
# Downscaling – Net-zero transitions, Australian communities, the land and sea

19 April 2023

NET ZERO AUSTRALIA

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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

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## 19 April 2023

Andrew Pascale[1], Dominic Davis[2], James Watson[1], Simon Smart[1], Michael Brear[2], Julian McCoy[2], Maria Lopez Peralta[2], Rod Keenan[2], Richard Eckard[2], April Reside[1], Michelle Ward[1], Hugh Possingham[1]

[1] The University of Queensland

[2] The University of Melbourne

*In the development of Net Zero Australia's energy system modelling, siting analyses and associated content used in this report we have engaged with and consulted the following organisations. The NZAu team is very grateful for their expertise and insight and sustained support. We do not purport to represent their positions or imply that they have agreed to our methodologies or results.*

- *The National Native Title Council (NNTC)*
- *The National Farmers Federation (NFF)*
- *The Australian Conservation Foundation (ACF)*

# Contents

# 1 Introduction

The Net Zero Australia (NZAu) project has undertaken modelling of pathways for Australia to achieve net-zero for both domestic Australian greenhouse gas emissions, as well as those associated with Australia's significant energy exports. A particular focus of this work has been to identify the composition of least-cost energy supply chains required to displace all current fossil fuel exports with an equivalent amount (by energy content) of clean energy, thereby abating ~1200 Mt-$CO_2$e/year and providing ~15 EJ/year of clean energy globally. This has involved development of macro-scale energy system modelling and determination of the activities and investments required across Australia over the period 2020 to 2060, for a series of Scenarios.

NZAu modelling is characterised by its highly spatially and temporally resolved outputs that enable siting – or downscaling – of the energy system assets required for the modelled transition, together with assessments of changes in land use that may impact those who live on and are custodians of those lands. In most net-zero scenarios we find that decarbonisation of both domestic and export energy systems is led by the expansion of the electricity system through deployment of renewable generators (solar PV and wind). Such a deployment of utility-scale solar PV and wind electricity generation assets for both domestic and export energy systems represents a large increase in the land and sea area that is required to host energy system assets in Australia.

With this work we seek to provide insight into the complexities of the land and sea use change associated with the net-zero transition by synthesising NZAu's macro-energy system modelling with the downscaling analyses of: renewable electricity generation and energy transmission infrastructure siting, employment modelling, capital mobilisation, and farmland afforestation. The process for siting new energy assets directly influences the distribution of employment and capital in Australia and will impact local and regional communities. We have made an effort to be thorough, transparent and inclusive in the development of principles for the siting new energy assets and activities, while also acknowledging that the maps of NZAu infrastructure presented in this section and all other NZAu publications are notional outputs of a modelling exercise and should not be confused with actual processes – either under consideration or under construction – for the actual siting of wind, solar PV and transmission infrastructure in Australia. The Net Zero Australia project has regularly consulted with the key stakeholder groups, The National Native Title Council (NNTC), The National Farmers Federation (NFF), and The Australian Conservation Foundation (ACF).

It is important to note that the location of NZAu's large candidate renewable energy export zones was not part of stakeholder consultation nor subject to any form of optimisation. Locations were chosen due to the coincidence of high-quality renewable (wind and solar) energy resource, low population density, and proximity to existing ports. Our sensitivity studies suggest that there exists significant optionality in the locations of renewable energy projects (as distinct from the energy export zones), without large increases in total system costs. This suggests that stakeholders have choice in the siting of assets and associated employment, capital and biodiversity impacts. In this document, we present two strongly differentiated renewable energy and electricity transmission builds, via the E+ Rapid Electrification Core Scenario and the E+ RemoteCost+ Sensitivity, to demonstrate that impacts and trade-offs between strategies have complex implications for land and sea use.

The E+ Scenario assumes nearly full electrification of transport and building stocks and all residential and commercial building energy services by 2050. No constraints are applied to the supply-side energy mix. The E+ RemoteCost+ Sensitivity is the same as the E+ scenario with the exception that remote northern regions of Australia have higher capital costs.

For each selected strategy (E+ and E+RemoteCost+), we analyse the overlap of NZAu solar PV, wind and electricity transmission infrastructure with the Indigenous Estate, land tenure categories, locations of current agricultural activity, and locations of importance for ecosystem conservation and biodiversity. While selected layers present each of those areas individually, we know that they are deeply interlinked and that the use of siloed analyses is limited and often problematic. For instance, Indigenous connections to land are deeply imbued with cultural knowledge and continually evolving understandings of local environments [1], and the separation of Indigenous Estate from biodiversity is artificial and misses understandings gained from their simultaneous consideration. There are numerous other land, sea and community impacts of the net-zero transition, that we have not examined. We offer the following analyses and insights in hopes of informing current and future deep decarbonisation efforts, and with the understanding that while the future will certainly not follow any of the NZAu modelled net-zero transition pathways, that an integrated approach to climate, biodiversity, community, and land offers the best chance for meeting the shared and diverse goals of Australia and its peoples.

# 2 Methods

## 2.1 Principles of land use and new energy asset siting

There are no generally accepted methods for integrating energy system planning and the Indigenous Estate, farming and ecosystem conservation. The NZAu modelling team developed an approach for identification of land areas that may host new energy assets, based on prior examples [5]–[8] and consultation with stakeholders. The team prioritised the use of public, best available and up-to-date data, but acknowledges that important data sets are continually evolving and that approaches to new energy asset siting will require regular and timely updates.

Net Zero Australia's **principles of land use and new energy asset siting** can be summarised as follows:

- Do not consider land and sea areas excluded by law.
- Remove from consideration all land areas for which empirical evidence, research, or stakeholder interaction provides reasonable cause. Provide transparent documentation, in companion reports: *Methods, Assumptions, Scenarios & Sensitivities* (MASS) [9] and *Downscaling – Solar, wind & electricity transmission siting.* Specific examples of land type exclusions are:
    a. No siting of new variable renewable energy (VRE) infrastructure on land cover categories [10] specified as irrigated lands and no siting of new solar PV infrastructure on rainfed cropland (NFF consultation).
    b. Unless specifically protected in a base exclusion dataset, all Indigenous Estate categories [11] are included for the purposes of siting energy infrastructure.
    c. Prefer existing transmission corridors [12] over greenfield corridors.
    d. Exclude the critical habitat of threatened species [13] and ecological communities [14] (ACF consultation).
    e. Exclude national reserves [4], those in the Collaborative Australia Protected Area Database [2], [3], and inland water, salt lakes, and wetlands [10], [15].
- Update approach as understanding of risks and threats evolve, collaborations deepen, and available data allows. A number of updates have been made throughout NZAu's two-year modelling period. Final rounds of stakeholder interactions have already identified the following areas for updating in future work:
    a. Consideration of Indigenous Estate in offshore areas [16], [17].
    b. Addition of Key Biodiversity Areas [18] and intact biodiversity areas [19] to exclusion areas, and updating of biodiversity approach as new resources emerge (see later biodiversity section).

Use of these principles results in a different set of land exclusions for solar PV and wind infrastructure, as shown in Figure 1. Additional exclusions for VRE (e.g. slope, overlap with existing projects, ocean depth, distance from load, capacity factor, population density) are also considered before siting VRE projects. A similar process is followed in the siting of electricity transmission, with the detailed processes for VRE and electricity transmission siting provided in the MASS [9] and *Downscaling – Solar, wind & electricity transmission siting* documents.

Following the full VRE and transmission siting processes results in the infrastructure maps shown in Figure 2, for the E+ Scenario and the E+RemoteCost+ Sensitivity. This figure shows the total footprint for VRE (utility solar PV, onshore wind and offshore wind) and transmission in 2060 and does not differentiate between infrastructure types.

**Figure 1 | Base utility solar PV (top) and wind (bottom) land exclusion layers used for the identification of candidate project areas.**

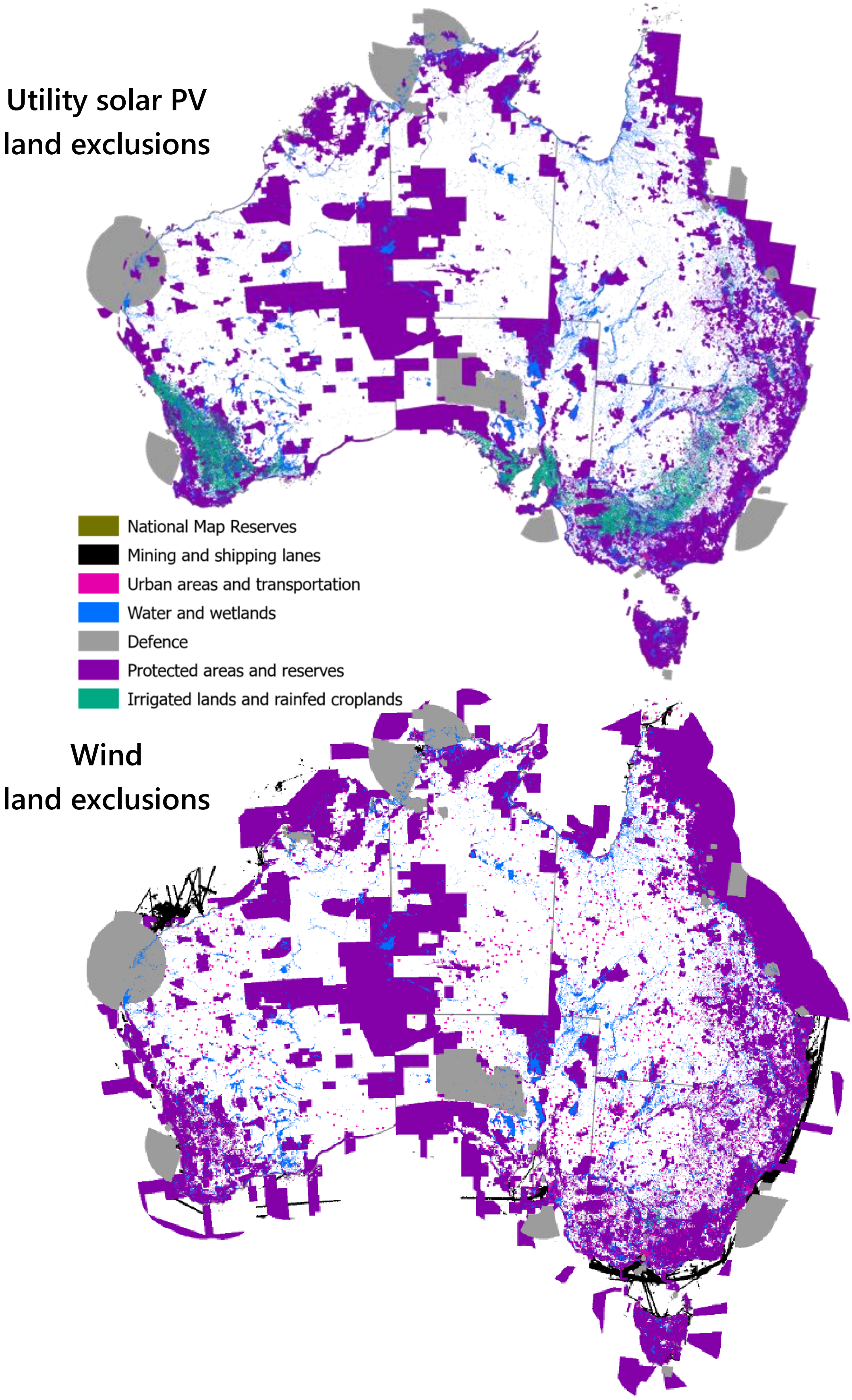
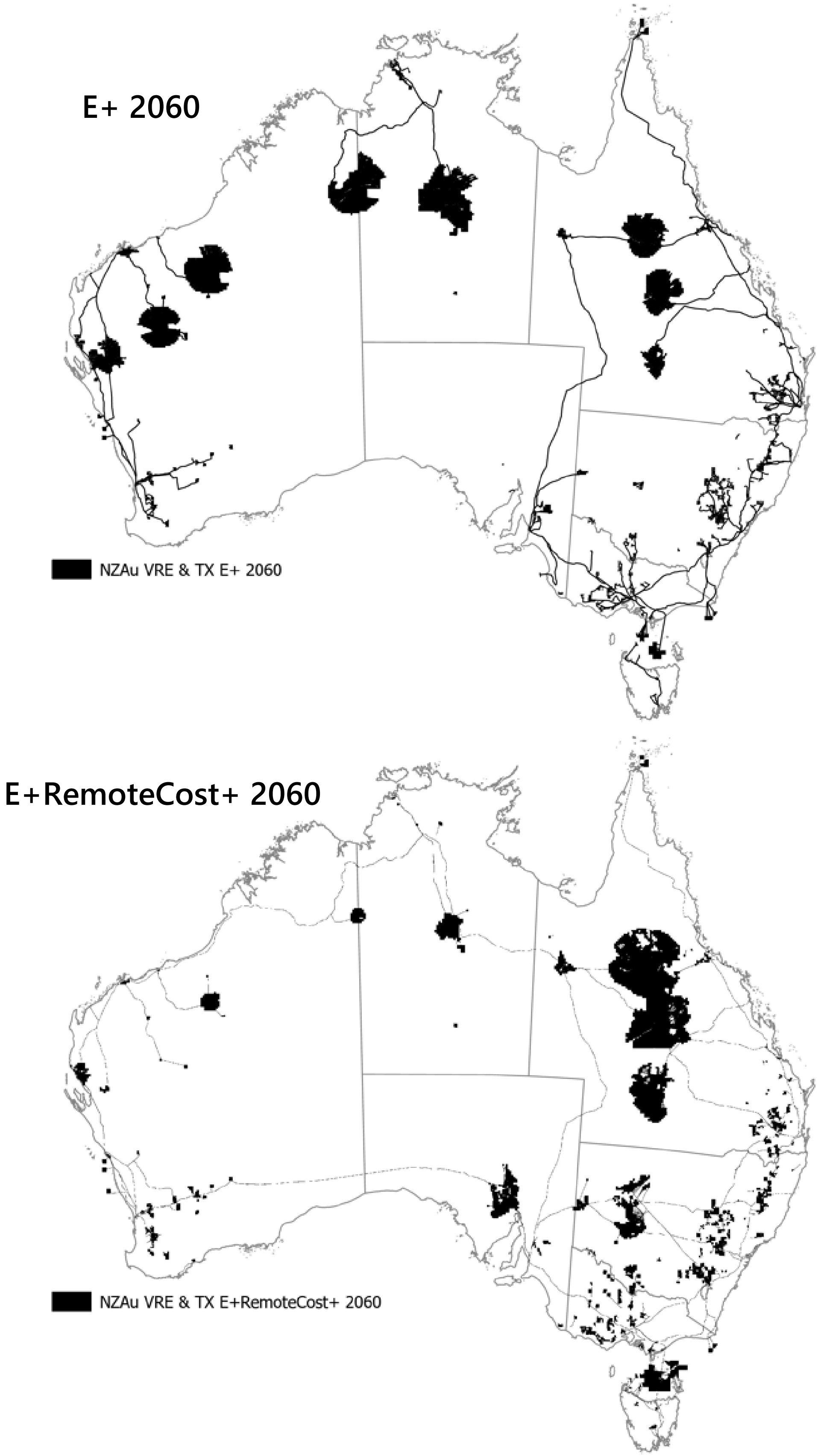


**Figure 2 | NZAu VRE (utility solar PV, onshore wind and offshore wind) and transmission infrastructure build in 2060 for the E+ Scenario (top) and the E+RemoteCost+ Sensitivity. The black areas show the infrastructure area without differentiating between infrastructure type.**



## 2.2 Land use analyses

We undertake land use analyses for the infrastructure maps shown in Figure 2 using a series of map layers that describe different characteristics of Australian lands. These form the bases of the assessment of impact of energy infrastructure siting on different communities, the land and sea. These layers are:

- The Indigenous Estate [11]
- Land Tenure [20]
- Protected Areas [2]–[4], [13]–[15]
- Key Biodiversity Areas [18]
- Intact Bioregions [19]
- Land Use Cover [10]

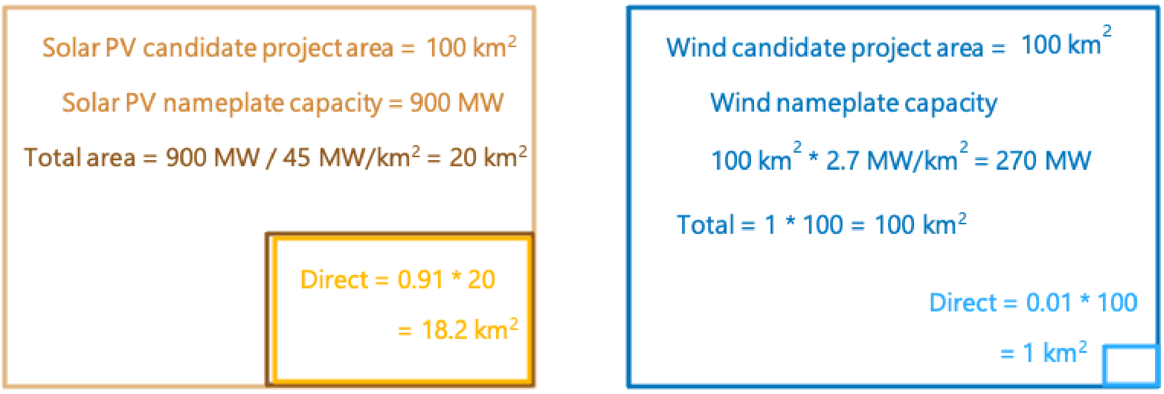
For each of these layers, land use analysis is performed with the following steps:

1. Select data at highest spatial resolution available to the public.
2. Generate a map of VRE and electricity transmission infrastructure with full project areas.
    a. Solar PV projects – full area used for project siting
    b. Wind projects – full area used for project siting
    c. Transmission projects – right-of-way widths have been sourced from Australia focused literature [9] or assumed for subsea corridors.
3. Pro-rate transmission project rights-of-way (ROWs) according to project type and transmission line capacity.
    a. Spur lines and inter-regional transmission project ROWs are pro-rated using the same method used in transmission costing [9]. 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 right-of-way width of 125MW/250MW × 35 meters = 17.5 meters.
    b. Bulk transmission project ROWs are not pro-rated. As current modelling methods are limited to stacking new transmission lines on top of one another, some underestimation of impacts is expected for transmission in corridors with more than one overlapping transmission line.
    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 6000 MW DC corridor will have a right-of way that is 2× a 3000 MW DC corridor).
4. Convert the infrastructure footprint and analysis layers into a raster with a 10m cell size, using the Polygon to Raster conversion tool [21] in ArcGIS Pro.
5. Run the Tabulate Area Tool [22] available in ArcGIS Pro to determine the overlap of each NZAu infrastructure type on the categories of the layer being analysed.
6. Calculate the **total** and **direct footprints** on different land categories of the base map layer under assessment (Figure 3 presents a visual representation total and direct project footprints).
    a. For utility solar PV projects:
        i. Total footprint = 20% of full candidate project area used for siting;
        ii. Direct footprint = 91% of total footprint [7].
    b. For wind projects:
        i. Total footprint = 100% of full candidate project area used for siting;
        ii. Direct footprint = 1% of total footprint [7].
    c. For transmission projects:

i. Total and direct footprints are 100% of full project area estimated after prior pro-rating step.

7. Report infrastructure impacts in terms of both **the total and direct area** impacted in square kilometres ($km^2$) and as percentage of the total area covered by each relevant category in the map layer under assessment.

**Figure 3 | Visual depiction of the total and direct project footprints used in NZAu.**




**We only present total area impacts in this section.** For direct area results, further detail on the analysis process, and some additional analyses, please see the companion *Downscaling – Solar, wind & electricity transmission siting* report. Note that the total and direct areas presented here are a small overestimate of the areas of the actual modelled power densities of solar and wind projects, due to the presence of a number of partial project builds in datasets (less than the full rated build of the candidate project area). The result of allowing partial project builds is 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 $MW/km^2$).

## 2.3 Other methods

This report synthesises Net Zero Australia's macro-energy system modelling of the domestic and export energy systems with downscaling analyses in areas of:

- renewable electricity generation and energy transmission infrastructure siting,
- employment modelling, and
- forestry systems.

Further detail on the methods used and analyses performed within these areas can therefore be found in the following companion reports:

- *Methods, Assumptions, Scenarios & Sensitivities*;
- *Downscaling – Solar, wind & electricity transmission siting*;
- *Downscaling – Employment impacts*; and
- *Downscaling – Forestry*.

# 3 Communities

This section considers both Indigenous Estate [11] and land tenure [20] categories — none of which have been explicitly excluded from the siting of energy assets, but some of which may be fully or partially represented in excluded reserve and protected areas [2]–[4]. Discussions with stakeholders indicated that the land tenure map might be useful for consideration alongside the Indigenous Estate map as a potential indication of the complexity of future land use negotiations and agreements.

## 3.1 Indigenous Estate

Results for the Indigenous Estate land use analysis are provided for total project areas (in $km^2$) of the E+ scenario in Table 1 and the E+RemoteCost+ sensitivity in Table 2; and including the total area as a percentage of the respective total NZAu infrastructure build presented in the final column of each table. Figure 4 then plots the total infrastructure footprint area on the categories of Indigenous Estate for E+ and E+RemoteCost+ in 2060.

**Table 1 | Results for overlap of E+ scenario infrastructure in 2060 with the Indigenous Estate categories in total area ($km^2$), and for the total area as a percentage of the total NZAu infrastructure build in 2060 in the scenario presented in the final column (in parentheses).**

| Category | Solar PV | Wind On | Wind Off | TX | Total |
|---|---|---|---|---|---|
| Indigenous co-managed | 0 | 0 | - | 17 | 17 (< 0.1) |
| Indigenous co-managed & subject to other special rights | 0 | 0 | - | 16 | 16 (< 0.1) |
| Indigenous managed | 724 | 0 | - | 151 | 875 (0.7) |
| Indigenous managed & subject to other special rights | 789 | 147 | - | 146 | 1,083 (0.9) |
| Indigenous owned & co-managed | 0 | 0 | - | 6 | 6 (< 0.1) |
| Indigenous owned & managed | 9,924 | 5,615 | - | 1,099 | 16,638 (13.9) |
| Indigenous owned & co-managed & w/ other special rights | 0 | 0 | - | 6 | 6 (< 0.1) |
| Indigenous owned & managed & w/ other special rights | 567 | 47 | - | 202 | 815 (0.7) |
| Subject to other special rights | 19,709 | 9,825 | - | 2,652 | 32,186 (26.8) |
| **Total** | **31,713** | **15,634** | **-** | **4,295** | **51,642 (43.0)** |
| **Other lands** | **32,148** | **31,628** | **-** | **4,757** | **68,534 (57.0)** |

**Table 2 | Results for the overlap of E+RemoteCost+ sensitivity infrastructure in 2060 with the Indigenous Estate categories in total area ($km^2$), and for the total area as a percentage of the total NZAu infrastructure build in 2060 in the sensitivity presented in the final column (in parentheses).**

| Category | Solar PV | Wind On | Wind Off | TX | Total |
|---|---|---|---|---|---|
| Indigenous co-managed | 0 | 0 | - | 25 | 25 (< 0.1) |
| Indigenous co-managed & subject to other special rights | 0 | 0 | - | 21 | 21 (< 0.1) |

| Category | Solar PV | Wind On | Wind Off | TX | Total |
|---|---|---|---|---|---|
| Indigenous managed | 279 | 0 | - | 56 | 335 (0.24) |
| Indigenous managed & subject to other special rights | 276 | 0 | - | 40 | 317 (0.23) |
| Indigenous owned & co-managed | 0 | 0 | - | 4 | 4 (< 0.1) |
| Indigenous owned & managed | 2,389 | 1,431 | - | 278 | 4,098 (2.92) |
| Indigenous owned & co-managed & w/ other special rights | 0 | 0 | - | 3 | 3 (0) |
| Indigenous owned & managed & w/ other special rights | 26 | 47 | - | 24 | 97 (0.07) |
| Subject to other special rights | 16,002 | 17,083 | - | 2,368 | 35,452 (25.3) |
| **Total** | **18,972** | **18,561** | **-** | **2,819** | **40,352 (28.8)** |
| **Other lands** | **38,219** | **54,986** | **0** | **6,563** | **99,768 (81.2)** |

**Figure 4 | Total VRE and transmission infrastructure footprint area on the categories of Indigenous Estate, for the E+ scenario and the E+RemoteCost+ sensitivity in 2060.**

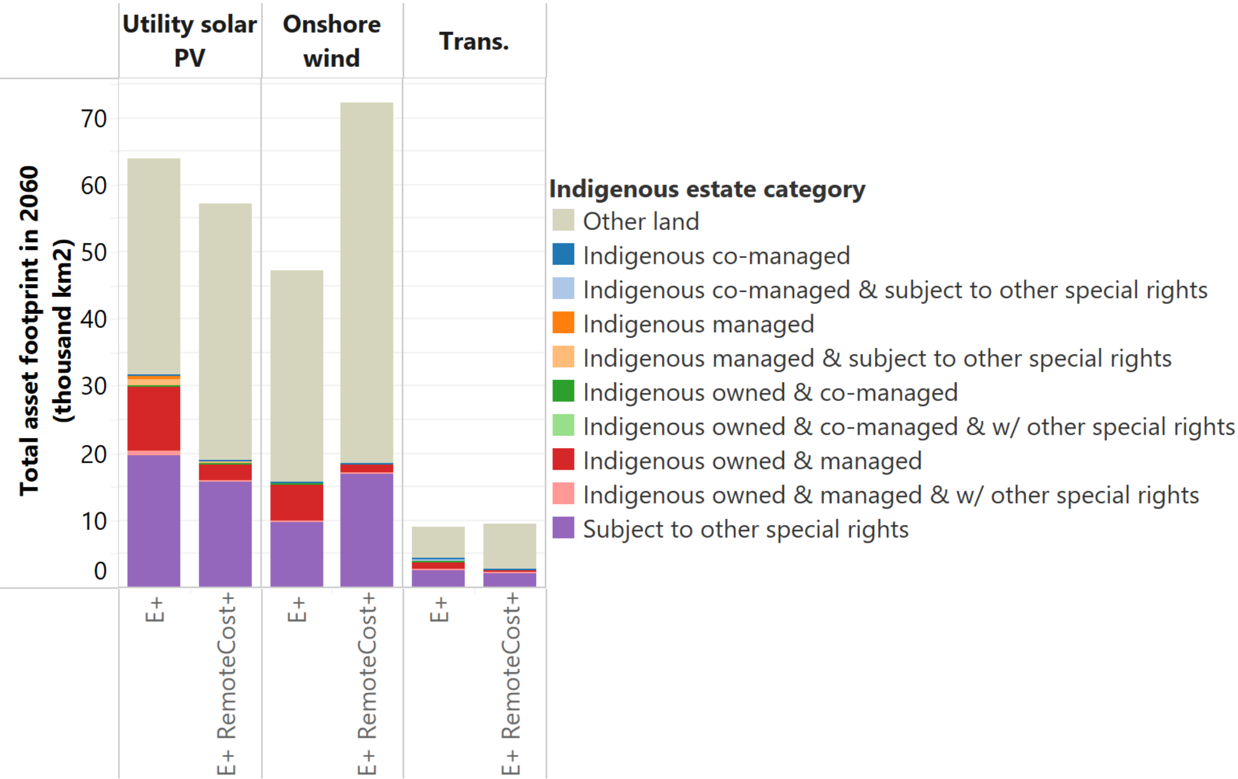


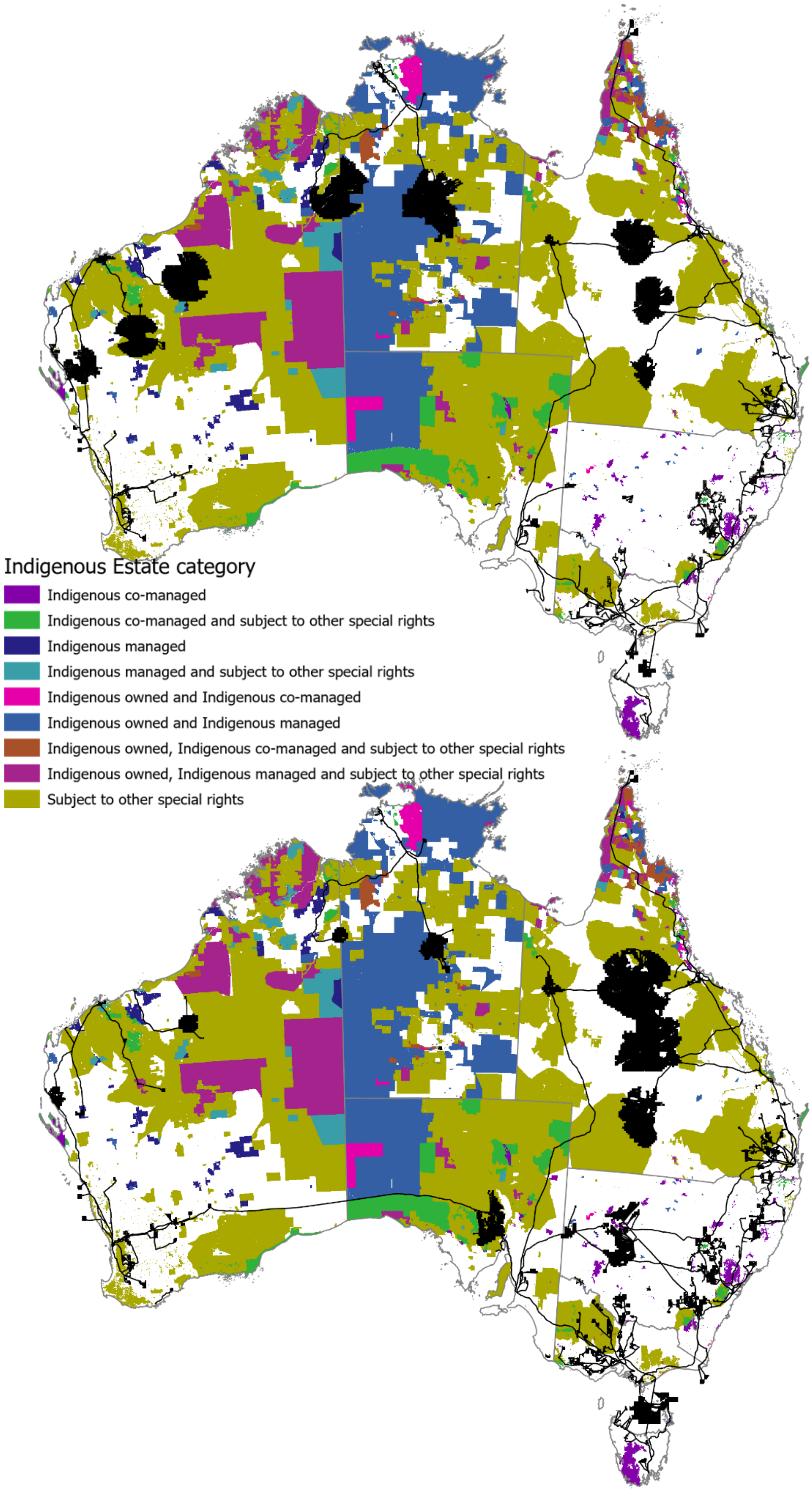
Table 1 shows that in the E+ Scenario in 2060, new energy system assets account for a total area footprint of 52 thousand $km^2$ (43% of sited asset area will be on Indigenous Estate) on lands designated under the various categories of the Indigenous Estate. This land area is predominantly used for utility solar PV assets, the large majority of that which is sited on the Indigenous Estate, is associated with the modelled energy export supply chain. It can also be seen that 27% of the sited infrastructure is located on land designated as *Subject to other special rights*[1], 14% on *Indigenous owned & managed*, while the energy asset footprint is lower on other categories of the Indigenous Estate. Comparison of Table 1 and Table 2 indicates that the effect of applying higher regional capital costs on siting of infrastructure in more remote regions of Western Australia, the Northern Territory and Queensland leads to ~14% less NZAu infrastructure being sited on the Indigenous Estate (~10 thousand $km^2$ less), although this figure needs to be understood in the context of not just a shift in the location of infrastructure, but also a shift in the footprint of the total infrastructure sited as more wind farms, having lower energy densities than solar PV farms, are sited in the E+RemoteCost+ sensitivity.

Figure 5 provides an overlay of 2060 NZAu VRE and electricity transmission infrastructure for the E+ scenario and the E+RemoteCost+ sensitivity on the Indigenous Estate. We note that development of energy system projects (both generation and transmission) on Indigenous lands should involve fair and just agreement making and early engagement with respect to the protection of cultural heritage and the environment, as well as benefit-sharing for communities, including royalties and equity sharing, local energy security and employment opportunities to follow *free, prior and informed consent*, including a right to say no, throughout the project lifecycle[2].

[1] Land or forest subject to native title determinations, registered Indigenous Land Use Agreements, and legislated special cultural use provisions.

[2] One example of best practice here is *The Best Practice Principles for Clean Energy Projects*, recently published by the First Nations Clean Energy Network.

**Figure 5 | Indigenous Estate map and 2060 NZAu VRE and electricity transmission infrastructure for the E+ scenario (top) and the E+RemoteCost+ sensitivity (bottom).**



## 3.2 Land Tenure

Results for the land tenure analysis are provided for total project areas (in $km^2$) of the E+ scenario in Table 3 and the E+RemoteCost+ sensitivity in Table 4; and including the total area as a percentage of the respective total NZAu infrastructure build presented in the final column of each table. Figure 6 then plots the total infrastructure footprint area on the land tenure categories for this scenario and sensitivity in 2060.

**Table 3 | Results for overlap of E+ infrastructure in 2060 with land tenure categories in total area ($km^2$), and for the total area as a percentage of the total NZAu infrastructure build in 2060 in the scenario presented in the final column (in parentheses).**

| Category | Solar PV | Wind On | Wind Off | TX | Total |
|---|---|---|---|---|---|
| Freehold | 7,776 | 31,832 | - | 1,982 | 41,591 (34.6) |
| Freehold - Indigenous | 9,310 | 5,679 | - | 1,116 | 16,105 (13.4) |
| Freeholding lease | 319 | 383 | - | 36 | 738 (0.6) |
| Multiple-use public forest | 0 | 33 | - | 76 | 109 (0.1) |
| Nature conservation reserve | 380 | 6 | - | 129 | 514 (0.4) |
| No data/unresolved | 12 | 13 | - | 3 | 29 (0) |
| Other Crown land | 8,237 | 1,944 | - | 901 | 11,083 (9.2) |
| Other Crown purposes | 631 | 228 | - | 153 | 1,013 (0.8) |
| Other Crown purposes - Indigenous | 6 | 0 | - | 4 | 10 (0) |
| Other lease | 229 | 84 | - | 41 | 355 (0.3) |
| Other lease - Indigenous | 1 | 0 | - | 0 | 1 (0) |
| Other perpetual lease | 5,521 | 612 | - | 591 | 6,725 (5.6) |
| Other term lease | 99 | 20 | - | 59 | 178 (0.2) |
| Other term lease - Indigenous | 0 | 0 | - | 0 | 0 (0) |
| Pastoral perpetual lease | 7,201 | 3,432 | - | 796 | 11,429 (9.5) |
| Pastoral perpetual lease - Indigenous | 0 | 0 | - | 0 | 0 (0) |
| Pastoral term lease | 23,866 | 2,995 | - | 3,128 | 29,989 (25) |
| Pastoral term lease - Indigenous | 273 | 0 | - | 37 | 310 (0.3) |
| **Total** | **63,861** | **47,261** | **-** | **9,052** | **120,179 (100)** |

Table 4 | Results for the overlap of E+RemoteCost+ sensitivity infrastructure in 2060 with land tenure categories in total area (km$^2$), and for the total area as a percentage of the total NZAu infrastructure build in 2060 in the sensitivity presented in the final column (in parentheses).

| Category | Solar PV | Wind On | Wind Off | TX | Total |
|---|---|---|---|---|---|
| Freehold | 13,945 | 46,914 | - | 3,395 | 64,254 (45.9) |
| Freehold - Indigenous | 2,074 | 986 | - | 281 | 3,342 (2.4) |
| Freeholding lease | 618 | 726 | - | 90 | 1,434 (1) |
| Multiple-use public forest | 0 | 43 | - | 94 | 137 (0.1) |
| Nature conservation reserve | 38 | 28 | - | 140 | 206 (0.2) |
| No data/unresolved | 28 | 35 | - | 7 | 70 (0.1) |
| Other Crown land | 875 | 1,493 | - | 194 | 2,563 (1.8) |
| Other Crown purposes | 1,116 | 410 | - | 251 | 1,777 (1.3) |
| Other Crown purposes - Indigenous | 0 | 0 | - | 2 | 2 (0) |
| Other lease | 636 | 164 | - | 111 | 912 (0.7) |
| Other perpetual lease | 11,658 | 944 | - | 1,325 | 13,928 (9.9) |
| Other term lease | 220 | 29 | - | 101 | 350 (0.3) |
| Pastoral perpetual lease | 4,733 | 7,778 | - | 674 | 13,185 (9.4) |
| Pastoral perpetual lease - Indigenous | 0 | 0 | - | 0 | 0 (0) |
| Pastoral term lease | 21,241 | 13,995 | - | 2,708 | 37,945 (27.1) |
| Pastoral term lease - Indigenous | 9 | 0 | - | 10 | 19 (0) |
| **Total** | **57,191** | **73,545** | **-** | **9,383** | **140,124 (100)** |

Figure 6 | Total VRE and transmission infrastructure footprint area on the various categories of Land Tenure, for the E+ scenario and the E+RemoteCost+ sensitivity in 2060.

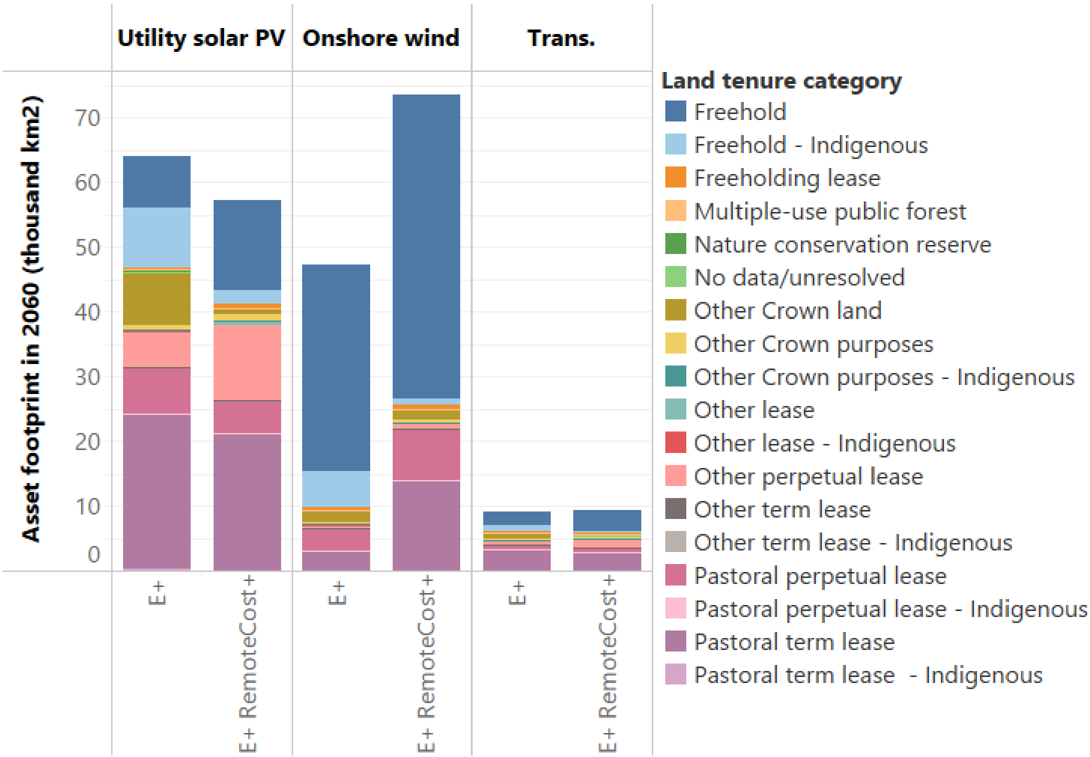


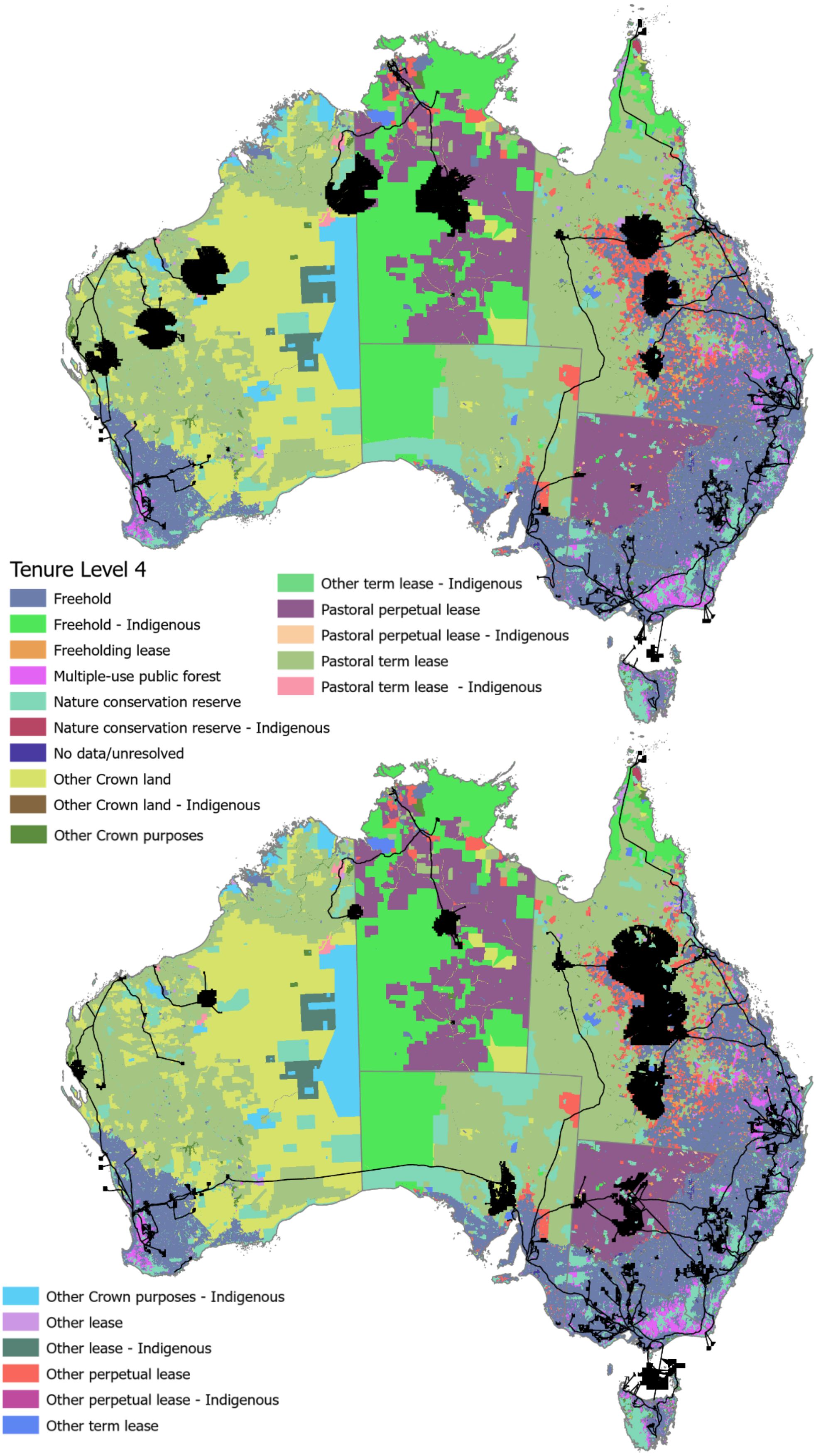
Table 3, Table 4 and Figure 6 show that, for both the scenario and sensitivity presented, roughly 49% of the NZAu infrastructure sits on freehold land. The land-tenure analysis for the E+ scenario shown in Table 4 then indicates that roughly 40% is leased land, with the remaining 10% being un-leased crown lands. Interestingly, it can be seen 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 major change in the E+RemoteCost+ sensitivity, relative to E+, aside from the addition of ~20,000 $km^2$ of wind infrastructure land footprint, is a 7% swing from un-leased crown lands (3%) to leased lands (47%), with increase in land footprints on *Other pastoral leases* and *Pastoral term leases*. A broad interpretation of the move from crown land to leased land in the E+RemoteCost+ sensitivity, is the potential for an increase in the complexity of negotiations over the use of the leased land, which may represent a bottleneck (unforeseen by modelling) in siting of some of the projects in these areas.

Figure 7 provides an overlay of 2060 NZAu VRE and electricity transmission infrastructure for the E+ scenario and the E+RemoteCost+ sensitivity on land tenure categories.

We note that the presence of solar PV and wind projects on the categories *Multiple-use public forest* and *Nature conservation reserve* suggests a misalignment between the exclusion layers used for identifying candidate project areas and the land tenure layer used 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. 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.

**Figure 7 | Land tenure categories and 2060 NZAu VRE and electricity transmission infrastructure for the E+ scenario (top) and the E+RemoteCost+ sensitivity (bottom).**



## 3.3 Employment

Here we provide a summary of the energy sector employment analyses for the E+ Scenario and the E+RemoteCost+ Sensitivity, as described in detail in the companion report *Downscaling – Employment impacts*. This analysis provides insights into the employment opportunities that may be afforded Australian communities by the establishment of renewable energy projects and other energy system infrastructure across Australia during the transition to both a net-zero domestic energy system and the large-scale production of clean energy exports.

Figure 8a presents gross energy sector employment in the domestic and export sectors, modelled for the E+ scenario and E+RemoteCost+ sensitivity across the years 2020 to 2060. In total, this shows that the modelled energy system could provide 650,000-700,000 jobs by 2050/2060, which are similar in aggregate between E+ and E+RemoteCost+ but differ in geographic distribution. The majority of new energy system workers will be employed in the areas of solar PV, electricity transmission & distribution, energy storage, and hydrogen technologies and activities, many of which will be ongoing jobs in operations & maintenance.

Figure 8b shows for the E+ scenario that the majority of energy sector employment is located in Western Australia, Northern Territory and Queensland, due to the large export energy system that the modelling found to be least-cost optimal in the regional and sunny areas of those states and territory. In each of these three states/territories Figure 8b shows average energy (domestic and export) sector employment over 2040-2060 could be greater than 130,000 jobs per annum, largely employed in renewable electricity, transmission and hydrogen technologies. The E+RemoteCost+ then shows that energy sector employment could be more evenly distributed across the country (notwithstanding the dominance of Queensland here) with the realisation of higher regional capital costs on siting of infrastructure in more remote regions of Western Australia, the Northern Territory and Queensland.

In most NZAu Scenarios prospective future clean energy export supply chains were predominantly found to comprise: renewable electricity generation (mostly utility solar PV) → hydrogen production via electrolysis → transmission of hydrogen via pipeline to – and storage at ports → Ammonia synthesis at ports → ammonia shipping. Figure 9 presents the distribution of average **export** energy sector employment over 2040-2060 in the technologies that comprise the dominant energy export supply chain for the E+ scenario and E+RemoteCost+ sensitivity. In E+ most of the export energy system employment is located in Western Australia, the Northern Territory and Queensland, much of which has been shown above to be located on various categories of Indigenous estate. This represents significant employment opportunities in the establishment of clean energy exports for traditional custodians of those lands. The E+RemoteCost+ sensitivity then has a greater energy export employment opportunity across the country.

**Figure 8 | Gross energy sector employment in the domestic and export sectors (a) in each year from 2020 to 2060; and (b) as average annual employment between 2040 and 2060, by state/territory. Data are in full-time equivalent jobs. Technologies/resources with low individual employment have been aggregated as 'Other'.**

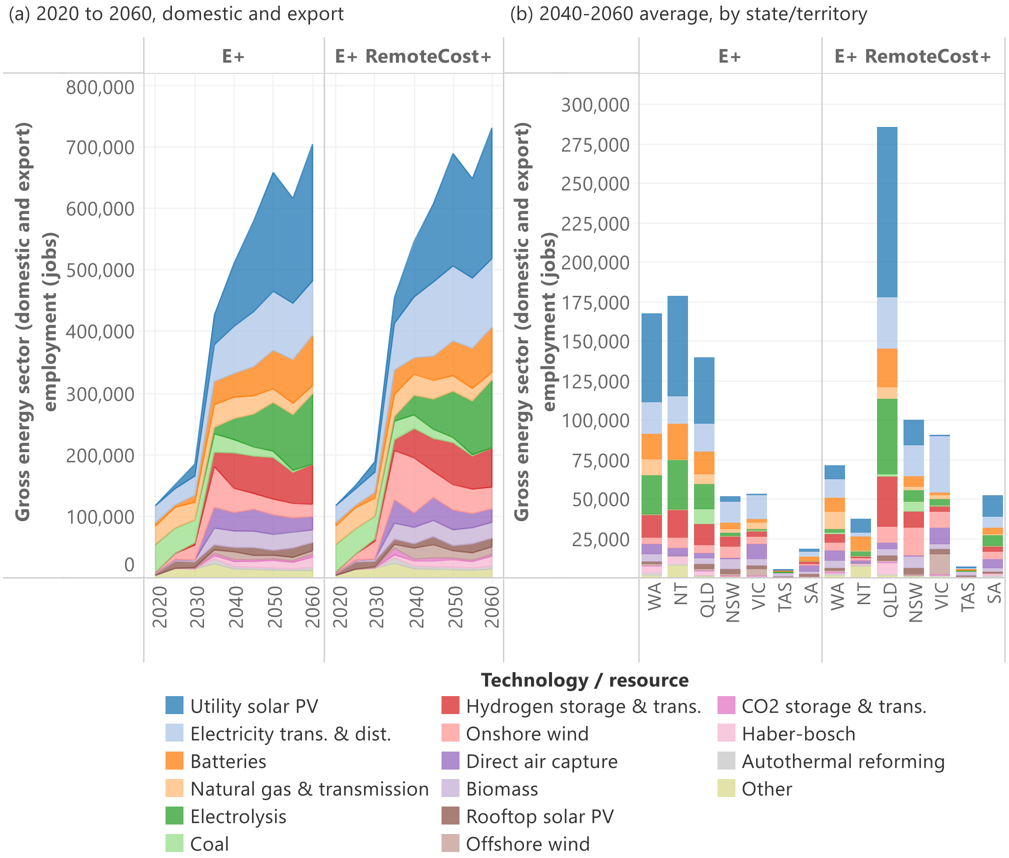
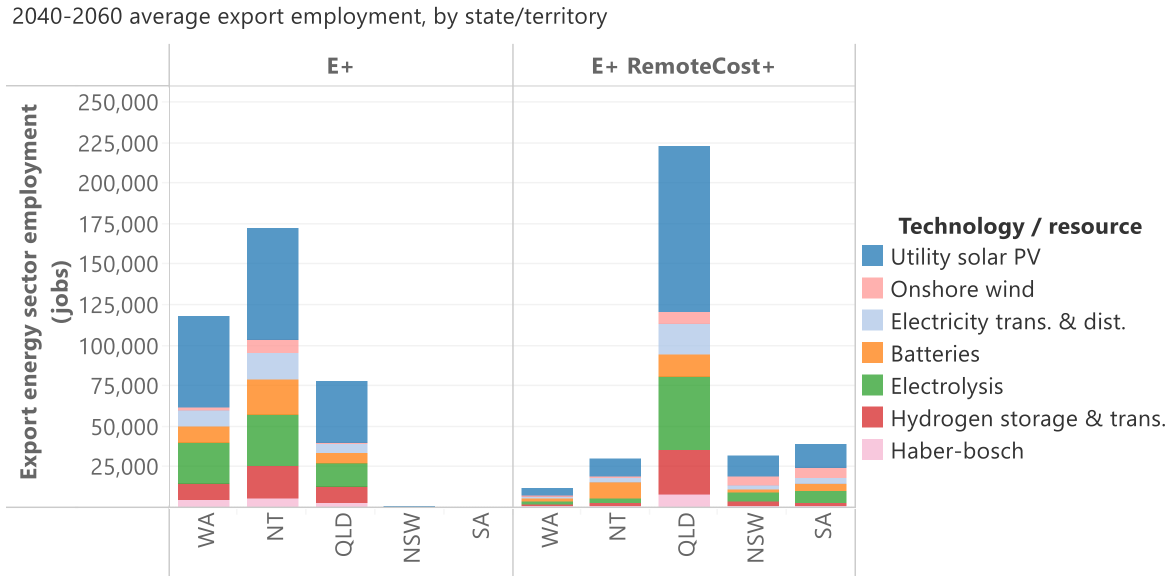



**Figure 9 | Average annual energy export sector employment between 2040 and 2060, for the technologies that comprise the dominant energy export supply chain, by state/territory. Data are in full-time equivalent jobs.**



# 4 Land and Sea

## 4.1 Biodiversity

The Kunming-Montreal Global Biodiversity Framework (GBF) [23] has recently been signed off by Convention for Biological Diversity (CBD) [24] signatory nations – of which Australia is one. The GBF will likely be a core plank in successful efforts to advance all biodiversity conservation agendas, considering that functioning, resilient ecosystems are essential for sustaining species and genetic diversity. At its core the GBF has fundamental goals aimed at halting species extinction, recovering species and sustaining and enhancing ecosystem area, connectivity, resilience, and integrity (see GBF Goal A and targets 1, 2, 3, 12). It is well established that prompt action is needed to ensure effective implementation, given the present rates of biodiversity loss and ecosystem degradation [25] and the proximity of 2030, a year in which GBF signatory nations are aiming to meet several action-oriented targets. This is especially true for Australia given it is a nation leading the global biodiversity crisis [26]. Thus, our aim here is to ensure that the modelled development and siting activities embedded in energy transitions focused on mitigating climate change do not erode or undermine the targets and goals set out in Kunming-Montreal GBF agenda.

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 [27]. While work remains to be done to ensure comprehensive coverage of all those areas in a single GIS map layer — while also laying out processes to update map layers as concerns and threats emerge over time — the GIS map layers listed in Table 5 have been selected as the bases for analysis of NZAu infrastructure footprint impacts on biological diversity in Australia.

When the PA (Figure 10), KBA and intact bioregions layers (Figure 11) listed in Table 5 are overlayed the combined terrestrial portions cover more than 35% of Australia’s total land area.

**Table 5 | GIS map layers selected as the bases for analysis of NZAu infrastructure footprint impacts on biological diversity in Australia.**

| Layer | NZAu exclusion | CBD alignment | Jurisdiction: protection status | Coverage, 1,000km$^2$ |
|---|---|---|---|---|
| **CAPAD terrestrial [2]** | Y | Target 3 of GBF | Government, Joint, Indigenous and Private : varies | 1,519 |
| **CAPAD marine [3]** | Y | Target 3 of GBF | State/Territory and Commonwealth waters : varies | 1,289 |
| **Species of National Environmental Significance [13]** | Y (< 6,600 km$^2$) | Target 4 of GBF | Commonwealth of Australia : EPBC 1999 [28] | 762 |
| **Ecological communities of National Environmental Significance [14]** | Y (< 6,600 km$^2$) | Target 4 of GBF | Commonwealth of Australia : EPBC 1999 [28] | 357 |
| **National Map Reserve Areas [4]** | Y | Target 3 of GBF | Varies | 1,505 |
| **Inland waterbodies, wetlands and salt lakes [10], [15]** | Y | Target 1, 3, 4 of GBF | Varies | 436 |

| Layer | NZAu exclusion | CBD alignment | Jurisdiction: protection status | Coverage, 1,000km$^2$ |
|---|---|---|---|---|
| **Key Biodiversity Areas [18]** | N | Targets 1, 3, & 4 of GBF | Commonwealth of Australia via the Key Biodiversity National Coordination Group : Varies | 448 |
| **Intact Bioregions [19]** | N | Criteria C guidelines intact ecosystems working group, & efforts to align to GBF Goal A, and targets 1, 2, 12 | Commonwealth of Australia via the Key Biodiversity National Coordination Group : Varies | 1,002 |

**Figure 10 | Overlay of protected area (PA) map layers.**

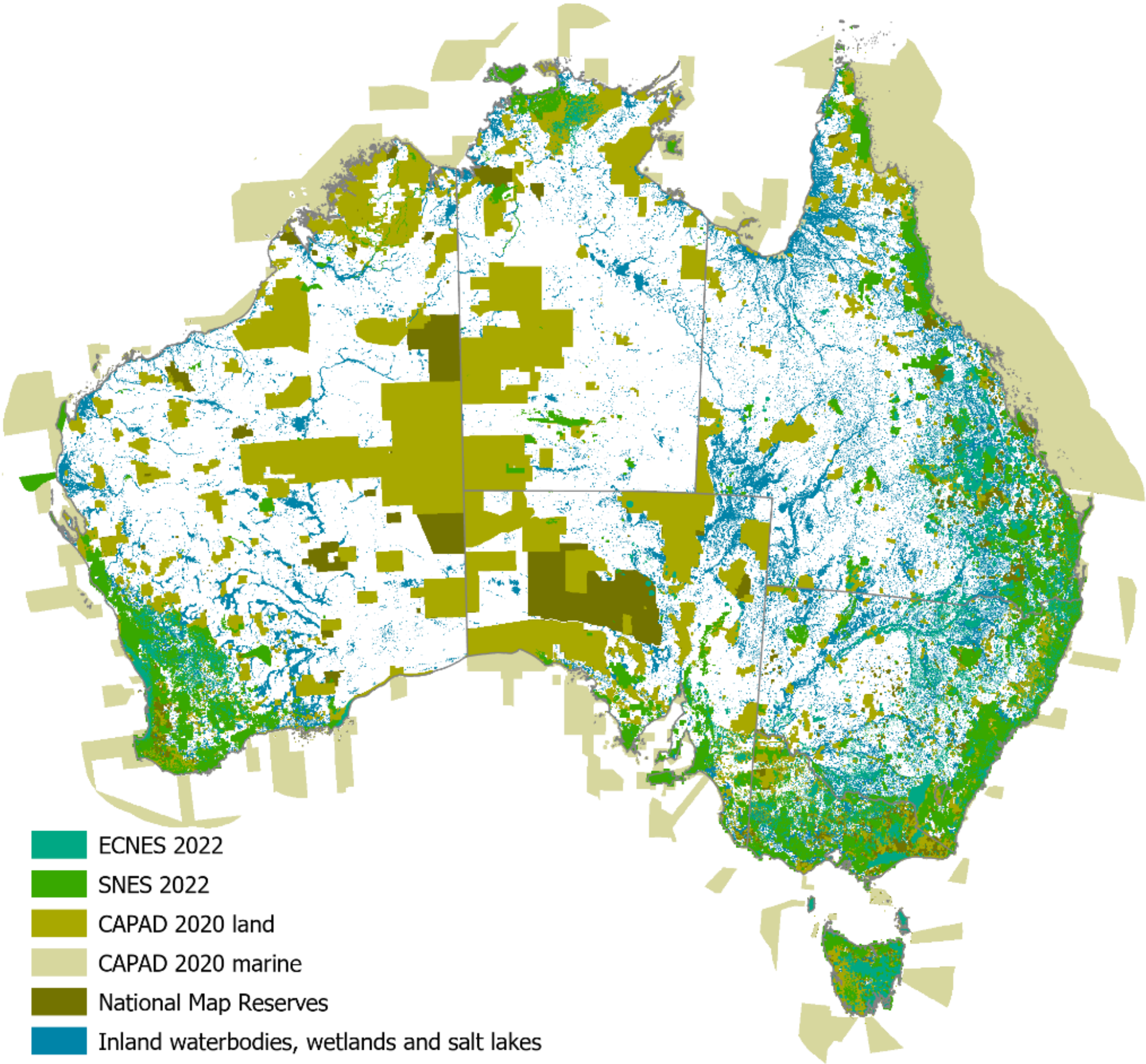
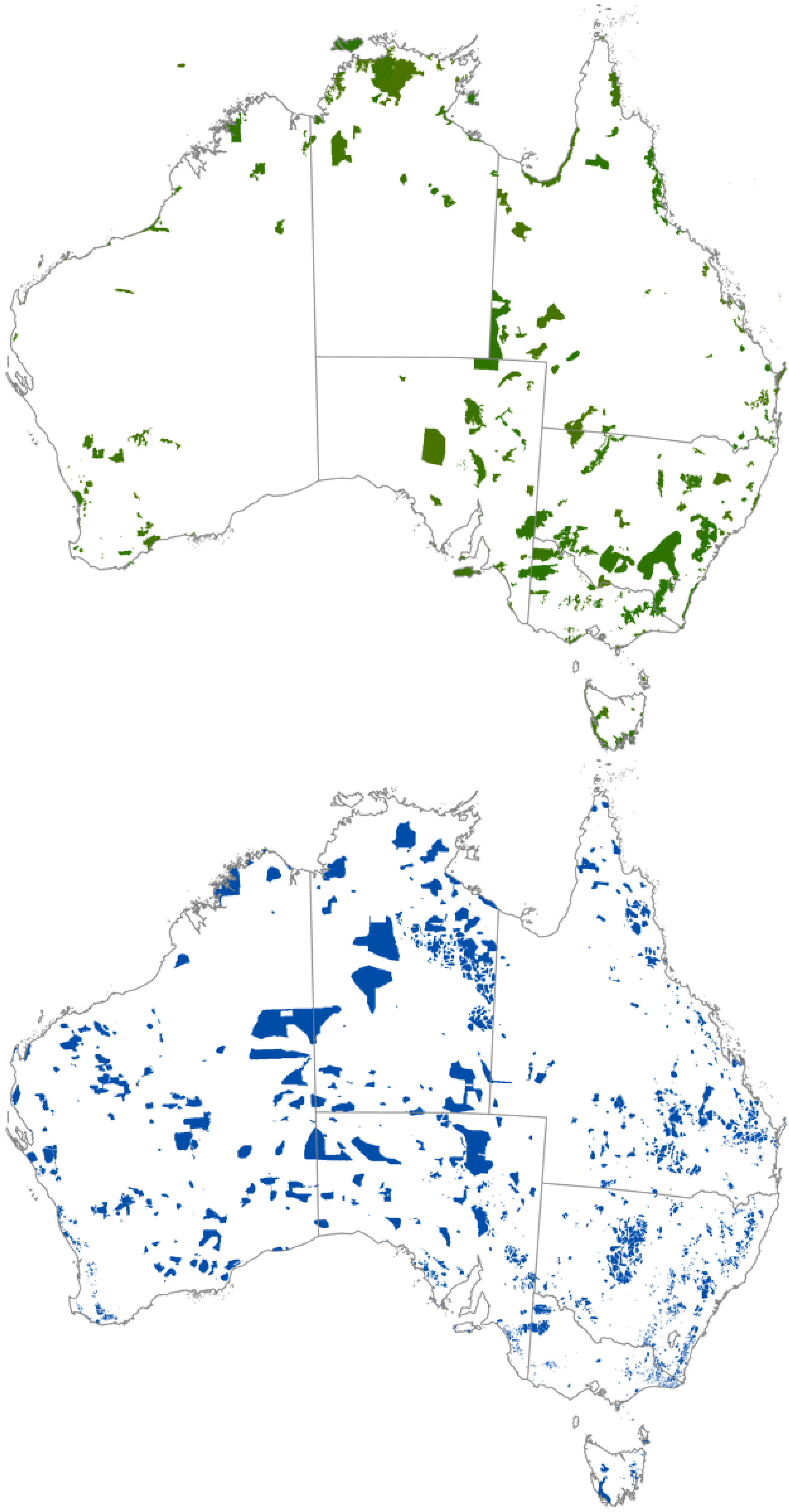


**Figure 11 | Map layers showing key biodiversity areas (KBAs, top); and intact bioregions (bottom).**



### 4.1.1 Biodiversity land impact analysis

Results for the biodiversity analysis are provided for total project areas (in $km^2$) for the E+ scenario in Table 6 and the E+RemoteCost+ sensitivity in Table 7; and for the total area of each table as a percentage of the respective total NZAu infrastructure build presented in the final column of each table. Figure 12 then plots the total infrastructure footprint area on the different biodiversity map layer types for this scenario and sensitivity in 2060.

Figure 13 provides an overlay of 2060 NZAu VRE and electricity transmission infrastructure for the E+ scenario and the E+RemoteCost+ sensitivity on the biodiversity land use analysis maps listed in Table 5.

Table 6 and Table 7, together with Figure 12, indicate that the conservation focused NZAu exclusion areas largely worked as intended (the 5-6 $km^2$ of solar PV in protected areas is likely an artifact of modelling on the borders of PAs), as did the decision to push new transmission into existing transmission corridors, even when those corridors cross protected areas. The latter policy is the reason that Table 6 and Table 7 report transmission (TX) footprints in the excluded PAs.

The shift in NZAu infrastructure from the E+ scenario's slightly more compact land area use in northern and western Australia to the E+RemoteCost+ sensitivity's aggregated land area that is 20,000 $km^2$ larger and covers more of eastern Australia, results in an additional ~3,500 $km^2$ crossover with KBA (most driven by wind farm areas), with a similar sized decrease in the crossover with intact bioregions (due to a large decrease in solar PV encroachment).

**Table 6 | Results for overlap of E+ scenario infrastructure in 2060 with the biodiversity map layers in total area ($km^2$), and for the total area as a percentage of the total NZAu infrastructure build in 2060 in the scenario presented in the final column (in parentheses).**

| Biodiversity layer type | Solar PV | Wind On | Wind Off | TX | Total $km^2$ (%) |
|---|---|---|---|---|---|
| Protected Areas (NZAu exclusions layers, allowing existing TX ROWS) | 5 | 0 | - | 989 | 994 (< 1 %) |
| Key Biodiversity Areas (KBA) | 227 | 1,427 | - | 133 | 1,787 (1.5%) |
| Intact Bioregions | 4,850 | 1,522 | - | 489 | 6,862 (5.7%) |

**Table 7 | Results for the overlap of E+RemoteCost+ sensitivity infrastructure in 2060 with the biodiversity map layers in total area ($km^2$), and for the total area as a percentage of the total NZAu infrastructure build in 2060 in the scenario presented in the final column (in parentheses).**

| Biodiversity layer type | Solar PV | Wind On | Wind Off | TX | Total $km^2$ (%) |
|---|---|---|---|---|---|
| Protected Areas (NZAu exclusions layers, allowing existing TX ROWS) | 6 | 0 | - | 1,496 | 1,503 (1.1 %) |
| Key Biodiversity Areas (KBA) | 474 | 4,530 | - | 219 | 5,225 (3.7 %) |
| Intact Bioregions | 1,250 | 2,102 | - | 177 | 3,529 (2.5 %) |

**Figure 12 | Total VRE and transmission infrastructure footprint area on the different biodiversity map layer types, for the E+ scenario and the E+RemoteCost+ sensitivity in 2060.**

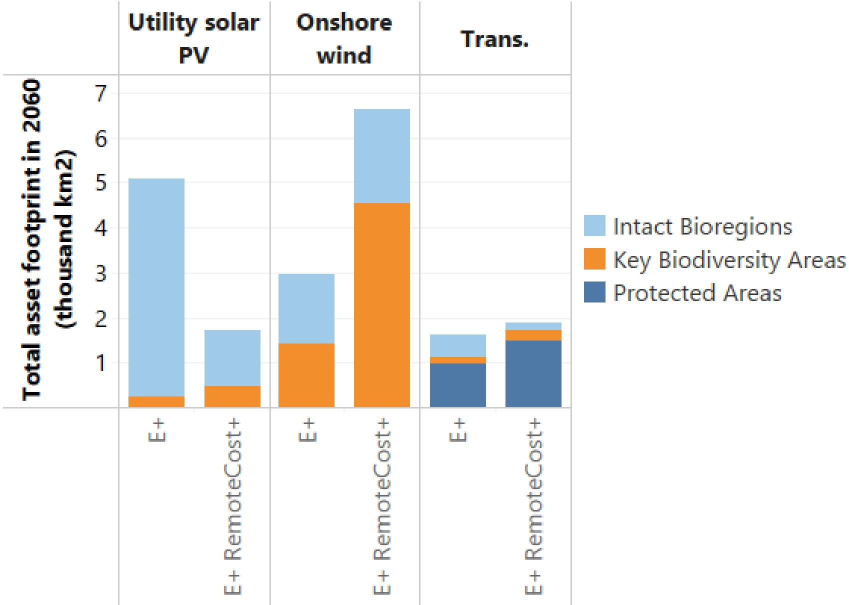
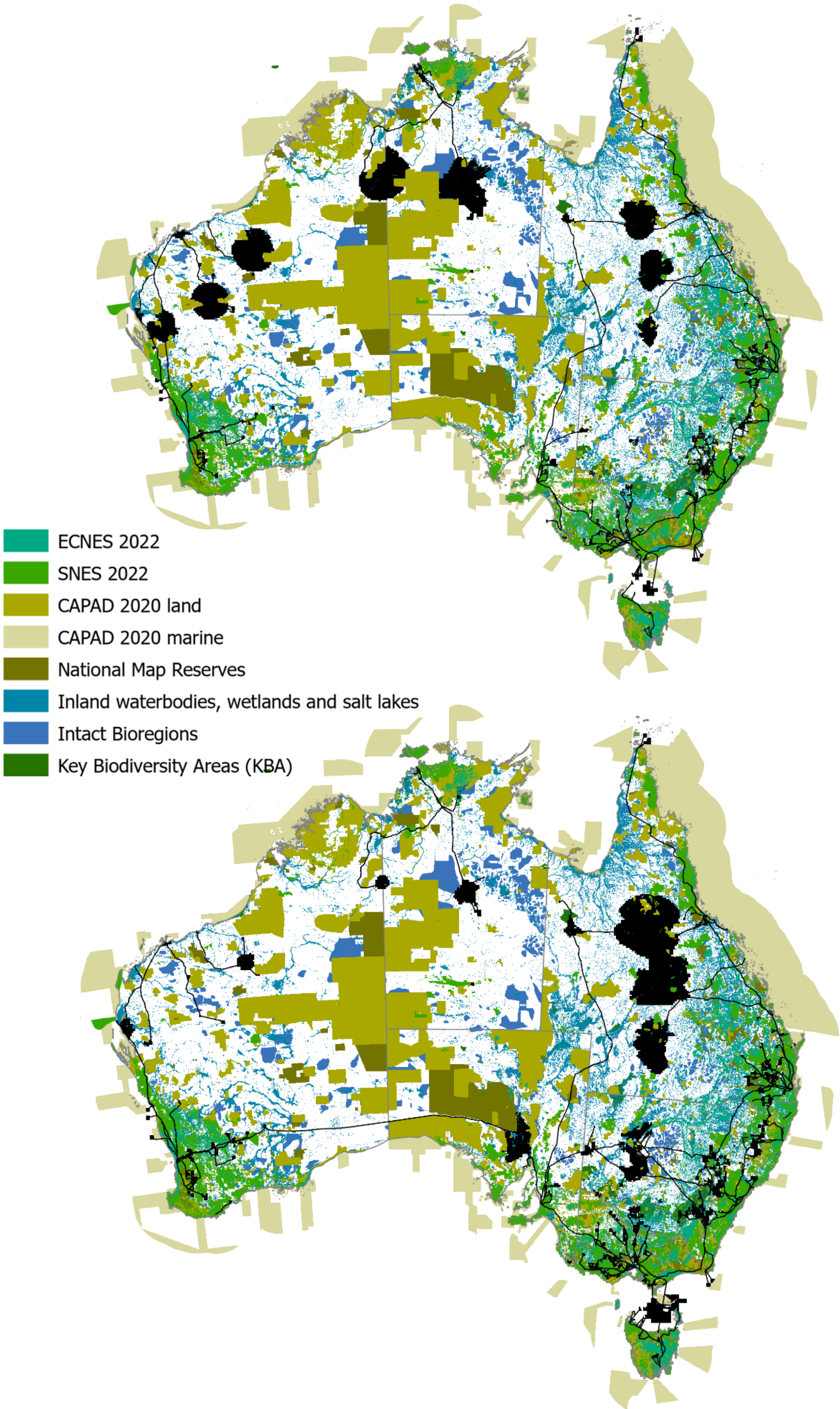


**Figure 13 | Combined biodiversity map and 2060 NZAu VRE and electricity transmission infrastructure for the E+ scenario (top) and the E+RemoteCost+ sensitivity (bottom).**



### 4.1.2 Falling short on biodiversity

Although NZAu has endeavoured to include conservation in modelling, our selected layers and process falls short of the comprehensive and systematic approach needed for biodiversity conservation, especially when considering the likely impacts of climate change itself on biodiversity. This is because to date there has been no comprehensive spatial assessment undertaken around the minimum levels of protection and restoration that are needed to ensure that Australia's biodiversity persists.

If we were to revisit the modelling today, both KBA and intact bioregions would be part of the core exclusions. However, the revised exclusions layers would still fall far short of a comprehensive approach to safeguarding biodiversity. In particular, our efforts have failed to adequately account for:

- The needs of all endangered species. Formal critical habitat mapping is missing for >99% of endangered species so we have had to assume thresholds across species ranges to capture the needs of endangered species. This approach, while considered best practice [29], lacks the spatial specificity needed for regional planning and has been a shortfall in conservation planning for decades.
- The likely refugial habitat and connectivity needs for species and ecosystems when considering the impacts of natural disasters and climate change. For instance, maps created before the 2019/2020 Australian bushfires, are likely out of date and need updating to reflect current reality. In addition, evidence that climate change was a driver of the 2019/2020 Australian bushfires is strong [30]. The timely response of habitat/biodiversity maps to changes wrought by climate change will become increasingly necessary throughout and beyond transitions to a net zero Australia and world. We lack a comprehensive resource and approach to ensure the timely updating of maps to protect biodiversity through the unprecedented changes and efforts of coming decades.
- All likely Key Biodiversity Areas that have yet to be mapped (right now there is a bias towards one criteria and one taxanomic group for KBAs in Australia)
- Most ecosystems, especially those that are considered at high risk of collapsing. These have yet to be mapped in the system. In addition, the location of intact ecosystems have only started to be mapped at broader scales (we utilised unpublished efforts undertaken by the Key Biodiversity Area conservation team but recognise finer scale efforts are needed).
- Areas of critical importance for ecosystem service provision (carbon, avoiding sedimentation in rivers and wetlands and the Great Barrier Reef, pollination etc.)
- Processes for the siting of transmission that are biodiversity aware. The use of existing corridors for new transmission builds is expedient, but is neither properly informed by nature positive principles or sufficient for the actual task of building all of the transmission called for under all NZAu core scenarios. The siting of NZAu transmission lines requires updated thinking regarding the threats species face [31] and responses needed [32] as well as what actions are needed to abate threats and where synergistic conservation opportunities are likely to be supported by the siting of new transmission.

To make necessary progress, the conservation community must prioritise development of maps that identify the sites most important for biodiversity conservation, including irreplaceable sites that cannot be recovered (e.g., old growth forests) and the facets of biodiversity we cannot afford to lose (habitat critical for species persistence). We also require an understanding how current and future energy activities pose threats to them. Such tools would enable industry and investors to improve their environmental commitments, which at present narrowly focus on avoiding world heritage and respecting protected area boundaries. There is irreplaceable biodiversity outside these areas.

Furthermore, while details vary from state to state, renewable energy facilities that impact native vegetation and/or impact dispersing and migrating species will incur biodiversity offset costs that greatly affect their economic viability. Avoidance of biodiversity loss, and the associated costs, is good for both the economy and the environment.

<u>While this data is being generated, there are some broad siting principles that can be adopted now:</u>

1. Recognise that many areas of Australia contain biodiversity that cannot be easily restored. Functioning biodiversity provides essential ecosystems services that sustain humanity and underpins the global economy. Degrading and eroding biodiversity impacts these services and many forms of biodiversity cannot be restored once degraded. This means siting infrastructure for the energy transition needs to be undertaken in a way that considers biodiversity.
2. Use the mitigation hierarchy. Applying the Mitigation Hierarchy (MH; avoid, minimise, rehabilitate, offset) at mine sites is international best practice and a requirement by governments and investors, yet rarely does it achieve no-net-loss of biodiversity. Many improvements are needed; three of which are essential to addressing impacts of siting projects.
    a. The MH must extend to address indirect and cumulative impacts on biodiversity, through strategic environmental assessments, particularly in regions where demand will cause rapid development of infrastructure and industry.
    b. Biodiversity losses and gains must be monitored and reported across the entire MH to enable transparent and adaptive management, and mainstream biodiversity earlier into energy infrastructure planning and investor decisions.
    c. Impacts and mitigation efforts and responsibilities must be mapped and shared across entire value chains to enable governance to address the geopolitical disparities emerging between areas of supply and demand.
3. Use the precautionary principle – "if in doubt, don't". The precautionary principle, or precautionary approach, is a widely and increasingly accepted general principle of environmental policy, law, and management. It is an approach to uncertainty and provides for action to avoid serious or irreversible environmental harm in advance of scientific certainty of such harm. There is much uncertainty in both where important biodiversity areas are currently located and what the impacts of siting energy projects are on them. Only reasonable assessment at the site scale will allow for this uncertainty to be reduced and development of an activity should only occur when the threshold of uncertainty is very low.
4. Recognise opportunities on degraded lands. There are many places in Australia where enormous damage has already been done and the ability of repair is unlikely. These should be targeted for site-based activities as the chance of harm to biodiversity is low. Abandoned mine sites and degraded agricultural lands experiencing high soil salinity, are salient examples. If the siting is done well, some level of landscape restoration around the site could even bring back some elements of biodiversity so there is a chance for nature positive outcomes.

The principles above are an interim measure for minimising biodiversity impacts. Detailed spatial planning, a science-based activity in which Australia leads the world, needs to be urgently commissioned in areas of energy infrastructure expansion. These can both identify where current sites are unacceptable and the best sites for deployment.

## 4.2 Agricultural lands

This section considers the agricultural lands shown in Figure 14, as inferred from land cover maps [10]. The land tenure map [20] is presented alongside the agricultural lands map in Figure 14, as discussions with stakeholders indicated that the land tenure map might be useful for consideration alongside the agricultural lands map as a potential indication of the complexity of future land use negotiations and agreements.

A visual inspection of the maps in Figure 14 results in the observation that irrigated lands, rainfed cropping, pasture and sugar lands largely overlap with freehold land tenure categories.

### 4.2.1 Farmland impact analysis

Results for the farmland analysis are provided for total project areas in $km_2$ for the E+ scenario in Table 8 and the E+RemoteCost+ sensitivity in Table 9; and for the total area in the final column of each table as a percentage of the respective total NZAu infrastructure build. Figure 15 then plots the total infrastructure footprint area on the land tenure categories for this scenario and sensitivity in 2060. Figure 16 provides an overlay of 2060 NZAu VRE and electricity transmission infrastructure for the E+ scenario and the E+RemoteCost+ sensitivity on farmland cover types.

Table 8 and Table 9, together with Figure 15, indicate that the VRE exclusion and TX routing layers worked as planned as VRE projects have not been sited on irrigated lands, solar PV projects have not been allowed on rainfed cropping lands, and transmission crosses all farm cover categories (in existing corridors).

Solar PV siting on rainfed pasture is similar in both the E+ scenario and E+RemoteCost+ sensitivity, while wind assets make up the majority of the land crossover between E+ and E+RemoteCost+ with all rainfed farmland categories, and with 12,500 $km^2$ of additional land area needed in the E+RemoteCost+ sensitivity.

**Table 8 | Results for overlap of E+ infrastructure in 2060 with the farm cover layer in total Area $km_2$, and for the total area in the final column as a percentage of the total NZAu infrastructure build in 2060 in the scenario.**

| Farm cover type | Solar PV | Wind On | Wind Off | TX | Total $km^2$ (%) |
|---|---|---|---|---|---|
| **Irrigated cropping** | 0 | 0 | 0 | 14 | 14 (< 1%) |
| **Irrigated pasture** | 0 | 0 | 0 | 4 | 4 (< 1%) |
| **Irrigated sugar** | 0 | 0 | 0 | 10 | 10 (< 1%) |
| **Rainfed cropping** | 0 | 6,025 | 0 | 174 | 6,199 (4.7%) |
| **Rainfed pasture and sugar** | 1,020 | 14,957 | 0 | 599 | 16,575 (12.5%) |

**Table 9 | Results for the overlap of E+RemoteCost+ sensitivity infrastructure in 2060 with the farm cover layer in total Area $km_2$, and for the total area in the final column as a percentage of the total NZAu infrastructure build in 2060 in the sensitivity.**

| Farm cover type | Solar PV | Wind On | Wind Off | TX | Total $km^2$ (%) |
|---|---|---|---|---|---|
| **Irrigated cropping** | 0 | 0 | 0 | 24 | 24 (< 1%) |
| **Irrigated pasture** | 0 | 0 | 0 | 6 | 6 (< 1%) |
| **Irrigated sugar** | 0 | 0 | 0 | 18 | 18 (< 1%) |
| **Rainfed cropping** | 0 | 10,766 | 0 | 318 | 11,084 (6.7%) |
| **Rainfed pasture and sugar** | 1,119 | 22,102 | 0 | 835 | 24,057 (14.6%) |

**Figure 14 | Land cover map highlighting agriculture (top) and Land tenure map (bottom).**

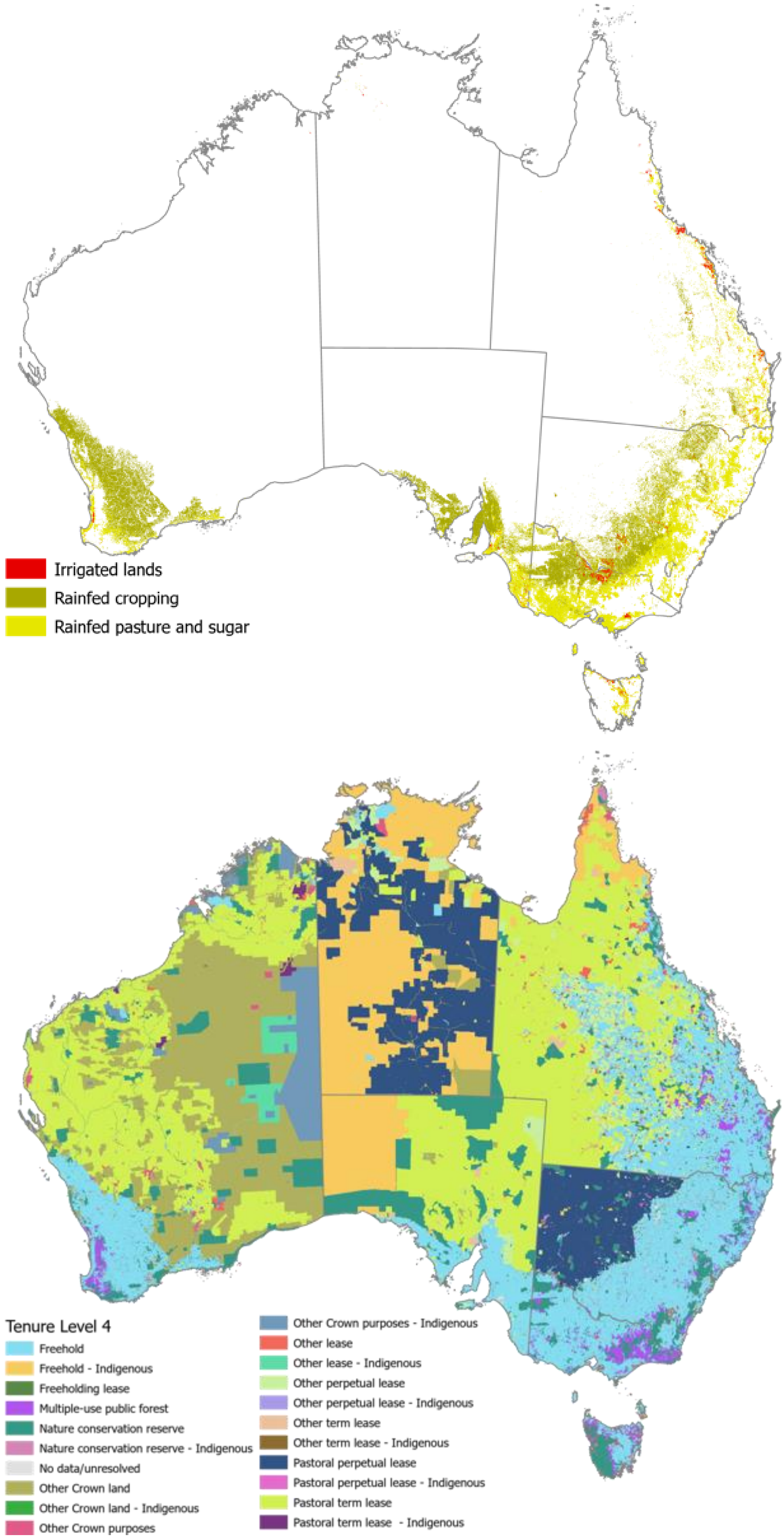


Figure 15 | Total VRE and transmission infrastructure footprint area on the categories of farmland, for the E+ scenario and the E+RemoteCost+ sensitivity in 2060.

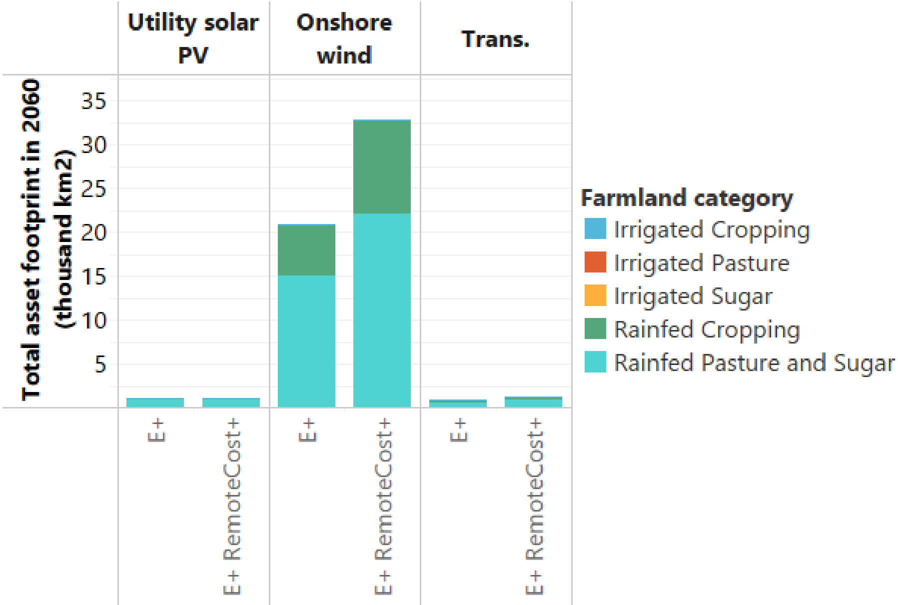
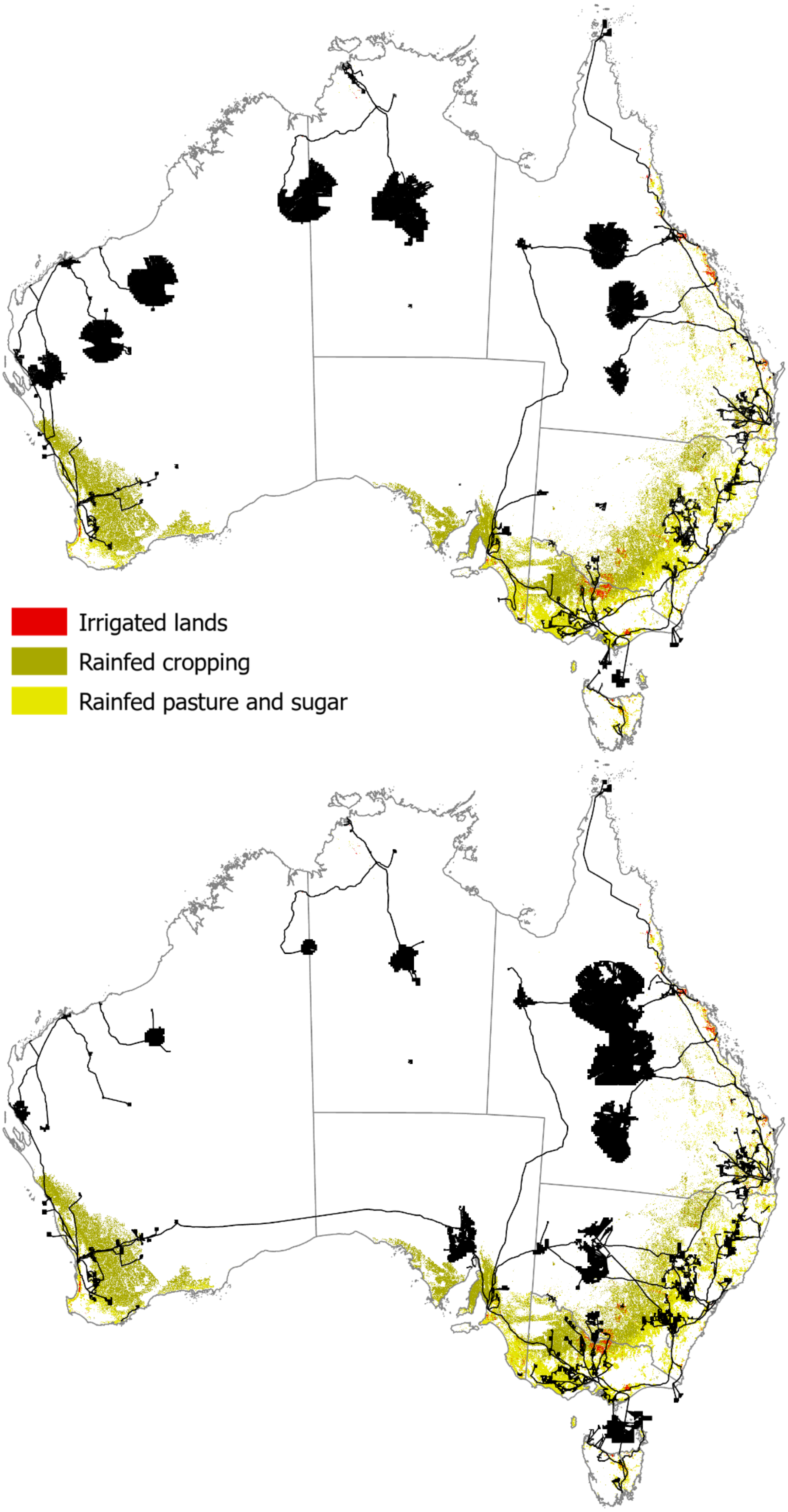


**Figure 16 | Farm cover map and 2060 NZAu VRE and electricity transmission infrastructure for the E+ scenario (top) and the E+RemoteCost+ sensitivity (bottom).**



### 4.2.2 Afforestation of Australian farmland

Net Zero Australia developed estimates of the emissions sequestration (net atmospheric $CO_2$ removal) that may be possible from a concerted afforestation of a portion of suitable agricultural land. This sequestration provides modest net negative levels of GHG emissions that enable important emissions abatement of agriculture and reduce the need for large net negative emissions from the energy sector modelling. The specific assumptions relating to modelled afforestation are presented in the companion reports: *Methods, Assumptions, Scenarios & Sensitivities* and *Downscaling – Forestry*.

In summary, our analysis assumes that a concerted effort involving tree planting on agricultural and grazing land or human-induced natural regeneration would result in an additional net sink of −51 Mt-$CO_2$e of annual sequestration by 2050. This projection involves new investment to expand the forest area through a combination of trees integrated with farming, environmental plantings, commercial plantations and human-induced regeneration. This would require cultural change in the farming community, new investment and technology development to support more efficient establishment and more rapid tree growth.

The assumed annual rate of new tree or forest establishment increases from the current low level near zero to an annual rate of 200,000 ha/year by 2030, which continues to 2050, resulting in a total new forest area of 5.1 million hectares (M ha). The average rate of carbon dioxide sequestration in these new forests was found to be approximately 10 t-$CO_2$/ha/year.

Downscaling analysis found that 5.1 M ha of new trees could be sited on current Australian farmland, predominantly located in southern and eastern Australia, as shown in Figure 17. This afforestation of farmland would be preferentially located on Australian pastureland, rather than cropping land. Depending on the siting strategy used, 2.9–3.4% of cropland would be required over 30 years to host new trees, while 14–15% of pastureland would be required. Table 10 then shows the total modelled farmland afforestation by state/territory. Further detail on the methods and analysis of the downscaling of this farmland afforestation can be found in the companion report: *Downscaling – Forestry*.

While this modelling has focussed on afforestation of Australia's current farmland, some of which is within the Indigenous Forest Estate, there is also significant potential to enhance the forest land sink in other regions of indigenous land ownership. Emissions abatement strategies on these forest lands can include reductions in deforestation, improved forest management, and savannah fire management. The benefits of such activities include biodiversity improvement, income through working on Country and practising culture, managing bushfire risk, and stimulating native seed production.

**Figure 17 | Farmland area afforested by 2050 across all SA3 regions.**

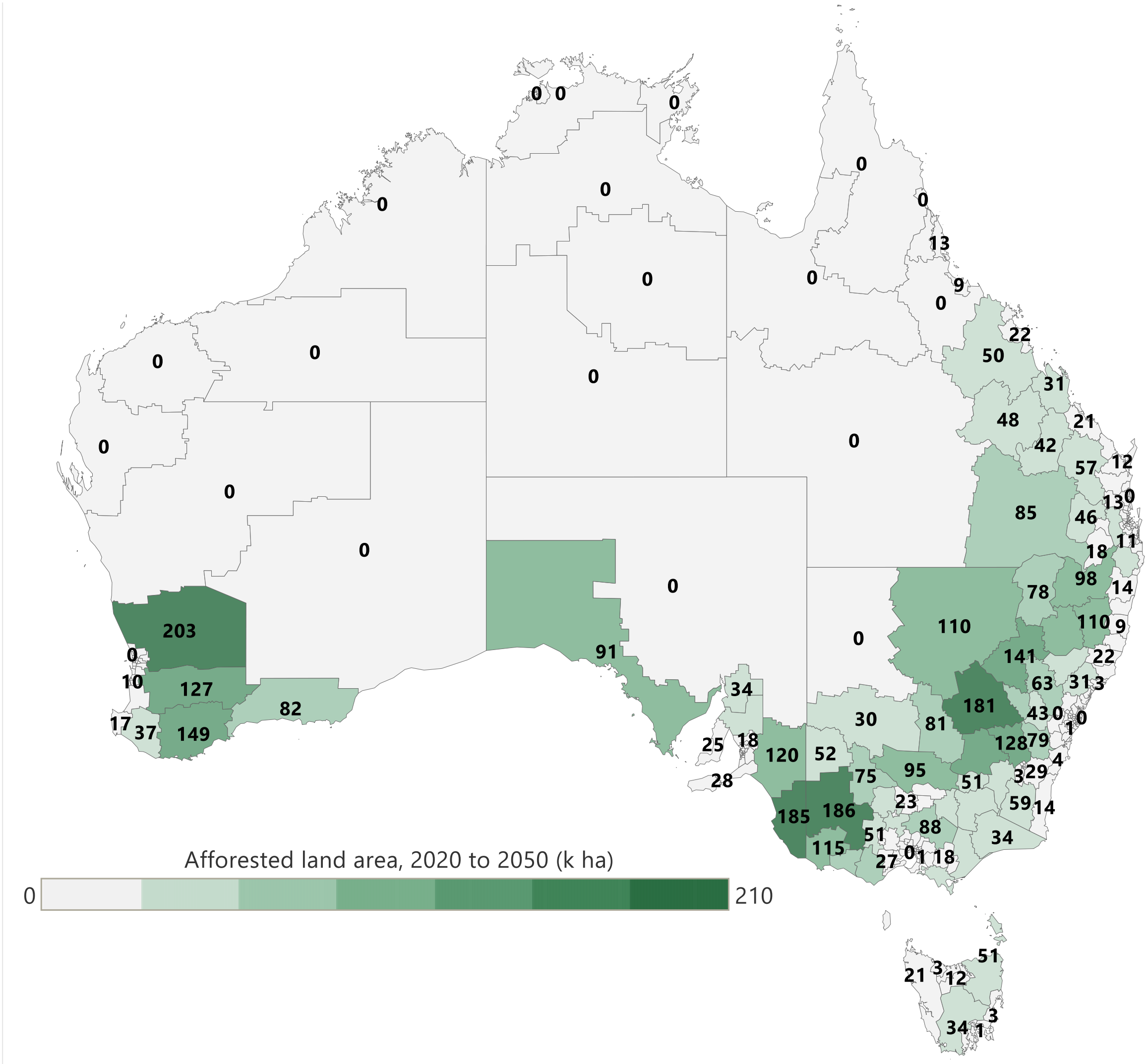



**Table 10 | Total farmland afforestation by state/territory.**

| State/territory | Farmland afforestation |
|---|---|
| WA | 0.66 M ha |
| NT | 0.00 M ha |
| QLD | 0.59 M ha |
| NSW & ACT | 2.0 M ha |
| VIC | 1.2 M ha |
| TAS | 0.13 M ha |
| SA | 0.57 M ha |

# 5 Concluding thoughts

NZAu modelling highlights the unprecedented pace and scale of transitions required to reach net-zero greenhouse gas emissions for Australia by 2050/2060. Land use change sits squarely at the core of all those transitions — with the main NZAu scenario (E+) siting VRE and electricity transmission on an aggregate land area larger than Cuba, and the E+RemoteCost+ scenario covering an additional 20,000 km$^2$ and an aggregate land area larger than Greece. While NZAu downscaling provides a notional indication of the availability and suitability of land to support widespread, sustained, and land intensive decarbonisation efforts over the next four decades, it raises questions that challenge even the notional mapping of infrastructure.

**Does Australia provide the necessary frameworks to support traditional owners, landowners and other stakeholders when choosing to engage with the scale and pace of climate action?**

The establishment of large-scale export industry for clean energy is likely to require development of large renewable energy generation and conversion hubs in areas of high-quality renewable resource. The E+ scenario sites ~43% or ~50,000 km$^2$ of VRE and electricity transmission infrastructure on land subject to indigenous ownership, management and/or other special rights. In the E+RemoteCost+ sensitivity that percentage is reduced to ~29% or ~40,000 km$^2$. The construction of extensive VRE, electricity transmission and connected infrastructure (e.g. hydrogen and ammonia producing infrastructure for export) brings with it the potential for industrialisation at scales unimagined in local and regional communities. Do current legal and policy frameworks (which have been largely concerned with mineral and fossil fuel projects) for community engagement as well as benefit-sharing and land and sea use on Indigenous Estate, need rethinking given the scale of the Net-Zero transition and differences with traditional resource extraction projects?

In both the E+ scenario and the E+RemoteCost+ sensitivity, 49% of infrastructure is sited in freehold tenure areas, with crown land reducing from 10% in the E+ scenario to 3% in the E+RemoteCost+ sensitivity and leased land growing by difference. Are the necessary policy frameworks in place to allow both free and lease holders to opt-in to the transition?

Rainfed cropping and pastureland are used extensively for wind farms in the E+ scenario and the E+RemoteCost+ sensitivity. Solar PV covers about the same land area in both the E+ scenario and the E+RemoteCost+ sensitivity. The energy density of solar PV leads to roughly 14× less land being needed for solar PV when compared on a total land area basis, but wind farms have significantly less land use if considering just the area in contact with the ground (the direct footprint). Wind farms appear to be the best match for productive farmlands — after accounting for local biodiversity concerns, especially when considering the habitat areas and migration routes of winged species — but NZAu's blanket exclusion of solar PV on rainfed cropland misses potential synergies for siting on heavily degraded and unrecoverable crop lands, some of which may also have potential for biodiversity restoration. Are the needed frameworks in place to support decision making on the use of farmlands for different clean infrastructure plant?

**Does Australia have enough biodiversity 'safe' space for the first ten years of the transition, as well as the full 40-year effort?**

Australia, a signatory nation to the GBF, is at the forefront of the global biodiversity crisis and currently rethinking its national strategies on safeguarding biodiversity. At the same time, it is grappling with the need to take rapid action to limit the extent and severity of impacts from climate change. Until Australians have the key resources needed to take confident and simultaneous action to address both challenges, the nation and its people risk the potential for unintended impacts from unilateral action to address either challenge.

This is a particularly acute possibility during the next decade, while integrated and updatable approaches to safeguarding biodiversity and climate are developed. NZAu scenarios call for the immediate and sustained construction of infrastructure with ~4,400 $km^2$ of new solar PV and wind projects called for by 2025 and 14,500 $km^2$ of new projects by 2030. There is a significant area of land laid out in AEMO's identified renewable energy zones (REZ) [33] for the siting of onshore solar PV and wind infrastructure. The majority of Net Zero Australia's siting of energy infrastructure occurs outside these zones as a consequence of the least-cost optimisation and exclusion criteria; however, the zones are likely to be prioritised under current frameworks for new VRE infrastructure build. Are the appropriate frameworks in place to ensure that no harm will come to biodiversity in using the 55% of REZs (covering ~460,000 $km^2$ of land – nearly half of which is in QLD and a quarter in NSW) not occupied by PA, KBA and intact bioregions?

# 6 References


Commonwealth of Australia, "Australia state of the environment 2021," 2022. https://soe.dcceew.gov.au/ (accessed Aug. 30, 2022).

Commonwealth of Australia, "Collaborative Australian Protected Areas Database (CAPAD) 2020," Australian Government Department of Agriculture, Water and the Environment, 2021. Accessed: Jul. 14, 2021. [Online]. Available: https://www.environment.gov.au/fed/catalog/search/resource/details.page?uuid=%7B4448CACD-9DA8-43D1-A48F-48149FD5FCFD%7D

Commonwealth of Australia, "Collaborative Australian Protected Areas Database (CAPAD) 2020 - Marine," Australian Government Department of Agriculture, Water and the Environment, May 09, 2019. Accessed: Aug. 08, 2021. [Online]. Available: https://www.environment.gov.au/fed/catalog/search/resource/details.page?uuid=%7BAF4EE98E-7F09-4172-B95E-067AB8FA10FC%7D

[Geoscience Australia, "NM_Reserves (MapServer)," Commonwealth of Australia (Geoscience Australia), 2016. Accessed: Jun. 15, 2021. [Online]. Available: https://services.ga.gov.au/gis/rest/services/NM_Reserves/MapServer

G. C. Wu *et al.*, "Power of Place, Land Conservation and Clean Energy Pathways for California," 2019.

G. C. Wu *et al.*, "Minimizing habitat conflicts in meeting net-zero energy targets in the western United States," *Proc. Natl. Acad. Sci.*, vol. 120, no. 4, p. e2204098120, Jan. 2023, doi: 10.1073/pnas.2204098120.

E. Larson *et al.*, "Net-Zero America: Potential Pathways, Infrastructure, and Impacts," Princeton University, Princeton, NJ, Final Report, Oct. 2021. Accessed: Oct. 29, 2021. [Online]. Available: https://netzeroamerica.princeton.edu/

J. D. Jenkins *et al.*, "REPEAT | Rapid Energy Policy Evaluation & Analysis Toolkit," 2021. https://repeatproject.org (accessed Nov. 12, 2021).

R. Batterham *et al.*, "Methods, Assumptions, Scenarios & Sensitivities." Aug. 25, 2022. Accessed: Oct. 04, 2022. [Online]. Available: https://www.netzeroaustralia.net.au/wp-content/uploads/2022/08/NZAu-Methods-Assumptions-Scenarios-Sensitivities.pdf

L. Lymburner, P. Tan, A. McIntyre, M. Thankappan, and J. Sixsmith, "Dynamic Land Cover Dataset Version 2.1," Geoscience Australia, Canberra, 2017. Accessed: Jun. 21, 2021. [Online]. Available: http://pid.geoscience.gov.au/dataset/ga/83868

ABARES, "Australia's Indigenous land and forest estate (2020)." Aug. 03, 2022. Accessed: Sep. 14, 2022. [Online]. Available: https://www.agriculture.gov.au/abares/forestsaustralia/forest-data-maps-and-tools/spatial-data/indigenous-land-and-forest

Geoscience Australia, "Foundation Electricity Infrastructure (MapServer)," Commonwealth of Australia (Geoscience Australia), 2021. Accessed: Jul. 01, 2021. [Online]. Available: https://services.ga.gov.au/gis/rest/services/Foundation_Electricity_Infrastructure/MapServer

DCCEEW, "Species of National Environmental Significance." Australian Government, Mar. 17, 2022. Accessed: Sep. 26, 2022. [Online]. Available: https://www.dcceew.gov.au/environment/environmental-information-data/databases-applications/snes

DCCEEW, "Ecological Communities of National Environmental Significance." Australian Government, Aug. 27, 2022. Accessed: Sep. 26, 2022. [Online]. Available: https://www.dcceew.gov.au/environment/environmental-information-data/databases-applications/ecnes

Krause et al, "DEA Waterbodies," Geoscience Australia, Jan. 21, 2020. Accessed: Jun. 21, 2021. [Online]. Available: https://www.ga.gov.au/dea/products/dea-waterbodies

Commonwealth of Australia, "Native Title Consent Determination in Cape York and the Torres Strait." Commonwealth of Australia, Nov. 30, 2022. Accessed: Mar. 27, 2023. [Online]. Available: https://ministers.ag.gov.au/media-centre/native-title-consent-determination-cape-york-and-torres-strait-30-11-2022

ABC News, "Area the size of Tasmania handed back to Far North Queensland traditional owners," *ABC News*, Nov. 30, 2022. Accessed: Mar. 27, 2023. [Online]. Available: https://www.abc.net.au/news/2022-11-30/cape-york-native-title-claim-aboriginal-torres-strait-islander/101716036

Australia's KBA National Coordination Group, "Key Biodiversity Area resources and spatial data," Bird Life Australia, 2022. Accessed: Feb. 01, 2023. [Online]. Available: https://www.keybiodiversityareas.org.au/resources

Australia's KBA National Coordination Group, "Intact Bioregions (work in progress, unpublished)," 2023.

ABARES, "Land tenure of Australia 2010–11 to 2015–16, 250 m." Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra, Sep. 2021. [Online]. Available: https://doi.org/10.25814/txp0-vs96

ESRI, "Polygon to Raster (Conversion)," *ArcGIS Pro | Documentation*. https://pro.arcgis.com/en/pro-app/latest/tool-reference/conversion/polygon-to-raster.htm (accessed Feb. 02, 2023).

ESRI, "Tabulate Area (Spatial Analyst)," *ArcGIS Pro | Documentation*. https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/tabulate-area.htm (accessed Jan. 23, 2023).

CBD, "Kunming-Montreal Global Biodiversity Framework," Montreal: Convention on Biological Diversity, 2022.

Convention on Biological Diversity, "Kunming-Montreal Global biodiversity framework," presented at the Conference of the Parties to the UN Convention on Biological Diversity, Montreal, Canada, Montreal, Canada: United Nations Environmental Programme, Dec. 2022. Accessed: Mar. 01, 2023. [Online]. Available: https://www.cbd.int/doc/c/e6d3/cd1d/daf663719a03902a9b116c34/cop-15-l-25-en.pdf

S. Díaz *et al.*, "Set ambitious goals for biodiversity and sustainability," *Science*, vol. 370, no. 6515, pp. 411–413, Oct. 2020, doi: 10.1126/science.abe1530.

F. C. Bolam *et al.*, "Over half of threatened species require targeted recovery actions to avert human-induced extinction," *Front. Ecol. Environ.*, vol. 21, no. 2, pp. 64–70, Mar. 2023, doi: 10.1002/fee.2537.

Allan James R. *et al.*, "The minimum land area requiring conservation attention to safeguard biodiversity," *Science*, vol. 376, no. 6597, pp. 1094–1101, Jun. 2022, doi: 10.1126/science.abl9127.

DCCEEW, "Environment Protection and Biodiversity Conservation Act 1999 - Compilation No. 59." Commonwealth of Australia, Jul. 01, 2022. Accessed: Feb. 24, 2023. [Online]. Available: https://www.legislation.gov.au/Details/C2016C00777/Html/Volume_1, http://www.legislation.gov.au/Details/C2016C00777

T. Polak, J. E. M. Watson, J. R. Bennett, H. P. Possingham, R. A. Fuller, and J. Carwardine, "Balancing Ecosystem and Threatened Species Representation in Protected Areas and Implications for Nations Achieving Global Conservation Goals," *Conserv. Lett.*, vol. 9, no. 6, pp. 438–445, 2016, doi: 10.1111/conl.12268.

B. Norman, P. Newman, and W. Steffen, "Apocalypse now: Australian bushfires and the future of urban settlements," *Npj Urban Sustain.*, vol. 1, no. 1, p. 2, Feb. 2021, doi: 10.1038/s42949-020-00013-7.

M. Ward *et al.*, "A national-scale dataset for threats impacting Australia's imperiled flora and fauna," *Ecol. Evol.*, vol. 11, no. 17, pp. 11749–11761, 2021, doi: 10.1002/ece3.7920.

S. G. Kearney *et al.*, "Threat-abatement framework confirms habitat retention and invasive species management are critical to conserve Australia's threatened species," *Biol. Conserv.*, vol. 277, p. 109833, Jan. 2023, doi: 10.1016/j.biocon.2022.109833.

AEMO, "2022 Integrated System Plan," Australian Energy Market Operator, Jun. 2022. Accessed: Jul. 13, 2022. [Online]. Available: https://www.aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp/2022-integrated-system-plan-isp