2019
Limondale 1	Solar	220	2021
Limondale 2	Solar	28.98	2021
Lincoln Gap Stage 1	Wind	126	2020
Lincoln Gap Stage 2	Wind	86.4	2022
Longreach	Solar	14	2018
Macarthur	Wind	420	2012
Manildra	Solar	50	2018
Mannum PS2	Solar	16.8	2023
Mannum PS3	Solar	16.62	2023
Manton dam	Solar	10	2022
Maryrorough	Solar	34.5	2021
Merredin	Solar	100	2020
Metz Solar Farm	Solar	135	2022
Middlemount	Solar	26	2020
Molong	Solar	36.08	2021
Moorabool	Wind	312	2019
Moree	Solar	56	2016
Morgan to Whyalla Pipeline No 1 PS	Solar	6.12	2021
Morgan to Whyalla Pipeline No 2 PS	Solar	5.88	2021
Morgan to Whyalla Pipeline No 3 PS	Solar	7.38	2021
Morgan to Whyalla Pipeline No 4 PS	Solar	5.88	2021
Mortlake South Wind Farm	Wind	157.5	2023
Mortons Lane	Wind	19.5	2012
Mount Barker	Wind	2.43	2010
Mount Emerald	Wind	180.52	2019
Mt Millar	Wind	70	2006
Moura Solar Farm	Solar	99	2023
Mt Gellibrand	Wind	138.6	2019
Mt Mercer	Wind	131.2	2014
Mumbida	Wind	55	2013

Facility	Technology	Capacity (MW)	Operational
Munna Creek Solar Farm	Solar	142.8	2023
Murra Warra	Wind	225.7	2019
Murra Warra Stage 2	Wind	209	2022
Murray Bridge Pump 2	Solar	13.74	2023
Musselroe	Wind	168	2012
Nevertire	Solar	104.64	2019
New England Solar Farm	Solar	400	2023
Northam	Solar	9.8	2019
Numurkah	Solar	110.48	2019
Nyngan	Solar	102.03	2015
Oakey 1	Solar	25	2019
Oakey 2	Solar	55.64	2019
Oaklands Hill	Wind	67.2	2011
Parkes	Solar	50.5	2018
Port Augusta Renewable Energy Park - Solar	Solar	79.2	2023
Port Augusta Renewable Energy Park - Wind	Wind	210	2023
Portland	Wind	151.7	2010
Riverina Solar Farm	Solar	32.4	2023
Robertson Barracks	Solar	10	2022
Rodds Bay Solar Farm	Solar	302.5	2023
Ross River	Solar	128	2019
Rugby Run	Solar	65	2019
Salt Creek	Wind	54	2019
Sapphire	Wind	270	2018
Sebastopol Solar Farm	Solar	90	2022
Silverton	Wind	198.94	2018
Snowtown Stage 2 North	Wind	144	2014
Snowtown Stage 2 South	Wind	126	2014
Snowtown Stage 1	Wind	98.7	2008
Starfish Hill	Wind	33	2003
Stockyard Hill	Wind	527.56	2023
Sun Metals	Solar	143	2018
Sunraysia	Solar	228.8	2021
Suntop	Solar	150	2022
Susan River	Solar	85.26	2019
Tailem Bend	Solar	108	2019

Facility	Technology	Capacity (MW)	Operational
Taralga	Wind	106.8	2014
Uterne	Solar	3.8	2016
Wagga North	Solar	36.014	2022
Walkaway	Wind	89.1	2005
Warradarge	Wind	180	2021
Warwick Stage 1	Solar	32.104	2022
Warwick Stage 2	Solar	32.104	2022
Waterloo	Wind	130.8	2011
Wattle Point	Wind	90.75	2005
Waubra	Wind	192	2009
Wellington	Solar	211.2	2021
Wemen	Solar	97.5	2019
West Hills	Wind	5	2013
West Wyalong Solar Farm	Solar	105.27	2023
Western Downs Green Power Hub	Solar	400	2022
White Rock	Solar	20	2019
White Rock	Wind	172.48	2019
Whitsunday	Solar	57.5	2019
Willogoleche	Wind	119.36	2019
Winton	Solar	85	2021
Wollar Solar Farm	Solar	280	2023
Woodlawn	Wind	48.3	2011
Woolnorth	Wind	139.75	2007
Woolooga Solar Farm	Solar	222.5	2022
Wyalong Solar Farm	Solar	62.32	2023
Yaloak South	Wind	28.7	2019
Yambuk	Wind	30	2010
Yandin	Wind	214.2	2021
Yarranlea	Solar	102.96	2020
Yatpool	Solar	92.56	2021
Yendon	Wind	144.4	2020

Appendix B: Estimating the total GW-km capacity of Australia's transmission networks

Placing the transmission build of each NZAu scenario in context requires an estimate of the GW-km of transmission capacity in Australia in 2020. The NZAu team made this estimate by removing transmission line entries with duplicate names from the Geoscience Australia Foundation Electricity Infrastructure Map [4], assuming the average MW capacities listed in Table 21 for all remaining entries marked as operational and having a rating of 132 kV or higher, multiplying each line's estimated GW capacity by the line's length in km (1000 MW = 1 GW), and then summing the resulting GW-km across the entire database.

Table 21 | Assumed average MW capacities by kV rating

kV rating	Assumed MW = (Single+Double)/2	Single circuit MW [6] unless otherwise marked	Double circuit MW [6] unless otherwise marked
132	375	250 [25]	500 [25]
220	600	400	800
275	675	400	950
330	900	600	1,200
400	500	500 [26]	500 [26]
500	2280	1,520	3,040

Using the above method results in an estimate of a 28,238 GW-km capacity over 46,613 km of transmission line. This estimate appears in the right ballpark for total length of transmission line against the Clean Energy Councils estimate of 45,000 km of transmission line [27]. The authors could not find a metric from any other source to aid in the validation of the estimation. Table 22 lists the k, GW-km, and % of total GW-km results of the analysis by kV rating.

Table 22 | Assumed average GW capacities by kV rating

kV rating	km	GW-km	% of total km	% of total GW-km
132	22,684	8,507	49%	30.1%
220	6,943	4,166	15%	14.8%
275	7,741	5,225	17%	18.5%
330	7,324	6,592	16%	23.3%
400	355	177	1%	0.6%
500	1,566	3,571	3%	12.6%
Total	**46,613**	**28,238**	**100%**	**100%**

The analysis in Table 22 indicates that if considering only distance, nearly half of Australia's existing high-voltage transmission networks operate at 132 kV. However, if considering the estimate of average GW-km capacity, 330 kV lines, which sum to less than a third of the total distance of the 132 kV lines, represent 23.3% of the total GW-km capacity as compared to the 30.1% represented by the 132 kV lines. Differing estimates of Australia's total GW-km can be arrived at based on different assumptions about the average MW capacity of Australia's existing transmission lines at each kV rating. For instance, if one assumes that all transmission lines in Australia operate at the average single circuit capacities listed in Table 21, a total GW-km capacity of 18,500 is estimated for Australia. If instead the average double circuit capacities in Table 21 are used for all lines, then one arrives at an estimate of just under 38,000 GW-km.

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