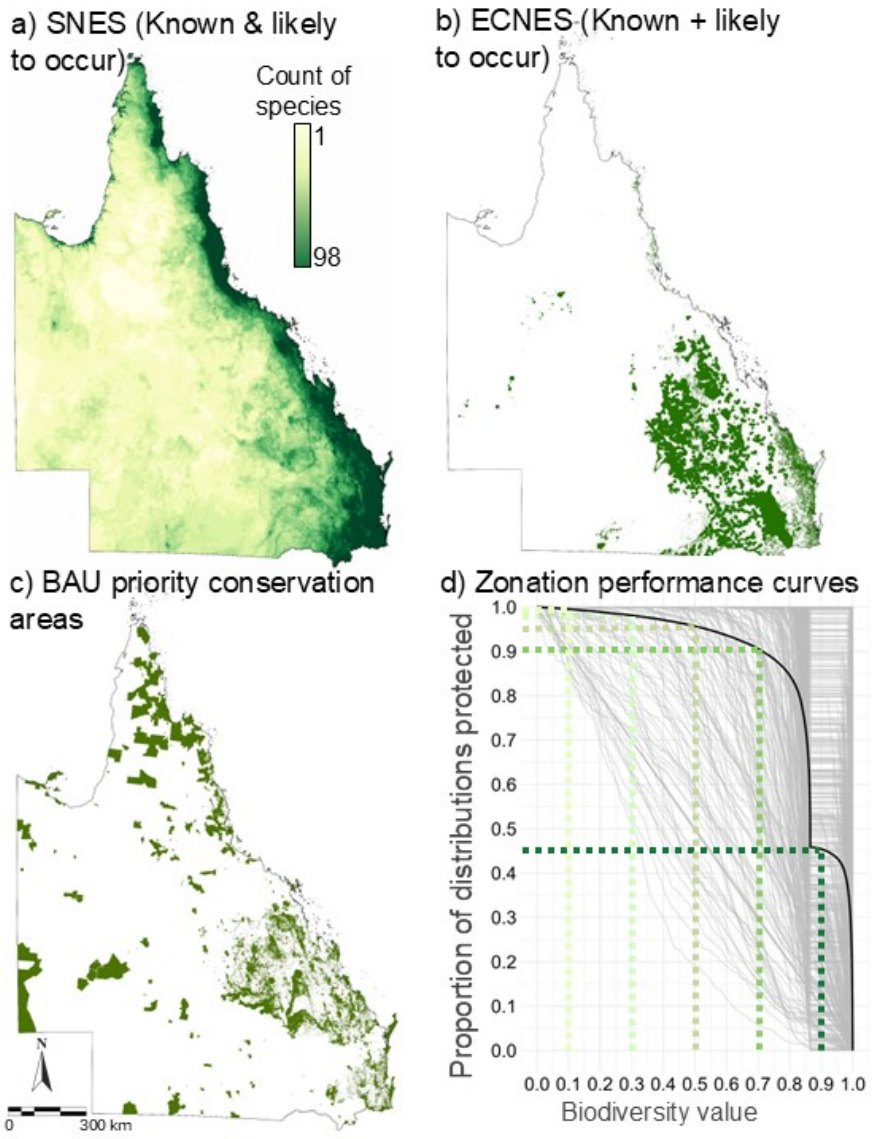
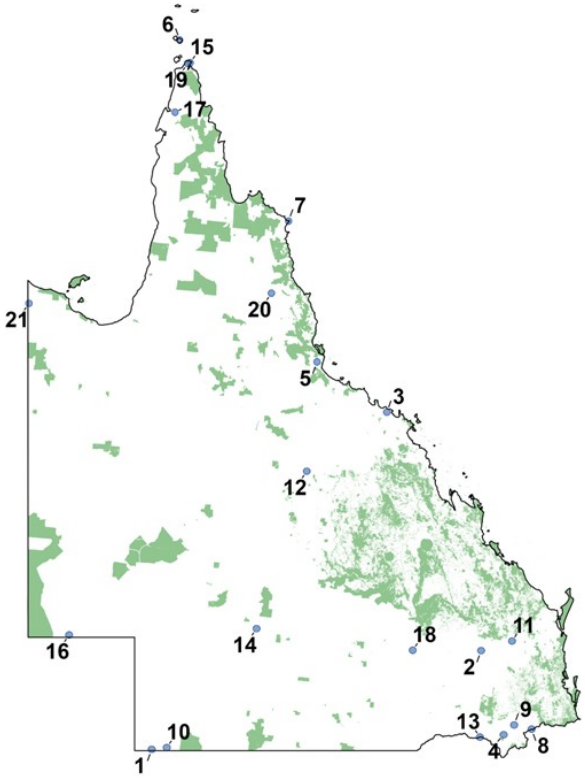
Supplementary data – figures and tables

Supplementary Figure 1. Inputs into prioritization. A) The count of known and likely-to-occur threatened species distributions. B) The extent of threatened ecological communities. C) Business-as-usual (BAU) priority protected area data including, CAPAD, RAMSAR, World Heritage Areas, and high-value habitats for threatened birds and mammals. D) The performance of the zonation curves, with the dark line representing the mean coverage of all species distributions at each priority rank, and the grey lines showing the individual species/TECs coverage at each priority rank used as VRE siting constraints.

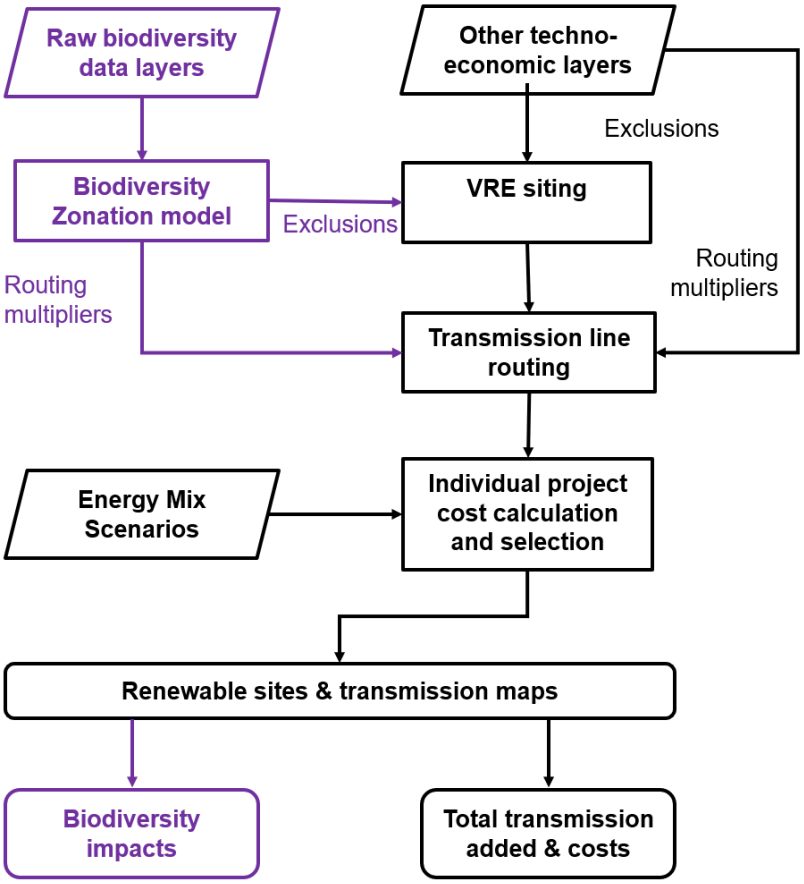


Supplementary Figure 2. Species from SNES dataset whose distributions occur entirely outside areas covered by our business as usual scenario. Blue dots are buffered points centered on the species distributions and the green areas are areas covered by the CAPAD database, RAMSAR wetlands, World Heritage Areas, and high-value habitat.

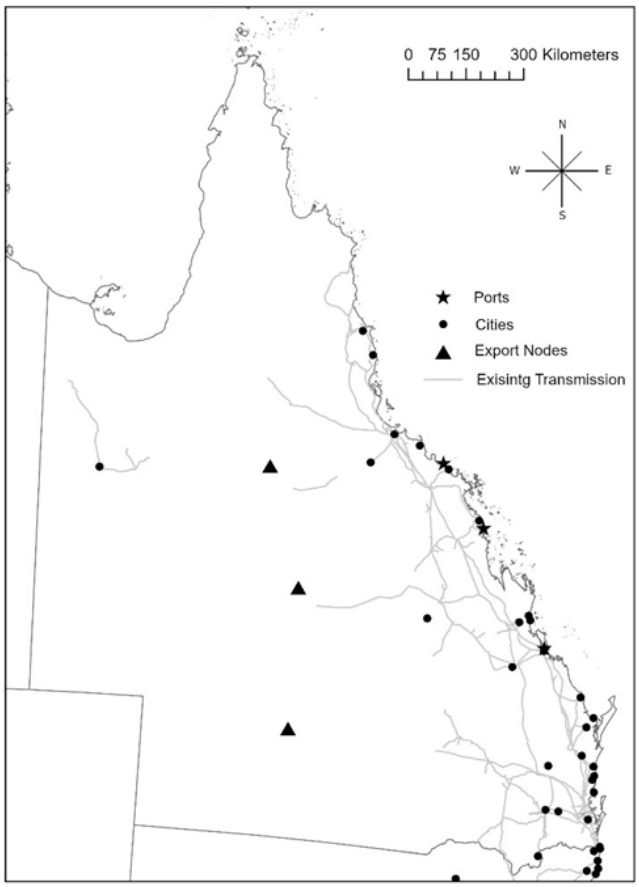


Number	Species Name	Threat status (2019)
1	Acacia cameorum	Vulnerable
2	Acacia handonis	Vulnerable
3	Aristida granitica	Endangered
4	Astrotricha roddii	Endangered
5	Cyperus cephalotes	Endangered
6	Dischidia litoralis	Vulnerable
7	Eremochloa muricata	Endangered
8	Eucalyptus glaucina	Vulnerable
9	Eucalyptus infera	Vulnerable
10	Grevillea kennedyana	Vulnerable
11	Lasiopetalum sp. Proston	Critically Endangered
12	Lawrencia buchananensis	Vulnerable
13	Lepidium monoplocoides	Endangered
14	Melaleuca kunzeoides	Vulnerable
15	Myriophyllum coronatum	Vulnerable
16	Pseudomys australis	Vulnerable
17	Solanum dunalianum	Vulnerable
18	Swainsona murrayana	Vulnerable
19	Syzygium velarum	Vulnerable
20	Zieria rimulosa	Vulnerable
21	Zyzomys palatalis	Endangered

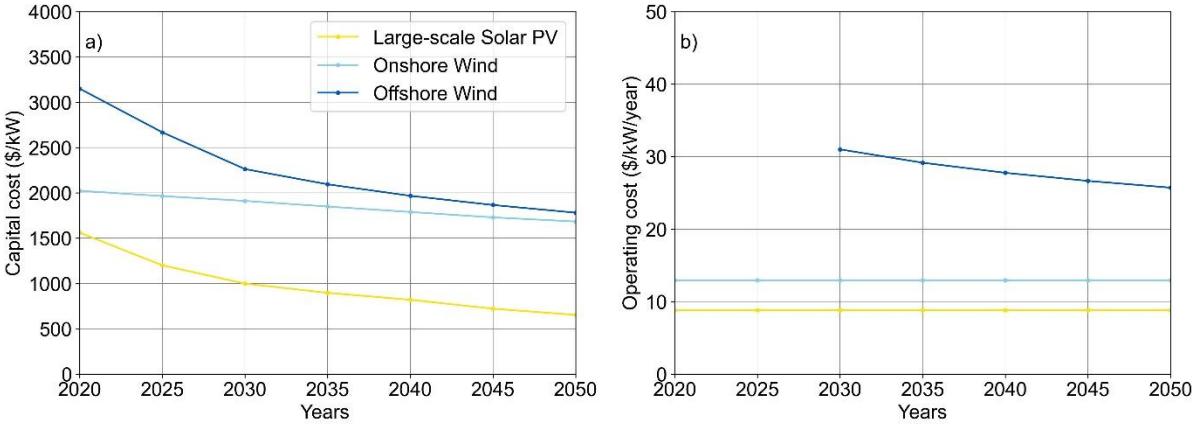
Supplementary Figure 3. The integration of biodiversity (purple) and other constraint data in a renewable energy project and transmission cost-optimisation algorithm. The variable renewable energy (VRE) siting algorithm considers areas using techno-economic and environmental considerations and breaks them into individual candidate projects. Other techno-economic layers include mapping of high-value irrigated agricultural land (ABARES, 2024), urban area maps (ABARES 2024), active mines (Geoscience Australia, 2020), remote communities (Geoscience Australia, 2016a) (Geoscience Australia, 2016a), defence areas (Department of Defence, 2015), transport infrastructure (Geoscience Australia, 2016b), existing energy infrastructure or in areas with large slopes (Hutchinson et al., 2009), low VRE resources (Geoscience Australia, 2021), mineral reserves (Geoscience Australia, 2016c), or offshore shipping lanes (Authority, 2019) that represent places excluded from energy project or transmission infrastructure siting. These are introduced to the transmission and energy project siting cost optimisation algorithm "Renewable Installation" as constraints. The outputs of the algorithm include renewable energy project siting that (on net) meet energy demands at minimum cost, subject to biodiversity and other constraints for a given biodiversity protection scenario.



Supplementary Figure 4. A map of Queensland, showing ports (*), cities (·), export nodes(⊗)and the existing transmission network as lines (*Dominic et al.,* 2023a).



Supplementary Figure 5. a) Capital cost projections for renewable energy generation and b) their operating cost (AEMO, 2021a; Graham, *et al.,* 2021; NREL, 2021)



Supplementary Tables

Supplementary Table 1. Areas excluded from VRE siting in addition to high biodiversity value areas.

Item	Layer	source
techno-economic	Active mines	Geoscience Australia, "Australian Critical Minerals Operating Mines And Deposits (MapServer)," Commonwealth of Australia (Geoscience Australia), 2020. Accessed: Jun. 15, 2021. [Online]. Available: https://services.ga.gov.au/gis/rest/services/AustralianCriticalMineralsOperatingMinesAndDeposits/MapServer
techno-economic	Built up areas	Geoscience Australia, "AREMI_Buildings_WM (MapServer)," Commonwealth of Australia (Geoscience Australia), 2016. Accessed: Jun. 15, 2021. https://services.ga.gov.au/gis/rest/services/AREMI_Buildings_WM/MapServer
techno-economic	Defence restricted - practice, training, prohibited	Department of Defence, "Defence_Restricted_Areas (MapServer)," Commonwealth of Australia (Department 2015. Accessed: Jun. 15, 2021. [Online]. Available: es.ga.gov.au/gis/rest/services/Defence_Restricted_Areas/MapServer
techno-economic	Transport infrastructure - roads (no buffer), airports, landing grounds, heliports, runways	Geoscience Australia, "NM_Transport_Infrastructure (MapServer)," Commonwealth of Australia (Geoscience Australia), 2016. Accessed: Jun. 15, 2021. [Online]. Available: https://services.ga.gov.au/gis/rest/services/NM_Transport_Infrastructure/MapServer
techno-economic	Irrigated farmland, sugar, pasture, rainfed farmland	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
techno-economic	Slope	M. F. Hutchinson, J. L. Stein, J. A. Stein, H. Anderson, and P. K. Tickle, "GEODATA 9 second, DEM and D8, Digital Elevation Model Version 3 and Flow Direction Grid 2008," Geoscience Australia, Canberra, 2009. Accessed: Jul. 12, 2021. [Online]. Available: http://pid.geoscience.gov.au/dataset/ga/66006
techno-economic	Capacity factor	Geoscience Australia, "Renewable Energy Capacity Factor Maps (2021)," Geoscience Australia, Canberra, 2021. Accessed: May 17, 2021. [Online]. Available: http://pid.geoscience.gov.au/dataset/ga/145109
techno-economic	Offshore shipping lanes	1) National Geospatial- Intelligence Agency, "Pub. 175, Sailing Directions (Enroute) North, West, and South Coasts of Australia, Thirteenth Edition." US Department of Defense, 2017. Accessed: Dec. 18, 2021. Available: https://msi.nga.mil/api/publications/download?key=16694491/SFH00000/Pub175bk.pdf&type=view. 2) Darwin Port, "Darwin Port," 2021. Accessed Dec. 18, 2021. https://www.darwinport.com.au/ 3) Flinders Port Holdings, "Flinders Port Holdings," Flinders Port Holdings. Accessed Dec. 18, 2021. https://www.flindersportholdings.com.au/
environmental	Reserves - forestry, indigenous, water supply, nature conservation land, nature conservation marine, prohibited	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
environmental	Inland water bodies [15], salt lakes, wetlands	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

Supplementary Table 2. Length of new transmission beyond the existing transmission network. The existing transmission lines (>=110kv) cover 19741.3 km. New transmission is the additional modelled transmission length needed for each threshold. The 'Total length' is the model length plus the existing length. The 'Percent increase' is the model 'Length' divided by the existing length times 100.

Scenario	biodiversity protection level	New transmission (km)	Total length (km)	Percent increase
tx1	BAU	20423.21	40164.5	103.45
	> 70	21702.44	41443.73	109.93
	> 50	23545.36	43286.65	119.26
	> 30	28090.51	47831.81	142.29
	> 10	45211.28	64952.57	229.02
tx2	BAU	20292.94	40034.24	102.79
	> 70	21754.03	41495.33	110.19
	> 50	23033.33	42774.62	116.67
	> 30	27902.43	47643.73	141.34
	> 10	45250.52	64991.82	229.21

Supplementary Table 3. Percent increase in area of existing transmission easements based on each transmission scenario, for the year 2050. The total area increase is the change in square kilometres required to upgrade the existing easements to the easements required by 500 kv lines. The percent increase is the upgraded easement area divided by the total existing transmission total existing easements.

Scenario	Threshold	Area increase (km2)	Percent increase
tx1	BAU	87.21	13.14
	> 70	101.78	15.33
	> 50	96.89	14.60
	> 30	90.45	13.63
	> 10	84.71	12.76
tx2	BAU	60.39	9.10
	> 70	85.11	12.82
	> 50	69.05	10.41
	> 30	62.93	9.48
	> 10	88.42	13.32

Supplementary Table 4. The extent of existing transmission easement within each biodiversity value threshold category.

Zonation value	Area of existing transmission easement (km2)	Percent of total
0 -.1	0.18	0.027127
0.1 - 0.3	6.17	0.929847
0.3 - 0.5	44.2	6.661141
0.5 - 0.7	161.2	24.29357
0.7 - 0.9	354.42	53.4127
0.9 - 1.0	97.38	14.67561
Grand Total	663.55	100

Supplementary Table 5. Summary of project size, project area, power density and land utilisation rate of VRE projects (Davis, *Dominic et al.,* 2023a; Larson *et al.,* 2021; Offshore Wind Industry Panel Discussion, 2021).

	Unit	**Solar PV**	**Onshore Wind**	**Offshore Wind**
Maximum project size	MW	900	1080	2200
Minimum project size	MW	20	50	100
Maximum project area	km^2	100	400	500
Maximum project area	km^2	2	19	23
Power density	MW/km^2	45	2.7	4.4
Land utilisation rate	%	20	100	100

Supplementary Table 6. Included and excluded transmission infrastructure in modelling each transmission category.

Infrastructure component	Inter-regional transmission	VRE to domestic load	VRE to export node
TX line to the existing transmission grid	NO	YES	NO
Sending converter/substation (terminal)	YES	YES	YES
New substations at connection to existing transmission grid (intermediary endpoint)	NO	YES	NO
TX line to the final destination	YES	YES	YES
New substation at destination (endpoint)	YES	YES	NO
New substation(s) to maintain power quality over longer TX lines	YES	YES	YES

Supplementary Table 7. Representative transmission types and costs used in the modelling. For each type we included the carrying capacity, maximum rated distance (km), cost per km of line (million 2021AU$), and per substation costs (million 2021AU$).

Voltage (kV)	Circuits	Type	Carrying capacity (MW) (Note 1)	Max Rated distance km (Note 2)	Cost mAU$2021 / km [25]	New substation cost m2021AU$ (cost at sending end of spur line) (Note 3)
132	double	HVAC	250	250	1.128	28 (21)
275	single	HVAC	400	250	1.270	36 (23)
275	double	HVAC	950	250	1.563	53 (27)
330	single	HVAC	600	250	1.469	41 (23)
330	double	HVAC	1200	250	1.794	62 (27)
500	double	HVAC	3040	250	2.542	70 (35)
500	twin	HVDC	3000	1000	2.016	633 (597)
500	single	HVDC	385	300	1.077	185 (167)
500	twin	HVDC	750	300	1.923	330 (295)
500	twin	HVDC	1500	300	3.158	633 (597)

1. Assumed to be half of MVA rating.
2. Maximum rated distance of line without adding a repeater substation to maintain power quality.
3. Costs for the sending substation on spur lines (in parentheses) are the same as the cost of the new substation minus transformers in AEMO's VRE project costs [25].

Supplementary Table 8. Costs of recent transmission projects and AEMO transmission database. The cost of transmission in Australia have increased significantly in recent years. This is a result of several factors: the increase in fuel costs, material costs and construction costs due to supply chain disruptions (Transgrid, 2024). Moreover, the transfer capacity of actual transmission projects can be much lower than estimated in this work due to regulation and safety. The following table summarises a comparison between recently reported transmission costs and cost estimates that use the AEMO transmission cost database that is a reference for this study (AEMO, 2021c). Overall, recent transmission cost estimates are more than double the estimates using the AEMO transmission cost database.

Projects	**Reported Transmission Costs**		**AEMO Estimated Transmission Costs** (AEMO, 2021c)
	Year	Capital Cost (m$/GW.km)	Capital Cost (m$/GW.km)
HumeLink Project (Transgrid, 2024)	2024	5.4 m$/GW.km	1 m$/GW.km
VNI West Project (AEMO, 2023)	2023	4.7 m$/GW.km	1 m$/GW.km
EnergyConnect (AER, 2021)	2021	3.3 m$/GW.km	1.7 m$/GW.km

Supplementary Table 9. The 524 species and their associated threat status. These species' distributions were used in the prioritization analysis to identify High Biodiversity Value Areas. Species are a subset of the national SNES dataset, that are known or likely to occur within the state of Queensland. The 22 ecological communities and their threat status. These communities' distributions were used in the prioritization analysis to identify High Biodiversity Value Areas. These are the communities that are known or likely to occur within the state of Queensland, and are a subset of the national ECNES dataset.

Supplementary Table_The 524 species and their associated threat status.xls

Supplementary Table_The 22 ecological communities and their threat status.xlsx

Supplementary Table 10. Estimated demand is the Gigawatts needed to meet domestic demand in 2050 based on the Net Zero Australia state targets for the Eplus scenario. The area available is the area, in square kilometers, that occur within each state but are not covered by Net Zero BAU exclusion layers. The total footprint is the estimated total footprint of the generation estimated using the equation total footprint for solar = (MW/45MW/km), for wind total footprint = (mw/2.7MW/km). The total and direct footprints are in square kilometers. The direct footprints are 90% of the total footprint for solar and 1% of the total footprint for wind. The percent of the available land for Total footprint and direct footprint are included in parenthesis after each area estimate.

State	Large scale solar target (GW)	Onshore wind target (GW)	Area (km) available for solar	Area (km) available for wind	Solar total footprint (% of available area)	Onshore Wind total footprint (% of avail. area)	Solar direct footprint (% of avail. area)	Onshore Wind direct footprint (% of avail. area)
New South Wales	44.14	33.8	474431	508003	981 (0.2%)	12519 (2.5%)	893 (0.2%)	125 (<0.01%)
Northern Territory	19.39	2.23	799800	742580	431 (0.1%)	826 (0.1%)	392 (0.05%)	8 (<0.01%)
Queensland	49.04	18.69	1244394	1179494	1090 (0.1%)	6922 (0.6%)	992 (0.08%)	69 (<0.01%)
South Australia	15.03	3.07	313639	337757	334 (0.1%)	1137 (0.3%)	304 (0.1%)	11 (<0.01%)
Tasmania	1.16	0.11	8405	7741	26 (0.3%)	41 (0.5%)	23 (0.3%)	0.2 (<0.01%)
Victoria	11.14	22.96	54562	74629	248 (0.5%)	8504 (11.4%)	225 (0.4%)	85 (<0.01%)
Western Australia	49.53	15.28	1097953	1161953	1101 (0.1%)	5659 (0.5%)	1002 (0.1%)	57 (<0.01%)

Supplementary data – upload eplus.gdb with all of the data layers.

Supporting data: eplus.gdb with all of the data

Table 11. Additional exclusions used in VRE and transmission citing. The analysis incorporated energy asset siting exclusions such as irrigated lands (prohibiting all new variable renewable energy infrastructure), rainfed cropland (prohibiting new solar PV), critical habitat of threatened species and ecological communities, national reserves, areas within the Collaborative Australian Protected Area Database, and inland water bodies, salt lakes, and wetlands. Unless specifically protected in a base exclusion dataset, all Indigenous Estate categories were considered for energy infrastructure siting. Furthermore, the analysis prioritized the utilization of existing transmission corridors over the development of new greenfield corridors

Supplementary table 12. Estimated total electricity costs relative to BAU. Industrial $/MWh = wholesale market $/MWh + TX cost $/MWh. Residential $/MWh = wholesale market $/MWh + TX cost $/MWh + DN cost $/MWh. Modest cost increases for both industrial and residential customers with up to 50% of most valuable biodiversity protected.

	x1 TX costs						x2 TX costs				
	BAU	**Top 30**	**Top 50**	**Top 70**	**Top 90**		**BAU**	**Top 30**	**Top 50**	**Top 70**	**Top 90**
Wholesale market $/MWh	174	174	174	174	176		174	174	174	175	176
TX cost $/MWh	44	47	49	53	62		59	64	69	78	96
DN cost $/MWh	131	131	131	131	131		131	131	131	131	131
Industrial $/MWh	218	221	223	228	239		233	238	243	252	272
Increase vs BAU %		**1%**	**2%**	5%	10%			**2%**	**4%**	8%	17%
Residential $/MWh	349	352	355	359	370		364	370	375	384	403
Increase vs BAU %		**1%**	**2%**	3%	6%			**2%**	**3%**	5%	11%
Renewable Availability TWh	215	211	205	206	216		225	221	212	215	225
Demand Twh	101	101	101	101	101		101	101	101	101	101