Data in Brief 47 (2023) 108896

Contents lists available at ScienceDirect

Data in Brief

journal homepage: www.elsevier.com/locate/dib

Data Article

Dataset for the Victorian energy transition including technical, social, economic, and environmental detail☆

Glen Currie*, Riley Cousins, Alexander Diplaris, Sebastian Drimer, Matthew Foley

Faculty of Engineering and Information Technology, The University of Melbourne, Australia

ARTICLE INFO

Article history:
Received 7 July 2022
Revised 2 January 2023
Accepted 9 January 2023
Available online 19 January 2023

Dataset link: Data in Brief article Dataset for the Victorian energy transition including technical, social, economic and environmental detail. (Reference data)

Keywords:
Energy transition
Victoria
Mixed-method
Renewable energy
N bottom line
Electricity
Carbon

ABSTRACT

This data relates to existing and planned electricity generation projects in Victoria, Australia. Planning Victoria, part of the Victorian Government, registered most projects. The technical performance data for the projects includes the electricity generated, input fuel, losses in the transmission of electricity, energy storage options, and transparency between grid operators and stakeholders. The social data related to the projects include health data for the effect of Victorian coal plant pollution, including a rich dataset on the health effects of a coal fire in (Jennens, 2021). A dataset for all the health effects of coal plants in Victoria was then compiled. The social data also includes a measure of customer engagement with electricity distribution companies in Victoria and public satisfaction with renewable projects in Victoria. The economic cost data includes capital costs, operation and maintenance costs, and externality costs related to greenhouse gasses emitted.

The environmental data used a life cycle assessment and the critical materials needed for the electricity generation projects.

The analysis performed was an nBL assessment (Foliente, 2007) which uses a comparative analysis of the four bot-

---

☆ Definitions An nBL assessment [1] uses a comparative analysis of the four bottom lines (environmental, social, economic and technology).

* Corresponding author.

E-mail address: glen.currie@unimelb.edu.au (G. Currie).

https://doi.org/10.1016/j.dib.2023.108896

2352-3409/© 2023 The Author(s). Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/)

tom lines (environmental, social, economic and technology). An nBL assessment is similar to a Triple Bottom Line assessment but includes additional parameters. The data used for this nBL analysis was for three scenarios (business as usual, a renewable generation future with electricity imported from other states and a renewable generation future with all electricity generated in Victoria). The first step in managing the raw data was to normalise, standardise and aggregate the data. These steps were done for the four bottom lines and the three scenarios. The reuse potential of this data is high as it is for a pipeline of projects that will continue to evolve. This data would also have the potential for other researchers to compare the Victorian electricity transition with other places internationally.

© 2023 The Author(s). Published by Elsevier Inc.
This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/)

Specifications Table

Subject:	Energy Economics
Specific subject area:	This subject area is for the electricity generation projects in Victoria and the options for a transition to renewables.
Type of data:	The types of data this article describes are tables and figures.
How the data were acquired:	Desktop research on published government reports, academic research output and public disclosures by private companies acquired the data. The data was collected via desktop research and followed a protocol that a government or a credible academic source could verify data. Some data was taken from worldwide sources and applied to Victoria, where the conditions were comparable (for example, losses over electricity transmission lines).
Data format:	The data format is a mix of Raw and Analysed data.
Description of data collection:	The starting point of data collection was to note all energy projects under planning permission from the Victorian State Government. This list is at https://www.planning.vic.gov.au/planning-permit-applications/specific-permit-topics All the solar and wind projects under planning with the Victorian Government were included, and additional projects in Transmission and Storage were sourced. The information about all these projects was then built up by checking alternate sources. There was a decision to exclude projects for CO_2 sequestration as the authors consider them unlikely candidates for the energy transition. All data included was relevant to the electricity supply side of the Victorian energy transition.
Data source location:	Victoria, Australia
Data accessibility:	Data are included in this article and supplemental repository called *figshare with a* data identification number: https://doi.org/10.26188/20237586.v1There are two Excel files in the supplemental repository: 1. Enviro Metrics is the Excel file containing the studied projects' LCA calculations. The file has three tabs: GHG emission, Material Breakdown and the LCA, and is a dataset with raw and analysed data. 2. Proposed Projects is the Excel file showing all the projects for the three scenarios. One scenario is Business As Usual (BAU), another is Alternative 1 (ALT1), and the third is Alternative 2 (ALT2). These are three tables in the Excel file.

Value of the Data

1. These data are useful because they link to an important and popular topic of the energy transition.
2. The parties who could benefit from these data are government, industry and academic researchers exploring the energy transition.
3. These data can be reused for further insights and the development of experiments exploring the energy transition. The data might be used for further research on Victoria's energy transition or for comparing the energy transition in Victoria and other places.
4. Another way other researchers could use this data would be to delve deeper into the analysis to uncover insights into the factors associated with the energy transition in Victoria.

1. Data Description

There are two files in the linked data file. They are both at https://doi.org/10.26188/20237586.v1 and are "Enviro Metrics and Projects.xlsx" and "Proposal Projects UPDATED.xlsx".

The Enviro Metrics and Projects file shows the total Greenhouse Gas emissions (GHG emissions), the Material Breakdown and the Life-Cycle Assessment (LCA) under its three tabs.

The Proposal Projects Updated file shows the Business As Usual data (BAU) under its three tabs, the ALT1 scenario (smart meter data sharing, inverter regulation, and cost-reflective pricing) and the ALT2 scenario (Victoria becoming self-sustainable in renewable energy).

2. Experimental Design Materials and Methods

The data relates to calculating the technological, social, environmental and economic impact of three scenarios, BAU, ALT1 and ALT2, for the future electricity supply in Victoria, Australia.

2.1. Defining the Three Scenarios

Table A1 shows a brief definition of these three scenarios.

Table A.1
Summary of the proposed changes for each nBL solution.

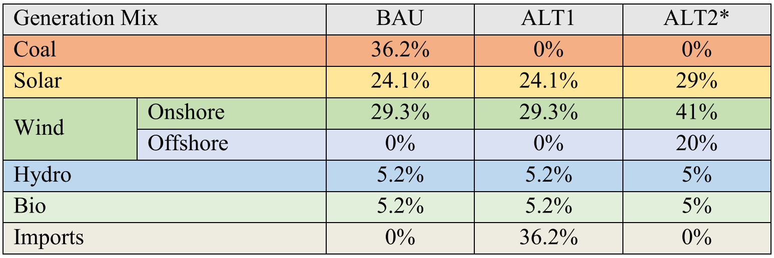
Solution	*Generation*	*Storage*	*Transmission*	*Policy*
BAU	Mix.	Gradual introduction.	No change.	Minimal changes to current policy.
ALT1 (Import/Export)	Existing renewable energy only.	Rapid introduction.	Heavy investment.	Release of smart meter data to the public with proper privacy changes. Inverter regulation. Cost-reflective pricing.
ALT2 (Self-Sustainable)	100% renewables sourced in Victoria.	Rapid introduction.	No change.	PV export limits. Release of smart meter data to the public with proper privacy changes. Local storage is mandated with PV. Regulation introduced to support grid-connected micro-grids and VPP's.

2.2. Generation Mix for Each Solution

The 2030 generation mix was determined using capacity factors used by AEMO for onshore, offshore, and solar PV [3]. These capacity factors were used to estimate the annual generation for the projects. The yearly demand was then calculated by viewing historical data available on OpenNEM.org.au and AEMO's demand predictions [4]. The difference between renewable generation and demand will be generated by coal in the BAU case, coal transitioning to imported energy by 2030 in ALT1, and coal transitioning to self-sufficient renewable production by 2030 in ALT2. Tables 2–5 and B6 show the calculations for each solution Table B.5b.

Table B.2 shows the BAU generation mix, and Table B.3 shows the calculation of generation for BAU.

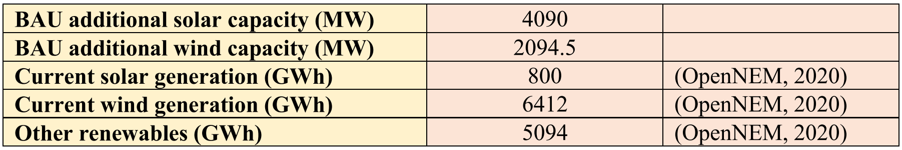
Table B.1
Proposed generation mix for each solution.



Generation Mix		BAU	ALT1	ALT2*
Coal		36.2%	0%	0%
Solar		24.1%	24.1%	29%
Wind	Onshore	29.3%	29.3%	41%
	Offshore	0%	0%	20%
Hydro		5.2%	5.2%	5%
Bio		5.2%	5.2%	5%
Imports		0%	36.2%	0%

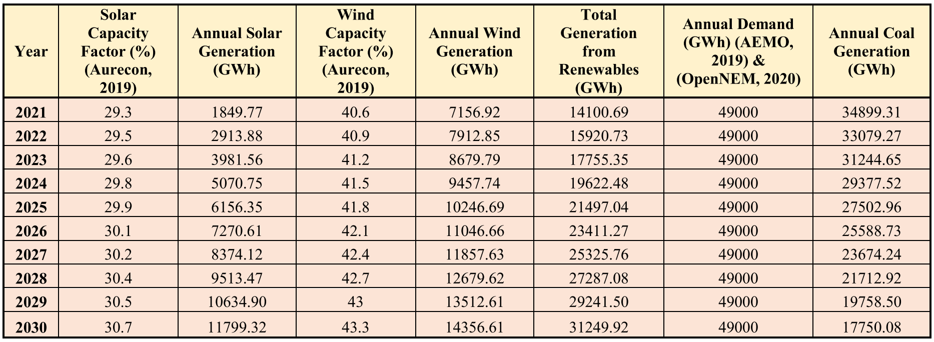
*ALT 2′s generation capacity shown in Table B.5 is enough to generate 115% of annual demand – values in Table B.1 have been scaled to achieve 100% collectively.

Table B.2
Summary of proposed new capacity and current generation for the BAU case.



BAU additional solar capacity (MW)	4090	
BAU additional wind capacity (MW)	2094.5	
Current solar generation (GWh)	800	(OpenNEM, 2020)
Current wind generation (GWh)	6412	(OpenNEM, 2020)
Other renewables (GWh)	5094	(OpenNEM, 2020)

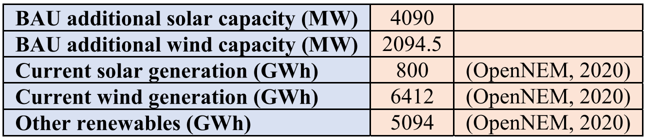
Table B.3
Calculation of annual generation for the BAU case.



Year	Solar Capacity Factor (%) (Aurecon, 2019)	Annual Solar Generation (GWh)	Wind Capacity Factor (%) (Aurecon, 2019)	Annual Wind Generation (GWh)	Total Generation from Renewables (GWh)	Annual Demand (GWh) (AEMO, 2019) & (OpenNEM, 2020)	Annual Coal Generation (GWh)
2021	29.3	1849.77	40.6	7156.92	14100.69	49000	34899.31
2022	29.5	2913.88	40.9	7912.85	15920.73	49000	33079.27
2023	29.6	3981.56	41.2	8679.79	17755.35	49000	31244.65
2024	29.8	5070.75	41.5	9457.74	19622.48	49000	29377.52
2025	29.9	6156.35	41.8	10246.69	21497.04	49000	27502.96
2026	30.1	7270.61	42.1	11046.66	23411.27	49000	25588.73
2027	30.2	8374.12	42.4	11857.63	25325.76	49000	23674.24
2028	30.4	9513.47	42.7	12679.62	27287.08	49000	21712.92
2029	30.5	10634.90	43	13512.61	29241.50	49000	19758.50
2030	30.7	11799.32	43.3	14356.61	31249.92	49000	17750.08

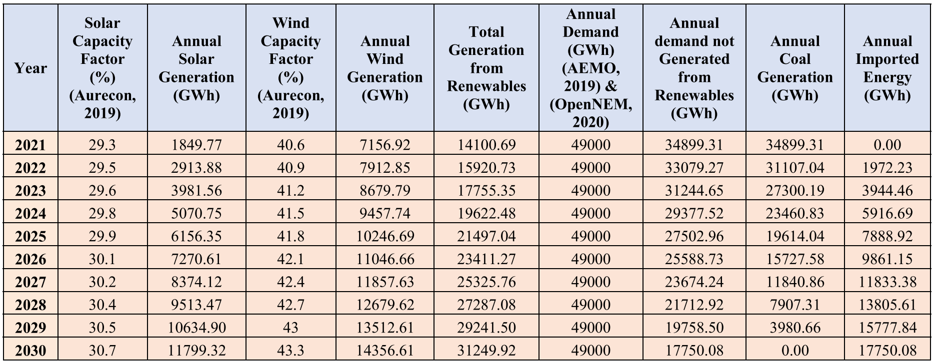
Table B4 shows the ALT1 generation mix, and Table B4 shows the calculation of generation for ALT1.

Table B.4
Summary of proposed new capacity and current generation for ALT1.



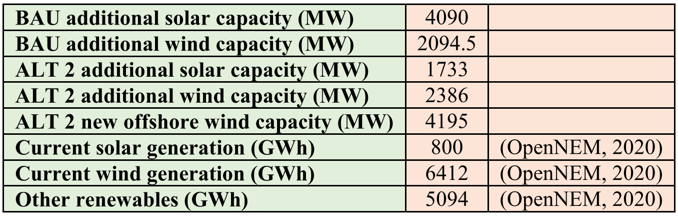
BAU additional solar capacity (MW)	4090	
BAU additional wind capacity (MW)	2094.5	
Current solar generation (GWh)	800	(OpenNEM, 2020)
Current wind generation (GWh)	6412	(OpenNEM, 2020)
Other renewables (GWh)	5094	(OpenNEM, 2020)

Table B.5
Calculation of annual generation for the ALT1.



Year	Solar Capacity Factor (%) (Aurecon, 2019)	Annual Solar Generation (GWh)	Wind Capacity Factor (%) (Aurecon, 2019)	Annual Wind Generation (GWh)	Total Generation from Renewables (GWh)	Annual Demand (GWh) (AEMO, 2019) & (OpenNEM, 2020)	Annual demand not Generated from Renewables (GWh)	Annual Coal Generation (GWh)	Annual Imported Energy (GWh)
2021	29.3	1849.77	40.6	7156.92	14100.69	49000	34899.31	34899.31	0.00
2022	29.5	2913.88	40.9	7912.85	15920.73	49000	33079.27	31107.04	1972.23
2023	29.6	3981.56	41.2	8679.79	17755.35	49000	31244.65	27300.19	3944.46
2024	29.8	5070.75	41.5	9457.74	19622.48	49000	29377.52	23460.83	5916.69
2025	29.9	6156.35	41.8	10246.69	21497.04	49000	27502.96	19614.04	7888.92
2026	30.1	7270.61	42.1	11046.66	23411.27	49000	25588.73	15727.58	9861.15
2027	30.2	8374.12	42.4	11857.63	25325.76	49000	23674.24	11840.86	11833.38
2028	30.4	9513.47	42.7	12679.62	27287.08	49000	21712.92	7907.31	13805.61
2029	30.5	10634.90	43	13512.61	29241.50	49000	19758.50	3980.66	15777.84
2030	30.7	11799.32	43.3	14356.61	31249.92	49000	17750.08	0.00	17750.08

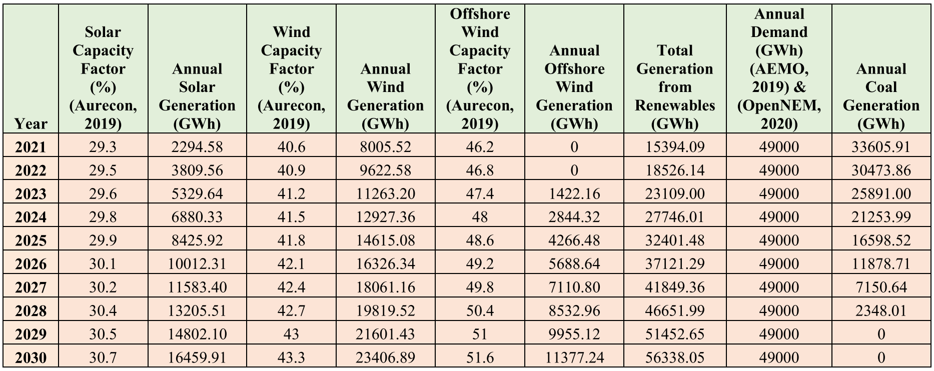
Table B.5b
Summary of proposed new capacity and current generation for ALT2.



BAU additional solar capacity (MW)	4090	
BAU additional wind capacity (MW)	2094.5	
ALT 2 additional solar capacity (MW)	1733	
ALT 2 additional wind capacity (MW)	2386	
ALT 2 new offshore wind capacity (MW)	4195	
Current solar generation (GWh)	800	(OpenNEM, 2020)
Current wind generation (GWh)	6412	(OpenNEM, 2020)
Other renewables (GWh)	5094	(OpenNEM, 2020)

Table B.2 shows the ALT2 generation mix, and Table B.3 shows the calculation of generation for ALT2.

Table B.6
Calculation of annual generation for the ALT2.



Year	Solar Capacity Factor (%) (Aurecon, 2019)	Annual Solar Generation (GWh)	Wind Capacity Factor (%) (Aurecon, 2019)	Annual Wind Generation (GWh)	Offshore Wind Capacity Factor (%) (Aurecon, 2019)	Annual Offshore Wind Generation (GWh)	Total Generation from Renewables (GWh)	Annual Demand (GWh) (AEMO, 2019) & (OpenNEM, 2020)	Annual Coal Generation (GWh)
2021	29.3	2294.58	40.6	8005.52	46.2	0	15394.09	49000	33605.91
2022	29.5	3809.56	40.9	9622.58	46.8	0	18526.14	49000	30473.86
2023	29.6	5329.64	41.2	11263.20	47.4	1422.16	23109.00	49000	25891.00
2024	29.8	6880.33	41.5	12927.36	48	2844.32	27746.01	49000	21253.99
2025	29.9	8425.92	41.8	14615.08	48.6	4266.48	32401.48	49000	16598.52
2026	30.1	10012.31	42.1	16326.34	49.2	5688.64	37121.29	49000	11878.71
2027	30.2	11583.40	42.4	18061.16	49.8	7110.80	41849.36	49000	7150.64
2028	30.4	13205.51	42.7	19819.52	50.4	8532.96	46651.99	49000	2348.01
2029	30.5	14802.10	43	21601.43	51	9955.12	51452.65	49000	0
2030	30.7	16459.91	43.3	23406.89	51.6	11377.24	56338.05	49000	0

2.3. Peak Load Estimation

Table C.1 shows the peak load events by year from 2022 to 2030.

Table C.1
Tabulation of Victoria's annual peak load with projection from 2022 to 2030.

Year	No.	Peak Load
2000	1	8019.00
2001	2	7581.00
2002	3	8041.00
2003	4	8583.00
2004	5	8492.00
2005	6	8742.00
2006	7	9080.00
2007	8	9830.00
2008	9	10490.00
2009	10	10088.00
2010	11	9906.00
2011	12	9155.00
2012	13	9670.00
2013	14	10308.00
2014	15	8635.00
2015	16	9523.00
2016	17	8730.00
2017	18	9159.00
2018	19	9318.00
2019	20	9618.00
2020	21	8391.00
2021	22	9665.44
2022	23	9715.72
2023	24	9766.00
2024	25	9816.28
2025	26	9866.55
2026	27	9916.83
2027	28	9967.11
2028	29	10017.39
2029	30	10067.67
2030	31	10117.95

2.4. Technical Performance Metric

2.4.1. Conversion Losses (%)

Given the variability in the generation type proposed by renewable methods, analysis of losses that occur in the initial conversion of potential energy to mechanical energy is critical to understanding the performance of each generation type as a long-term, viable choice from a technical efficiency standpoint. The generation mix in 2030 for each scenario (Section B) was utilised to calculate each solution's overall efficiency, with the loading of generation type a critical value. The generation demand for 2030 was estimated by linearly projecting the trend of demand change into the next ten years. The next step was finding each solution's overall energy loss value as a percentage. Kazi [5] calculated that brown coal is converted to energy at an efficiency of 28%. We assumed that this rate of efficiency would hold until 2030. A review of costs and technical parameters for the Australian Energy Market Operator (AEMO) [3] postulates efficiency values of 30.7, 43.3 and 51.6% for solar, onshore wind and offshore wind, respectively, The Clean Energy Council attribute an efficiency value of 90% for pumped hydropower [6]. Total conversion losses as a percentage are calculated by first finding each generation type's total potential energy following Eq. (1).

$$\text{Potential Energy} = \frac{L_G}{e_G} \tag{1}$$

L_G is the individual load generated by each type, and e_G is the efficiency of each generation type. Hence, the energy lost in basic units (i.e., MW) is the potential energy minus the delivered load. The sum of all energy lost and potential energy can then be calculated for the entire solution, with Eq. (2) delivering a final per cent value of conversion loss. The final calculations show in Table D.1.

$$e_T = \frac{\sum \text{Energy Lost}}{\sum \text{Potential Energy}} * 100 \tag{2}$$

2.4.2. Transmission Losses (%)

We present energy losses from grid infrastructure (e.g., transformers and conduction) as a percentage, which assists in comparing systems of varying magnitudes in size. Bahrman [7] estimates a line loss of 6.93% per 1000 km. The only transmission of electricity across state borders was considered in this analysis since approximately 5% of power is lost once it falls within the boundaries of distribution companies. Current transmission lines were analyzed using a map of Australian transmission lines [8], while future transmission lines were included in the Future Projects (see online file Proposal Projects Updated). The total percentage loss for each transmission line was calculated using Formula 3.

$$\%\ \text{loss} = 9.5\% + \frac{\text{Length of line in km}}{1000} * 6.93\% \tag{3}$$

A weighting method was applied to calculate each proposal's total percentage loss across the transmission network. For each transmission line, the given weighting depended on the length ratio for the combined length of the network, as outlined in Formula 4.

$$\text{Weighted Loss [\%]} = \text{Line loss [\%]}* \frac{\text{Individual line length [km]}}{\text{Total line length [km]}} \tag{4}$$

We then calculated a total network loss using the sum of all individually weighted loss percentages, and this loss shows in Table D.2.

2.4.3. Storage Capacity (MW)

Storage capacity is critical in the energy transition [9], namely through the improvement of grid reliability and asset utilisation. Hence, storage capacity was a key metric chosen to describe the technical performance of each proposal. The total storage capacity is available for each of the three scenarios.

Table D.1
Summary of conversion loss calculations, including the generation share from Section B and the individual loss percentages for each generation type.

	Generation Share		Load [MW]	Conversion Rate	Source	Total Pot Energy [MW]	Energy Lost [MW]
BAU	Coal	36%	3662.70	28.00%	Kabir (2014), Seligman (2010)	13081.06	9418.37
	Solar	24%	2438.43	30.70%	Aurecon (2019)	7942.76	5504.33
	Onshore Wind	29%	2964.56	43.30%	Aurecon (2019)		
	Hydro	5%	526.13	90.00%	Killingtveit (2020), Clean Energy Council (2014)	584.59	58.46
	Bio	5%	526.13	65.00%	EPA (2013)	809.44	283.30
		100.00%	10117.95			22417.85	15264.46
						Efficiency Losses	68.09%
ALT1	Coal	0%	0.00	28.00%	Kabir (2014), Seligman (2010)	0.00	0.00
	Solar	24%	2438.43	30.70%	Aurecon (2019)	7942.76	5504.33
	Wind	29%	2964.56	47.00%	Aurecon (2019)	6307.57	3343.01
	Hydro	5%	526.13	90.00%	Killingtveit (2020), Clean Energy Council (2014)	584.59	58.46
	Bio	5%	526.13	65.00%	EPA (2013)	809.44	283.30
		63.80%	6455.25			15644.36	9189.11
						Total Efficiency	58.74%
ALT2	Coal	0%	0.00	28.00%	Kabir (2014), Seligman (2010)	0.00	0.00
	Solar	29%	2934.21	30.70%	Aurecon (2019)	9557.67	6623.47
	Onshore Wind	41%	4148.36	43.30%	Aurecon (2019)	9580.51	5432.15
	Offshore Wind	20%	2023.59	51.60%	Aurecon (2019)	3921.69	1898.10
	Hydro	5%	505.90	90.00%	Killingtveit (2020), Clean Energy Council (2014)	562.11	56.21
	Bio	5%	505.90	65.00%	EPA (2013)	778.30	272.41
		100.00%	10117.95			24400.28	14282.33
						Efficiency Losses	58.53%

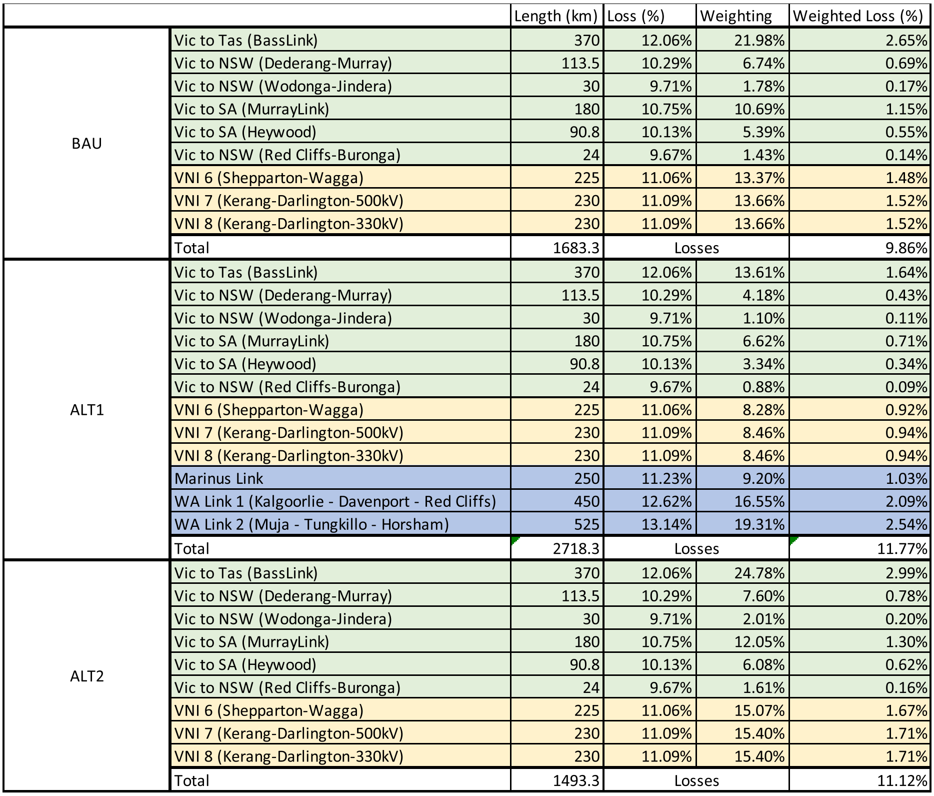
2.4.4. *Data Transparency (-)*

The final technical performance metric addresses data-sharing issues across grid stakeholders. This metric aims to capture each solution's capability to create and share accessible data between stakeholders such as DBs, grid operators, retailers, government, and consumers. European distribution system operators (DSOs) provide one method to quantify this indicator in a report designed to address challenges associated with smart grids [10]. Their calculation formula is:

$$\text{Transparency Data Access Sharing} = \text{TDAS} * \frac{\sum_{i=1}^{9} (KI\ 5.i * w_{TDASi})}{\sum_{i=1}^{9} w_{TDASi}} \tag{5}$$

w_{TDASi} is a weighting factor between 0 and 1 attributable to each of the inputs. Table D.3 summarises the inputs adapted from Brazier et al. [10].

Table D.2
Summary of transmission loss calculations following the weighting method described.



		Length (km)	Loss (%)	Weighting	Weighted Loss (%)
BAU	Vic to Tas (BassLink)	370	12.06%	21.98%	2.65%
	Vic to NSW (Dederang-Murray)	113.5	10.29%	6.74%	0.69%
	Vic to NSW (Wodonga-Jindera)	30	9.71%	1.78%	0.17%
	Vic to SA (MurrayLink)	180	10.75%	10.69%	1.15%
	Vic to SA (Heywood)	90.8	10.13%	5.39%	0.55%
	Vic to NSW (Red Cliffs-Buronga)	24	9.67%	1.43%	0.14%
	VNI 6 (Shepparton-Wagga)	225	11.06%	13.37%	1.48%
	VNI 7 (Kerang-Darlington-500kV)	230	11.09%	13.66%	1.52%
	VNI 8 (Kerang-Darlington-330kV)	230	11.09%	13.66%	1.52%
	Total	1683.3	Losses		9.86%
ALT1	Vic to Tas (BassLink)	370	12.06%	13.61%	1.64%
	Vic to NSW (Dederang-Murray)	113.5	10.29%	4.18%	0.43%
	Vic to NSW (Wodonga-Jindera)	30	9.71%	1.10%	0.11%
	Vic to SA (MurrayLink)	180	10.75%	6.62%	0.71%
	Vic to SA (Heywood)	90.8	10.13%	3.34%	0.34%
	Vic to NSW (Red Cliffs-Buronga)	24	9.67%	0.88%	0.09%
	VNI 6 (Shepparton-Wagga)	225	11.06%	8.28%	0.92%
	VNI 7 (Kerang-Darlington-500kV)	230	11.09%	8.46%	0.94%
	VNI 8 (Kerang-Darlington-330kV)	230	11.09%	8.46%	0.94%
	Marinus Link	250	11.23%	9.20%	1.03%
	WA Link 1 (Kalgoorlie - Davenport - Red Cliffs)	450	12.62%	16.55%	2.09%
	WA Link 2 (Muja - Tungkillo - Horsham)	525	13.14%	19.31%	2.54%
	Total	2718.3	Losses		11.77%
ALT2	Vic to Tas (BassLink)	370	12.06%	24.78%	2.99%
	Vic to NSW (Dederang-Murray)	113.5	10.29%	7.60%	0.78%
	Vic to NSW (Wodonga-Jindera)	30	9.71%	2.01%	0.20%
	Vic to SA (MurrayLink)	180	10.75%	12.05%	1.30%
	Vic to SA (Heywood)	90.8	10.13%	6.08%	0.62%
	Vic to NSW (Red Cliffs-Buronga)	24	9.67%	1.61%	0.16%
	VNI 6 (Shepparton-Wagga)	225	11.06%	15.07%	1.67%
	VNI 7 (Kerang-Darlington-500kV)	230	11.09%	15.40%	1.71%
	VNI 8 (Kerang-Darlington-330kV)	230	11.09%	15.40%	1.71%
	Total	1493.3	Losses		11.12%

Table D.3
Description of each variable included in the formula for data transparency.

Code	Description
TDAS	Value equal to 0 or 1. Describes the ability of data access and sharing between stakeholders (1 if available, 0 if not).
5.1	Value equal to 0 or 1. Describes the availability of consumer data to distribution operators (i.e., AEMO).
5.2	Value equal to 0 or 1. Describes the availability of real-time consumer data to distribution operators (i.e., AEMO).
5.3	Value equal to 0 or 1. Describes the availability of consumer data to distribution businesses (i.e., AusNet)
5.4	Value equal to 0 or 1. Describes the availability of real-time consumer data to distribution businesses (i.e., AusNet)
5.5	Value equal to 0 or 1. Describes the ability of distribution operators (i.e., AEMO) to provide real-time data to operators of distributed energy resource operators.
5.6	Value equal to 0 or 1. Describes the ability of distribution operators (i.e., AEMO) to provide non-real-time data to operators of distributed energy resource operators.
5.7	Value equal to 0 or 1. Describes the ability of smart meters installed at the customer interface to provide real-time data to customers.
5.8	Value equal to 0 or 1. Describes the ability of smart meters installed at the customer interface to provide non-real-time data to customers.
5.9	Value equal to 0 or 1. Describes whether data is shared between system operators and retail businesses.

Table D.4
Applied values for data transparency metric.

	BAU	ALT1	ALT2	w
TDAS	1	1	1	1
5.1	1	1	1	1
5.2	1	1	1	1
5.3	1	1	1	1
5.4	1	1	1	1
5.5	0	1	1	1
5.6	1	1	1	1
5.7	0	1	1	1
5.8	1	1	1	1
5.9	0	1	1	1

Table D.4 summarises the attributed values for each of the proposals.

2.5. Social Metric

2.5.1. Employment

A primary factor in evaluating the social performance of the different transition proposals is the level of employment generated from the wind, solar, storage and transmission projects for each proposal. We assumed that each project's total number of jobs included construction and permanent ongoing jobs. Due to the insignificant number of permanent jobs required for each farm and the analysis taking place early in the lifespan of the farms, the permanent jobs were not included in the analysis as they had only a small impact on the results. Furthermore, the jobs lost from the closures of Yallourn, Loy Yang A and Loy Yang B were not included due to the small number of jobs lost relative to the jobs created overall.

When we could not find the jobs for the wind and solar projects in available resources, then the number of jobs required was estimated from a linear regression model, which plotted the jobs created against the capacity (MW) for projects where the information was available. The created plots of interpolated job numbers for each corresponding solar and wind project are shown in Figs. E.1 and E.2.

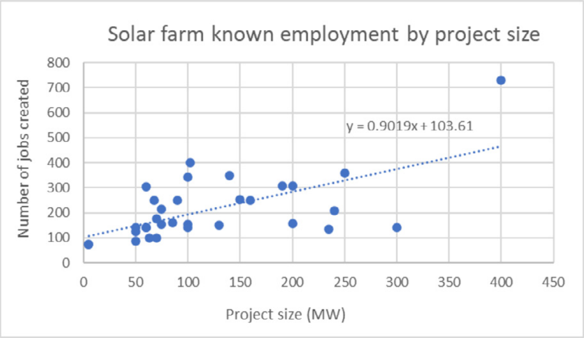


Fig. E.1. Relationship between jobs and project size for solar projects.

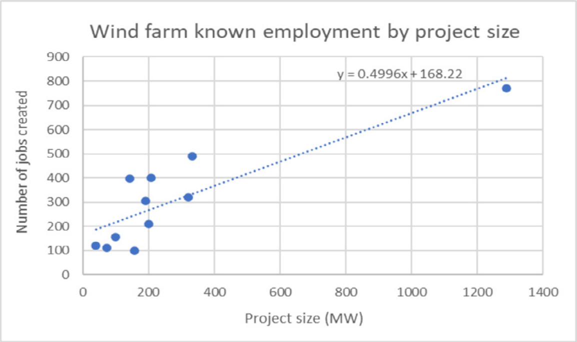
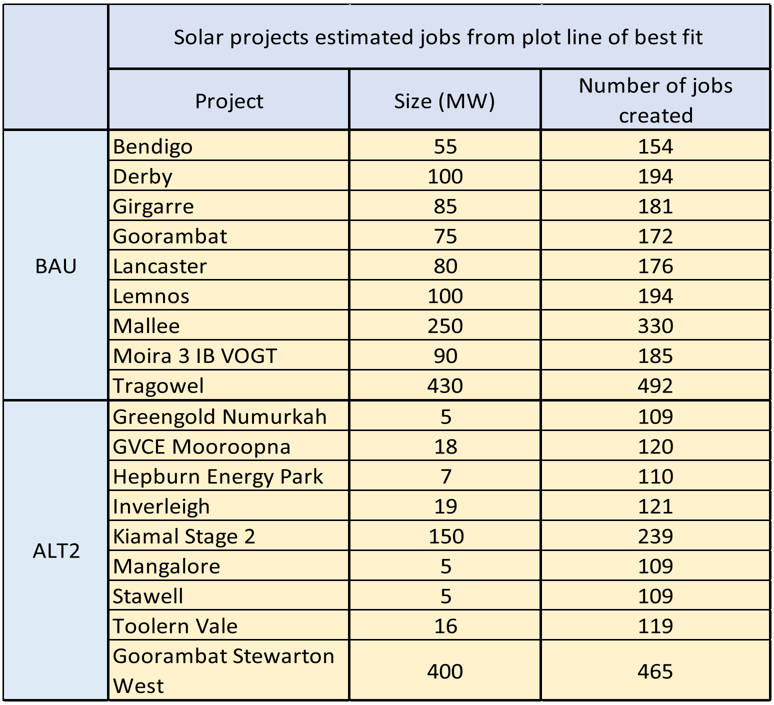


Fig. E.2. Relationship between jobs and project size for wind projects.

The calculated number of jobs for unknown solar projects is shown in Tables E.1 and E.2. When the storage and transmission project jobs were unavailable. When data were available, we estimated a scaled factor for project capacity. The total number of jobs created for each solution and the average annual jobs between 2021 and 2030 are shown in Table E.3. Note that the annual jobs were calculated by dividing the overall jobs by five years. If the projects commence construction in an even distribution between 2021 and 2029, we assume each project's construction period is approximately two years. The final jobs created for each infrastructure type for each proposal are in Table E.3.

Table E.1
Calculated number of jobs for unknown solar projects.



	Solar projects estimated jobs from plot line of best fit		
	Project	Size (MW)	Number of jobs created
BAU	Bendigo	55	154
	Derby	100	194
	Girgarre	85	181
	Goorambat	75	172
	Lancaster	80	176
	Lemnos	100	194
	Mallee	250	330
	Moira 3 IB VOGT	90	185
	Tragowel	430	492
ALT2	Greengold Numurkah	5	109
	GVCE Mooroopna	18	120
	Hepburn Energy Park	7	110
	Inverleigh	19	121
	Kiamal Stage 2	150	239
	Mangalore	5	109
	Stawell	5	109
	Toolern Vale	16	119
	Goorambat Stewarton West	400	465

Table E.2
Calculated number of jobs for unknown solar projects.

	Project estimated jobs from line of best fit		
	Project	Size (MW)	Number of jobs created
BAU	Hawkesdale	107	222
	Ryan Corner	235	286
	Woolsthorpe	72	205
	Jung	8	173
	Diapur	8	173
	Stockyard Hill	532	435
ALT2	Brewster	24	181
	Mount Fyans	400	369
	Wimmera Plains	300	319
	Wombelano	30	184

Table E.3
Employment outcome for each proposal.

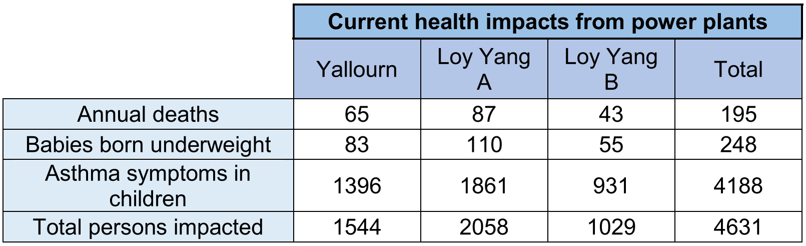
	Number of jobs created		
	BAU	ALT1	ALT2
Solar	7121	7121	10474
Wind	2860	2860	4944
Offshore wind	-	-	3370
Storage	150	535	1018
Transmission	1767	4939	3240
Total	11898	15455	23046
Annual Average	2380	3091	4609

2.5.2. Health

Another measure used to quantify the social outcomes of the energy transition is the physical health impacts of ageing brown coal-fired plants in Victoria. We used information from a report by Dr Henry Jennens addressed to the Environment Protection Agency [2]. Jennens highlighted that there are 195 premature deaths, 248 cases of low birth weight in babies, and 4188 cases of asthma symptoms in young children due to air pollution from coal-fired power plants in Victoria. The statistics above were assumed to be split between Yallourn, Loy Yang A and Loy Yang B depending on GHG emissions, assuming that the health impacts were relative to these emissions. Yallourn, Loy Yang A and Loy Yang B were calculated to emit 15, 20 and 10 million tonnes of CO_2 equivalent annually. Thus these ratios were used to quantify the health impacts in the current year, shown in Table E.4.

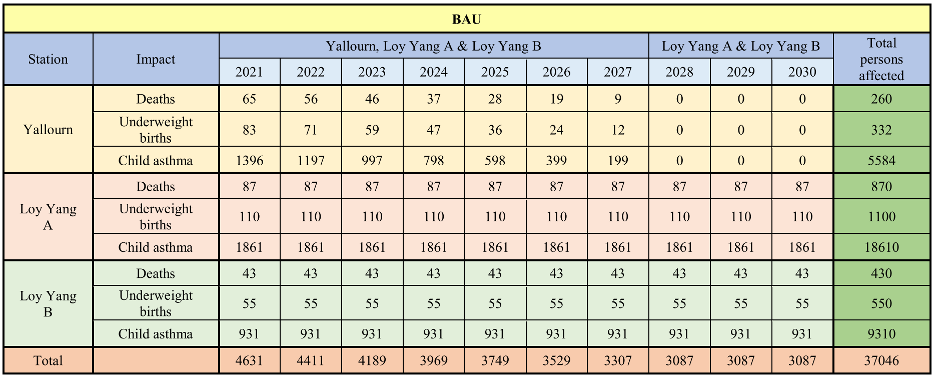
Yallourn will be decommissioned by its owner in 2028. For all three solutions, the impact of Yallourn was linearly reduced between 2021 and 2028. For the BAU solution, Loy Yang A and Loy Yang B were assumed to continue their current GHG emissions until 2030. The health impacts of Loy Yang A and Loy Yang B were linearly reduced from 2021 to 2029 for ALT1 and from 2021 to 2028 for ALT2. The overall estimated physical health outcomes for BAU, ALT1 and ALT2 are shown in Table E.5, Table E.6 and Table E.7, respectively.

Table E.4
Health impact attributed to each power plant (2021).



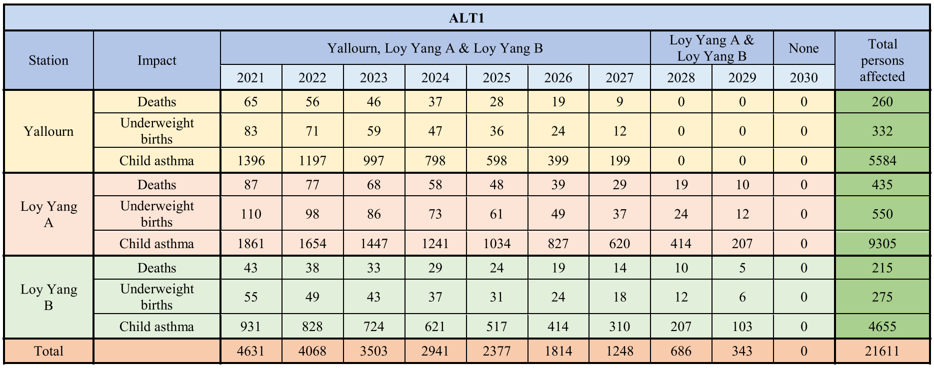
	Current health impacts from power plants			
	Yallourn	Loy Yang A	Loy Yang B	Total
Annual deaths	65	87	43	195
Babies born underweight	83	110	55	248
Asthma symptoms in children	1396	1861	931	4188
Total persons impacted	1544	2058	1029	4631

Table E.5
Total physical health impact of BAU.



BAU												
Station	Impact	Yallourn, Loy Yang A & Loy Yang B							Loy Yang A & Loy Yang B			Total persons affected
		2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	
Yallourn	Deaths	65	56	46	37	28	19	9	0	0	0	260
	Underweight births	83	71	59	47	36	24	12	0	0	0	332
	Child asthma	1396	1197	997	798	598	399	199	0	0	0	5584
Loy Yang A	Deaths	87	87	87	87	87	87	87	87	87	87	870
	Underweight births	110	110	110	110	110	110	110	110	110	110	1100
	Child asthma	1861	1861	1861	1861	1861	1861	1861	1861	1861	1861	18610
Loy Yang B	Deaths	43	43	43	43	43	43	43	43	43	43	430
	Underweight births	55	55	55	55	55	55	55	55	55	55	550
	Child asthma	931	931	931	931	931	931	931	931	931	931	9310
Total		4631	4411	4189	3969	3749	3529	3307	3087	3087	3087	37046

Table E.6
Total physical health impact ALT1.



ALT1												
Station	Impact	Yallourn, Loy Yang A & Loy Yang B							Loy Yang A & Loy Yang B		None	Total persons affected
		2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	
Yallourn	Deaths	65	56	46	37	28	19	9	0	0	0	260
	Underweight births	83	71	59	47	36	24	12	0	0	0	332
	Child asthma	1396	1197	997	798	598	399	199	0	0	0	5584
Loy Yang A	Deaths	87	77	68	58	48	39	29	19	10	0	435
	Underweight births	110	98	86	73	61	49	37	24	12	0	550
	Child asthma	1861	1654	1447	1241	1034	827	620	414	207	0	9305
Loy Yang B	Deaths	43	38	33	29	24	19	14	10	5	0	215
	Underweight births	55	49	43	37	31	24	18	12	6	0	275
	Child asthma	931	828	724	621	517	414	310	207	103	0	4655
Total		4631	4068	3503	2941	2377	1814	1248	686	343	0	21611

Table E.7
Total physical health impact ALT2.

ALT2												
Station	Impact	Yallourn, Loy Yang A & Loy Yang B							Loy Yang	None		Total persons affected
		2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	
Yallourn	Deaths	65	56	46	37	28	19	9	0	0	0	260
	Underweight births	83	71	59	47	36	24	12	0	0	0	332
	Child asthma	1396	1197	997	798	598	399	199	0	0	0	5584
Loy Yang A	Deaths	87	76	65	54	44	33	22	11	0	0	392
	Underweight births	110	96	83	69	55	41	28	14	0	0	495
	Child asthma	1861	1628	1396	1163	931	698	465	233	0	0	8375
Loy Yang B	Deaths	43	38	32	27	22	16	11	5	0	0	194
	Underweight births	55	48	41	34	28	21	14	7	0	0	248
	Child asthma	931	815	698	582	466	349	233	116	0	0	4190
Total		4631	4025	3417	2811	2206	1600	992	386	0	0	20068

2.5.3. *Public satisfaction*

General public satisfaction levels toward renewable infrastructure were measured solely on the approximate number of complaints arising from each proposal. The data for this evaluation was obtained from a report from the Australian wind farm commissioner [11]. The report highlighted the recorded complaints between 2015 and 2019, ranging from topics of project planning processes, construction, and amenity to those of general community engagement, health, and safety. The figures in the report for the whole of Australia were used to calculate an average complaint rate per project, shown in Table E.8.

Table E.8
Total physical health impact of ALT2.

	Actual complaints between November 2015 and December 2019		
	Complaints	number of farms	Approx. complaints per farm
Operating wind farms	70	14	5.0
Proposed wind farms	234	58	4.0
proposed solar farms	6	5	1.2

As seen in Table E.8, the wind farm complaints are divided between ’operating’ wind farms and ’proposed’ wind farms. The complaints per farm ratio were combined to form a resulting ’9.0′ ratio for wind farms. The calculated ratios were multiplied by the number of predicted projects outlined in each proposal. It must be noted that there were several ’other’ complaints in response to unspecified types of projects. Due to this, several other complaints were added to each solution as an average between wind-related and solar-related complaints. The total number of predicted complaints about each solution shows in Table E.9.

Table E.9
Total physical health impact of ALT2.

	Wind			Solar			Other	Total
	Number of proposed wind farms	Estimated complaints per wind farm	Total complaints	Number of proposed solar farms	Estimated complaints per solar farm	Total complaints	Total complaints	
BAU	12	9.0	108	32	1.2	38.4	73.2	219.6
ALT1	12	9.0	108	32	1.2	38.4	73.2	219.6
ALT2	17	9.0	153	50	1.2	60	106.5	319.5

2.6. Economic Cost Metrics

2.6.1. Capital Cost

For most projects in each scenario, the estimated capital cost was derived from information available online, such as information about the project on the company's website or estimates from sources such as AEMO. This method allowed the estimation of a sizable proportion of the proposed projects, which allowed us to find trends in the capital cost of the projects as a MW value. The total capital needed for each solution shows in Table F.1. Since these projects will be beginning over the following ten years, the values were discounted across the timeline between now and 2030 to give an approximate Net Present Cost (NPC) value in 2030. For this report, it was assumed that expenditure is to be evenly distributed across each year, which will supply a reasonable estimate of capital expenditure for comparison between the solutions. The Australian government commonly uses a 7% discount rate in infrastructure projects; therefore, a 7% discount rate was used; however, a sensitivity analysis revealed that any sensible discount rate did not influence the outcome of this metric. The total capital needed for each solution shows in Table F.1.

Table F.1
Total capital needed for each proposed solution.

	BAU ($m)	ALT1 ($m)	ALT2 ($m)
Solar	5549.6	0	2518
Wind	2954.8	0	3480
Offshore Wind	0	0	16588.5
Storage	425.8	2169.55	4383.45
Transmission	4935.0	13435	6069
From BAU	0	8530.63	8530.63
Total Capital Cost	13865.18	24135.18	41569.58

The NPC shows in Table F.2.

Table F.2
Final capital expenditure NPC to be used in nBL analysis.

BAU			ALT 1			ALT 2		
Year	Capital cost ($m)	Present cost ($m)	Year	Capital cost ($m)	Present cost ($m)	Year	Capital cost ($m)	Present cost ($m)
1	1386.52	1295.81	1	2413.52	2255.62	1	4156.96	3885.01
2	1386.52	1211.04	2	2413.52	2108.06	2	4156.96	3630.85
3	1386.52	1131.81	3	2413.52	1970.15	3	4156.96	3393.32
4	1386.52	1057.77	4	2413.52	1841.26	4	4156.96	3171.32
5	1386.52	988.57	5	2413.52	1720.81	5	4156.96	2963.85
6	1386.52	923.90	6	2413.52	1608.23	6	4156.96	2769.96
7	1386.52	863.45	7	2413.52	1503.02	7	4156.96	2588.74
8	1386.52	806.97	8	2413.52	1404.69	8	4156.96	2419.39
9	1386.52	754.17	9	2413.52	1312.79	9	4156.96	2261.11
10	1386.52	704.84	10	2413.52	1226.91	10	4156.96	2113.19
NPC		**9738.32**	**NPC**		**16951.54**	**NPC**		**29196.73**

2.6.2. Annual Operation and Maintenance Cost

The annual operation and maintenance costs for each proposal were gathered through research to approximate the annual O&M costs of the proposed new infrastructure. The methods were:

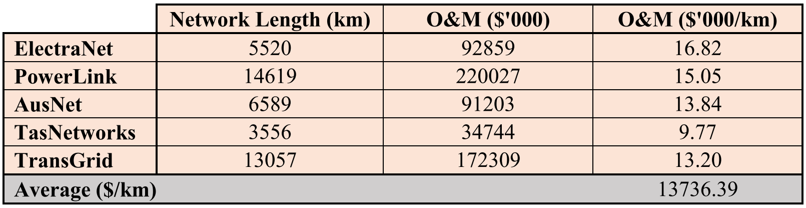
For solar, wind, offshore wind and battery storage, O&M costs were gathered from a report prepared by Aurecon for AEMO, which uses Aurecon's internal database of projects, recent bid information from EPC (Energy Performance Contract) competitive tendering processes as well as industry publications and publicly available data to generate approximate costs for a range of energy generation infrastructure.

The operational costs of coal were first estimated through analysis of AGLs annual reports. While no exact figure was stated, all costs associated with coal were analysed; however, they included all AGLs coal mines (black and brown coal). Estimates from this data revealed a range of $30–$45 MWh. However, it is known that brown coal is much cheaper than black coal. In 2017 the marginal cost of generating power from an existing black coal-fired station was $40 MWh, with brown coal-fired power even cheaper. Therefore, the generation cost for Victorian brown coal-fired power was estimated to be $30 MWh.

For ALT1, as coal is phased out, the gap formed between demand and generation is to be filled by interstate imports. The cost of these imports was estimated from historical data available on OpenNEM's generation statistics. Due to the large variation in the cost of imports year to year, an approximate median value of $120 MWh was chosen.

The annual OPEX of different Australian TNSPs and their network length were used to find a $/km value for the operational cost of the additional transmission infrastructure required. This information was gathered from the AEMO annual benchmarking report [3] and shown in Table F.3.

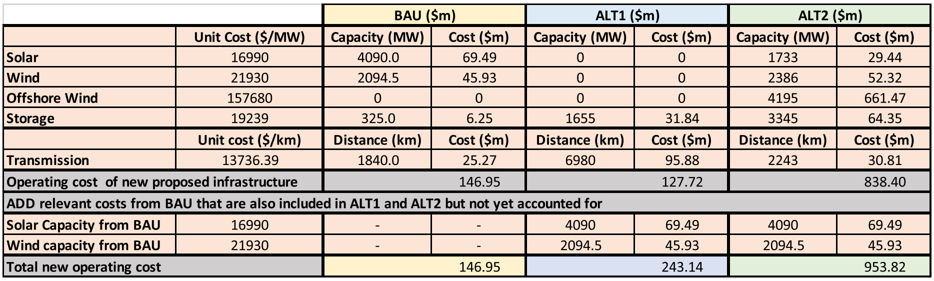
Table F.3
Transmission network OPEX determination [12].



	Network Length (km)	O&M ($'000)	O&M ($'000/km)
ElectraNet	5520	92859	16.82
PowerLink	14619	220027	15.05
AusNet	6589	91203	13.84
TasNetworks	3556	34744	9.77
TransGrid	13057	172309	13.20
Average ($/km)			13736.39

A summary of the new operational costs from the proposed projects in 2030 is shown in Table F.4.

Table F.4
Additional infrastructure O&M costs in 2030 [12].



		BAU ($m)		ALT1 ($m)		ALT2 ($m)	
	Unit Cost ($/MW)	**Capacity (MW)**	**Cost ($m)**	**Capacity (MW)**	**Cost ($m)**	**Capacity (MW)**	**Cost ($m)**
Solar	16990	4090.0	69.49	0	0	1733	29.44
Wind	21930	2094.5	45.93	0	0	2386	52.32
Offshore Wind	157680	0	0	0	0	4195	661.47
Storage	19239	325.0	6.25	1655	31.84	3345	64.35
	Unit cost ($/km)	**Distance (km)**	**Cost ($m)**	**Distance (km)**	**Cost ($m)**	**Distance (km)**	**Cost ($m)**
Transmission	13736.39	1840.0	25.27	6980	95.88	2243	30.81
Operating cost of new proposed infrastructure			146.95		127.72		838.40
ADD relevant costs from BAU that are also included in ALT1 and ALT2 but not yet accounted for							
Solar Capacity from BAU	16990	-	-	4090	69.49	4090	69.49
Wind capacity from BAU	21930	-	-	2094.5	45.93	2094.5	45.93
Total new operating cost			146.95		243.14		953.82

Tables F.5–F.7 detail the yearly changes in O&M costs for all three solutions, followed by the NPC calculation in Table F.8, again using a 7% discount rate.

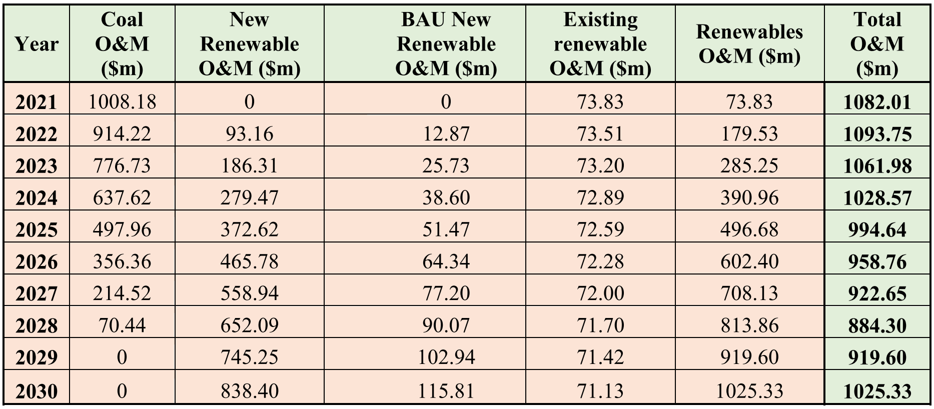
Table F.5
BAU O&M costs each year.

Year	Coal O&M ($m)	New Renewable O&M ($m)	Existing renewable O&M ($m)	Renewables O&M ($m)	Total O&M ($m)
2021	1046.98	0	73.83	73.83	**1120.81**
2022	992.38	16.3	73.51	89.81	**1082.18**
2023	937.34	32.6	73.20	105.80	**1043.14**
2024	881.33	48.9	72.89	121.79	**1003.11**
2025	825.09	65.2	72.59	137.79	**962.88**
2026	767.66	81.5	72.28	153.78	**921.44**
2027	710.23	97.8	72.00	169.80	**880.02**
2028	651.39	114.1	71.70	185.80	**837.18**
2029	592.75	130.4	71.42	201.82	**794.57**
2030	532.50	147	71.13	218.13	**750.63**

Table F.6
ALT1 O&M costs each year.

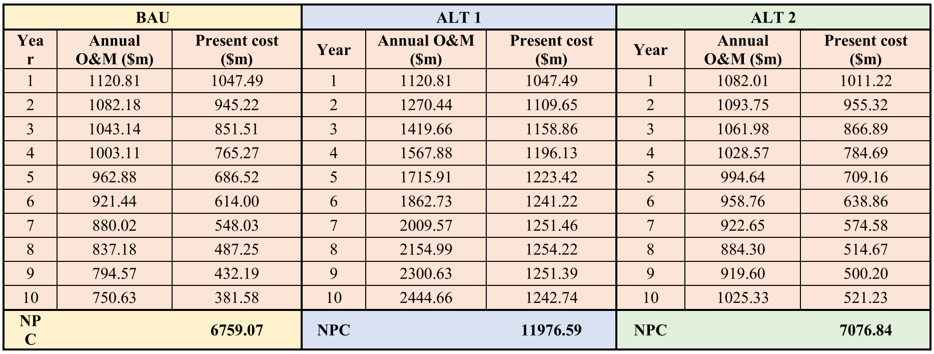
Year	Coal O&M ($m)	New Renewable O&M ($m)	BAU new Renewable O&M ($m)	Existing renewable O&M ($m)	Renewables O&M ($m)	Import Costs ($m)	Total O&M ($m)
2021	1046.98	0	0	73.83	73.83	0.00	**1120.81**
2022	933.21	14.19	12.87	73.51	100.56	236.67	**1270.44**
2023	819.01	28.38	25.73	73.20	127.32	473.34	**1419.66**
2024	703.82	42.57	38.60	72.89	154.06	710.00	**1567.88**
2025	588.42	56.76	51.47	72.59	180.82	946.67	**1715.91**
2026	471.83	70.95	64.34	72.28	207.57	1183.34	**1862.73**
2027	355.23	85.14	77.20	72.00	234.34	1420.01	**2009.57**
2028	237.22	99.33	90.07	71.70	261.10	1656.67	**2154.99**
2029	119.42	113.52	102.94	71.42	287.87	1893.34	**2300.63**
2030	0.00	127.72	115.81	71.13	314.65	2130.01	**2444.66**

Table F.7
ALT2 O&M costs each year.



Year	Coal O&M ($m)	New Renewable O&M ($m)	BAU New Renewable O&M ($m)	Existing renewable O&M ($m)	Renewables O&M ($m)	Total O&M ($m)
2021	1008.18	0	0	73.83	73.83	**1082.01**
2022	914.22	93.16	12.87	73.51	179.53	**1093.75**
2023	776.73	186.31	25.73	73.20	285.25	**1061.98**
2024	637.62	279.47	38.60	72.89	390.96	**1028.57**
2025	497.96	372.62	51.47	72.59	496.68	**994.64**
2026	356.36	465.78	64.34	72.28	602.40	**958.76**
2027	214.52	558.94	77.20	72.00	708.13	**922.65**
2028	70.44	652.09	90.07	71.70	813.86	**884.30**
2029	0	745.25	102.94	71.42	919.60	**919.60**
2030	0	838.40	115.81	71.13	1025.33	**1025.33**

Table F.8
Final O&M NPC to be used in nBL analysis.

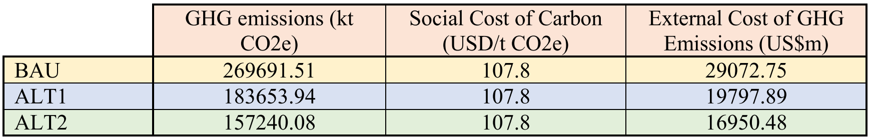


BAU			**ALT 1**			**ALT 2**		
Year	**Annual O&M ($m)**	**Present cost ($m)**	**Year**	**Annual O&M ($m)**	**Present cost ($m)**	**Year**	**Annual O&M ($m)**	**Present cost ($m)**
1	1120.81	1047.49	1	1120.81	1047.49	1	1082.01	1011.22
2	1082.18	945.22	2	1270.44	1109.65	2	1093.75	955.32
3	1043.14	851.51	3	1419.66	1158.86	3	1061.98	866.89
4	1003.11	765.27	4	1567.88	1196.13	4	1028.57	784.69
5	962.88	686.52	5	1715.91	1223.42	5	994.64	709.16
6	921.44	614.00	6	1862.73	1241.22	6	958.76	638.86
7	880.02	548.03	7	2009.57	1251.46	7	922.65	574.58
8	837.18	487.25	8	2154.99	1254.22	8	884.30	514.67
9	794.57	432.19	9	2300.63	1251.39	9	919.60	500.20
10	750.63	381.58	10	2444.66	1242.74	10	1025.33	521.23
NPC		**6759.07**	**NPC**		**11976.59**	**NPC**		**7076.84**

2.6.3. External Costs of GHG Emissions

The social cost of carbon (SCC) was used to evaluate the external economic costs of GHG emissions resulting from each proposal [13]. Hardisty found that there was significant variability in estimates of the SCC, with estimates ranging from US$5.5-500/t CO_2e. The BAU estimate was adopted as US$85/t CO_2e. This value was estimated in 2009, with multiple other estimations stating that this value should be increased by 2% per annum. Therefore, for 2021 the value will be US$107.8/t CO_2e—the external costs of GHG are shown in Table F.9.

Table F.9
Final external cost of GHG emissions to be used in nBL analysis.



	GHG emissions (kt CO2e)	Social Cost of Carbon (USD/t CO2e)	External Cost of GHG Emissions (US$m)
BAU	269691.51	107.8	29072.75
ALT1	183653.94	107.8	19797.89
ALT2	157240.08	107.8	16950.48

2.7. Environmental Metric

2.7.1. GHG Emissions

Each proposal's greenhouse Gas Emission (GHG) was calculated from production rates against the intended infrastructure required to fund projects for each solution. A constant CO_2 equivalent per kWh was sourced for implementing solar, wind (onshore/offshore), storage and transmission infrastructure. The costs of phasing out coal generation must be included in our analysis. The deceleration of coal generation was made for each solution progressively until 2030 when the analysis is to take place. Carbon emissions from coal generation are about 1000 g CO_2 eq/kWh [14]. The energy produced was reflected for each solution, with alternative one (ALT1) having a faster rate of phasing out coal generation than the business as usual and alternative two (ALT2) being at an even more rapid rate. Table G.1 shows the overall energy generation and the GHG emissions linked to each solution.

Table G.1
CO_2 emissions from coal generation.

	BAU	ALT1	ALT2
Year	Coal (GWh)	Coal (GWh)	Coal (GWh)
2021	34899.31	34899.31	33605.91
2022	33079.27	31107.04	30473.86
2023	31244.65	27300.19	25891.00
2024	29377.52	23460.83	21253.99
2025	27502.96	19614.04	16598.52
2026	25588.73	15727.58	11878.71
2027	23674.24	11840.86	7150.64
2028	21712.92	7907.31	2348.01
2029	19758.50	3980.66	0
2030	17750.08	0	0
Total (GWh)	264588.17	175837.81	149200.63
Total CO2e (t)	264588168.80	175837813.60	149200632

Renewable infrastructure and consequent storage and transmission systems were introduced steadily until net-zero emissions were reached in 2030 in the analysis. The expansion rate depended on the infrastructure needed to meet each planned solution.

The National Renewable Energy Laboratory [15] deemed GHG Emissions throughout the life cycle of solar photovoltaics to be about 40 g CO_2 eq/kWh, quantified against the proposed solar projects for each solution. The results of these calculations show in Table G.2.

Table G.2
CO_2 emissions from solar panels.

	BAU	ALT1	ALT2
Year	Solar (GWh)	Solar (GWh)	Solar (GWh)
2021	1849.77	1849.77	2294.58
2022	2913.88	2913.88	3809.56
2023	3981.56	3981.56	5329.64
2024	5070.75	5070.75	6880.33
2025	6156.35	6156.35	8425.92
2026	7270.61	7270.61	10012.31
2027	8374.12	8374.12	11583.40
2028	9513.47	9513.47	13205.51
2029	10634.90	10634.90	14802.10
2030	11799.32	11799.32	16459.91
Total (GWh)	67564.72	67564.72	92803.26
Total CO2e (t)	2702588.60	2702588.60	3712130.42

The GHG emissions produced throughout the life cycle of onshore and offshore wind turbines were found to have rates of about 15 g CO_2 eq/kWh and about 12 g CO_2 eq/kWh, and Table G.3 details the results [14]. These are shown in Table G.3.

Table G.3
CO_2 emissions from wind turbines.

	BAU	ALT1	ALT2	ALT2
Year	Wind (GWh)	Wind (GWh)	Wind (GWh)	Offshore Wind (GWh)
2021	7156.92	7156.92	8005.52	0
2022	7912.85	7912.85	9622.58	0
2023	8679.79	8679.79	11263.20	1422.16
2024	9457.74	9457.74	12927.36	2844.32
2025	10246.69	10246.69	14615.08	4266.48
2026	11046.66	11046.66	16326.34	5688.64
2027	11857.63	11857.63	18061.16	7110.80
2028	12679.62	12679.62	19819.52	8532.96
2029	13512.61	13512.61	21601.43	9955.12
2030	14356.61	14356.61	23406.89	11377.24
Total (GWh)	106907.12	106907.12	155649.09	51197.72
Total CO2e (t)	1603606.74	1603606.74	2334736.32	614372.67

For the utility-scale lithium-ion batteries intended to be installed to store the energy captured from renewables, the power the storage systems enable needs to be converted into the energy they can distribute over time. The average discharge duration per day is 1.7 h for battery storage systems, but we can see figures reaching up to 4 h and will be used to capture the full potential of CO_2 emissions. The carbon intensity for implementing batteries systems for storing electricity is about 100 g CO_2 eq/kWh, and the results are presented in Table G.4

Table G.4
CO_2 emissions from utility-scale batteries.

BAU (MW)	BAU (MWh)	ALT1	ALT1 (MWh)	ALT2	ALT2 (MWh)
300	438000	300	438000	300	438000
20	29200	5	7300	5	7300
5	7300	450	657000	450	657000
		350	511000	350	511000
		350	511000	350	511000
		200	292000	200	292000
				600	876000
				300	438000
				240	350400
				200	292000
				350	511000
Total (MWh)	474500		2416300		4883700
Total CO2e (t)	47450		241630		488370

Nature Sustainability addresses embodied GHG emissions for power transmission units, which are directly applied to planned projects for each scenario based on typical projects from 2017. Table G.5 outlines projected lines that would need to be built, their length in kilometres and corresponding electric potential emissions.

The overall GHG emissions for each solution are the sum of each scenario's energy resources GHG until the planned net-zero dates of 2030.

Table G.5
CO_2 emissions from transmission.

BAU			
kV	km	t CO2e/km	Total CO2e (t)
220	95	280	26600
500	85	490	41650
500	440	490	215600
500	605	490	296450
300	605	280	169400
TOTAL			749700
ALT 1			
kV	km	t CO2e/km	Total CO2e (t)
500	340	490	166600
500	1800	490	882000
500	3000	490	1470000
220	95	280	26600
500	85	490	41650
500	440	490	215600
500	605	490	296450
TOTAL			3268300
ALT 2			
kV	km	t CO2e/km	Total CO2e (t)
220	230	280	64400
220	43	280	12040
500	130	490	63700
220	95	280	26600
500	85	490	41650
500	440	490	215600
500	605	490	296450
300	605	280	169400
TOTAL			889840

The best-case scenarios for all potential solutions are shown in Table G.6. The highlighted figures in Table G.6 were used to standardise the analysis. The best-case scenario is immediately ceasing coal generation using the BAU approach, and the worst-case scenario has coal generation continuing at current rates until 2030 using the BAU approach.

Table G.6
GHG emissions best- and worst-case scenarios.

Units kt CO2e	Best	Worst
BAU	**5103.35**	**270221.98**
ALT 1	7816.13	184184.41
ALT 2	8039.45	157770.55

2.7.2. Pollutants

GHG Emissions are a key part of pollutants and damage the planet's health, but a life cycle assessment must be assessed against standard industry life span. While we have current technology to manufacture such renewable infrastructure, the de-manufacturing processes are not in place to appropriately recycle infrastructure at the end of its useful life. Therefore, an analysis of the infrastructure capacity to power the energy system over its useful life will be reflected. Energy System capacities for the three scenarios show in Table G.7. These values were then used to quantify and justify the useful life capacity for each scenario.

Table G.7
Energy systems.

Units: MW	Solar	Onshore wind	Offshore wind	Storage	Transmission	Total (MW)
BAU	4090	2094.5	0	325	5300	11809.5
ALT 1	4090	2094.5	0	1655	10964	18803.5
ALT 2	1722	2386	4195	3345	9700	21348

Renewable resources' useful life was determined for solar (photovoltaics) and wind turbines as 25 and 20 years [14]. Utility-scale batteries for grid connection useful life were deemed nine years, presented at the 2017 American Control Conference [16]. The transmission lines to transport the given electricity have a useful life of 60 years.

The useful life was then quantified against each energy system's capacity and presented in Table G.8.

Table G.8
Useful life capacity over useful life.

Units MW Y	Solar	Onshore wind	Offshore wind	Storage	Transmission	Total (MW Y)
BAU	102250	41890	0	2925	318000	465065
ALT 1	102250	41890	0	14895	657840	816875
ALT 2	43050	47720	83900	30105	582000	786775

The best- and worst-case scenarios for Pollutants because of useful life from LCA are shown in Table G.9. In the best-case scenario, renewables and transmission lines have a 60-year useful life. A worst-case scenario was that utility-scale batteries might have a life as short as nine years.

Table G.9
Pollutants best- and worst-case scenarios.

Units MW Y	Best	Worst
BAU	708570	106285.5
ALT 1	1128210	169231.5
ALT 2	1280880	192132

2.7.3. *Materials*

2.7.3.1. Initial Assessment. Energy System capacities for the three scenarios show in Table G.10.

Table G.10
Energy systems.

Units: MW	Solar	Onshore wind	Offshore wind	Storage	Transmission
BAU	4090	2094.5	0	325	5300
ALT 1	4090	2094.5	0	1655	10964
ALT 2	1722	2386	4195	3345	9700

Table G.11
Relative importance of minerals for clean energy technology types.

Material Scale 1-3	Solar	Onshore Wind	Offshore Wind	Storage	Transmission	Avg.
Copper	3	3	3	3	3	3
Nickel	1	2	2	3	1	1.8
Manganese	1	3	3	3	1	2.2
Cobalt	1	1	1	3	1	1.4
Chromium	1	2	2	1	1	1.4
Molybdenum	1	2	2	1	1	1.4
Zinc	1	3	3	1	1	1.8
Rare earth	1	3	3	3	1	2.2
Silicon	1	1	1	1	1	1
Others	1	1	1	1	1	1
Lithium	1	1	1	3	1	1.4

The capacities in Table G.10 were then used to quantify and justify material usage for each solution and are shown in Table G.11. Firstly, appropriate identification of the link between materials required for a given infrastructure and how critical they are about dependence and scarcity was made. We developed from the importance scale by the International Energy Agency [17], with a scale from 1-3 (3 most important) given and outlined in Table G.11. From this, a relative conclusion of which materials were considered critical in the analysis. Silicon and “Other” minerals were omitted from the analysis.

2.7.3.2. Clean Energy. International Energy Agency data [17] was used to find minerals used in clean energy technologies, which were then directly associated with clean infrastructure planned to determine an appropriate assessment on measuring materials for each case. A clear comparison between other power generation sources shows in Table G.12.

Table G.12
Minerals used in clean energy technologies compared to other power generation sources.

kg/MW	Offshore wind	Onshore wind	Solar	Nuclear	Coal	Natural gas
Copper	8000	2900	2822.1	1473	1150	1100
Nickel	240	403.5	1.3	1297.4	721.04	15.75
Manganese	790	780	0	147.69	4.63	0
Cobalt	0	0	0	0	201.46	1.8
Chromium	525	470	0	2190	307.5	48.34
Molybdenum	109	99	0	70.8	66.25	0
Zinc	5500	5500	29.99	0	0	0
Rare earth	239	14	0	0.5	0	0
Silicon	0	0	3948.3	0	0	0
Others	6	0	31.95	94.28	33.9	0

Densities for each critical mineral were used to determine the overall intended requirements for each scenario, as shown in Table G.13.

Table G.13
Critical clean energy minerals.

Units: kg	BAU	ALT 1	ALT 2
Copper	17616439	17616439	45339056
Nickel	850447.8	850447.8	1971790
Manganese	1633710	1633710	5175130
Chromium	984415	984415	3323795
Molybdenum	207355.5	207355.5	693469
Zinc	11642409	11642409	36247143
Rare earth	29323	29323	1036009
Silicon	16148547	16148547	6798973
Others	130675.5	130675.5	80187.9

The best-case scenarios for Clean Energy are shown in Table G.14. The best-case scenario is no new projects, and the worst-case scenario has 50% more projects going ahead than anticipated.

Table G.14
Clean energy best- and worst-case scenarios.

Units kg	Best	Worst
BAU	0	49446149.03
ALT 1	0	49446149.03
ALT 2	0	**140679587.40**

2.7.3.3. Storage Systems. kWh ratings for battery storage systems were determined from capacities and addressed from planned projects. The alternative solutions' proposed systems used four-hour discharge rates daily to determine energy rating [18]. Therefore, storage for each scenario is shown in Table G.15.

Table G.15
Storage energy ratings.

Units: kWh	Storage
BAU	491500
ALT 1	5557500
ALT 2	10137500

While specific battery products, such as the Tesla Megapack intended to be installed in Moorabool, could not be explicitly broken down. Lithium-ion is used in most storage systems, and analysts show no move away from the technology anytime soon. Therefore, an assessment will be made assuming a single-car lithium-ion battery contains 9 kg of Lithium, 35 kg of Nickel, 20 kg of Manganese and 14 kg of Cobalt [18]

Lithium-ion batteries are expected to have the critical materials shown in Table G.16.

Table G.16
Storage materials [19].

Units: kg	Lithium	Nickel	Manganese	Cobalt
BAU	8170.39	35745.45	20425.97	14298.18
ALT 1	92384.42	404181.81	230961.04	161672.70
ALT 2	168519.48	737272.73	421298.70	294909.10

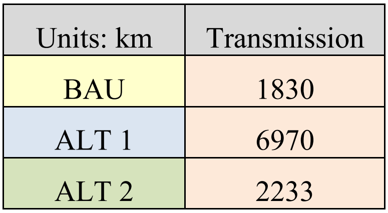
The best-case scenarios for Storage Systems are shown in Table G.17. The best-case scenario is no new projects, and the worst-case scenario has 50% more projects going ahead than anticipated.

Table G.17
Storage systems best- and worst-case scenarios.

Units kg	Best	Worst
BAU	0	117960
ALT 1	0	1333800
ALT 2	0	2433000

2.7.3.4. Transmission Systems. The transmission analysis assessed the length of lines for each scenario and is shown in Table G.18.

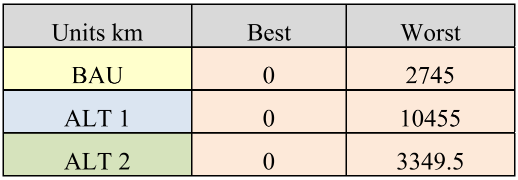
Table G.18
Storage distance.



Units: km	Transmission
BAU	1830
ALT 1	6970
ALT 2	2233

The best-case scenarios for Transition Systems are shown in Table G.19. The best-case scenario is no new projects, and the worst-case scenario has 50% more projects going ahead than anticipated.

Table G.19
Transmission systems best- and worst-case scenarios.



Units km	Best	Worst
BAU	0	2745
ALT 1	0	10455
ALT 2	0	3349.5

2.7.3.5. Third-level Analysis. As each energy system is not transparent in comparing the material used, a third-level analysis was conducted. To do this, we broke the analysis into Clean Energy, Storage Systems and Transmission Systems. The weighting between all three metrics in the third-level analysis was equal, as generation, transmission and distribution of electricity are all vital in coordinating a functional power system.

Third-level results with best-case justifications presented to normalise results are shown in Table G.20.

Table G.20
Material third-level analysis.

	Data			Best		Worst		Normalised		
Metric	**BAU**	**ALT1**	**ALT2**	**Value**	**Evidence**	**Value**	**Evidence**	**BAU**	**ALT1**	**ALT2**
Clean Energy Material (kg)	32964099	32964099	93786392	0	No new projects to go ahead	140679587.4	50% more projects go ahead than anticipated (ALT 2)	0.77	0.77	0.33
Storage (kg)	78640	889200	1622000	0	No new projects to go ahead	2433000	50% more projects go ahead than anticipated (ALT 2)	0.97	0.63	0.33
Transmission (km)	1830	6970	2233	0	No new projects to go ahead	10455	50% more projects go ahead than anticipated (ALT 1)	0.83	0.33	0.79

Further, aggregations for each scenario to be input into the second-level metrics results to standardise results are shown in Table G.21.

Table G.21
Aggregation from weightings.

	Aggregation	Weighting
BAU	0.28	0.33
ALT1	0.19	0.33
ALT2	0.16	0.33

2.7.3.6. Final Assessment. The best-case scenarios for materials were based on the highest aggregation (best – 1) and lowest aggregation (worst - 0) for normalising the material's second-level metric.

2.8. Conclusion to the Experimental Design, Materials, and Methods

Quantitative assessment takes place in n-bottom line (nBL) analysis. Application of the nBL framework enables comparative analysis by selecting objective metrics which characterise and reflect individual bottom lines (e.g., environmental, social, economic) [1]. Therefore, each proposal is analysed across identical metrics, supplying a pathway to comparatively assess the results. The nBL assessment process was applied to Victoria's three energy transition scenarios for the four bottom lines: social, economic, environmental, and technical performance. The following section will display the nBL process applied to each bottom line. BAU, ALT1 and ALT2 proposals are compared by first quantifying the performance of each metric and then by calculating the overall value of each bottom line. The analysis will use forecasts for 2030, considering data from 2021 to 2030.

The metrics for each of the four bottom lines were used to undertake an nBL analysis across the three scenarios. The following three sub-sections outline the methods adopted to select and quantify each metric. The metrics are technical performance, social, economic cost and environmental.

2.8.1. Technical Performance

The literature guided our selection of metrics to describe the energy system's technical performance. This research assessed losses associated with converting potential energy to electricity and transmission losses. Next, utility-scale storage capacity was measured based on the projects unique to the three scenarios. Finally, data transparency between relevant grid operators and stakeholders was measured. Methods adopted to calculate second-level metrics for each technical performance, along with any assumptions and justifications, are shown in Section D.

2.8.2. Social

The literature suggests that employment outcomes are central to the social measure of transitions. Our method used ten years of annual average construction and permanent operational jobs for each new project (Section E).

We also estimated health effects over ten years and considered the plan to close Yallourn Power Station in 2028. This health measure included annual deaths, underweight births, and childhood asthma attributed to brown coal [2,20]. People impacted by the emissions from these power plants were assumed to be distributed between the three coal plants and assessed yearly (Section E)

As a proxy measure for customer engagement between DBs and energy customers, we measure public complaints about renewable projects (Section E).

2.8.3. Economic Cost

Capital costs are a major roadblock to the rapid uptake of renewables, with key decision-makers hesitant to invest too heavily too quickly [9].

Externality costs are another significant factor in this cost analysis. The value of the world's biosphere is US$33 trillion, and the external cost of GHG emissions has been estimated to cost society anywhere from $5.5/tCO$_2$e up to $500/tCO$_2$e [13]. Section F shows our calculations for:

- Capital cost.
- Operation and maintenance (O&M) cost.
- External costs due to GHG emissions.

2.8.4. Environmental

The energy transition uses resources [21]. Managing how the materials for renewable energy infrastructure are sourced, processed, manufactured, constructed, and disposed of is a vital consideration for sustainability. Hence, projects for each scenario were evaluated for their environmental impact.

Section G shows the steps of our method and the assumptions made.

2.8.5. Application of nBL Assessment

Once the raw metric values of each bottom line were compiled, the nBL assessment was applied, which meant a process of normalising, standardising, and aggregating the data into a final score.

Raw values (RV) are normalised to remove units and allow for comparing different metrics. The normalisation process delivers an index between 0 and 1 by incorporating a theoretical best value (BV) and worst value (WV), as shown in Eq. (6).

$$\text{Normalised Value (NV)} = \frac{RV - WV}{BV - WV} \tag{6}$$

Standardising each metric involves finding the inverse of each average result and standardising these inversed values. Hence, the sum of all metrics about a unique bottom line equals 1. The values were found from the standardised weighting value for each metric.

The next step involves an additive aggregation method using Eq. (7).

$$\text{Aggregated Indicator (AI)} = \frac{1}{k} * \sum_{i}^{n} W * NV \tag{7}$$

- k = the number of datasets (i.e., the number of second-level metrics) of each metric
- W = relative weight of importance of each metric found in the standardisation process.

The three steps associated with the nBL assessment framework are repeated to obtain aggregated values for the bottom lines for the three scenarios. Hence, applying the nBL process will return a single numerical value for each scenario.

Ethics Statements

Ethical controls do not cover this data for humans, animals, or social media. All data was publicly available.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data in Brief article Dataset for the Victorian energy transition including technical, social, economic and environmental detail. (Reference data) (figshare).

CRediT Author Statement

Glen Currie: Conceptualization, Methodology, Writing – review & editing; **Riley Cousins:** Data curation, Writing – original draft; **Alexander Diplaris:** Data curation, Writing – original draft; **Sebastian Drimer:** Data curation, Writing – original draft; **Matthew Foley:** Data curation, Writing – original draft.

Acknowledgments

This research received no specific grant from public, commercial, or not-for-profit funding agencies.

References

[1] G. Foliente, A. Kearns, S. Maheepala, X. Bai, & G. Barnett (2007). Beyond triple bottom line–sustainable cities RD&D at CSIRO. Retrieved 5 Jan 2022 from https://www.researchgate.net/publication/254970926_Beyond_Triple_Bottom_Line_-_Sustainable_Cities_RDD_at_CSIRO.

[2] D.H. Jennens (2021). Air pollution inquiry- healthy futures submission. https://www.parliament.vic.gov.au/images/stories/committees/SCEP/Air_Pollution/Submissions/070_2021.04.22_-_Healthy_Futures.pdf.

[3] AURECON. (2019). Cost and technical parameter review. Retrieved 5 July 2022 from https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/Inputs-Assumptions-Methodologies/2019/Aurecon-2019-Cost-and-Technical-Parameters-Review-Draft-Report.PDF.

[4] AEMOElectricity Statement of Opportunities, AEMO, 2019 https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/NEM_ESOO/2019/2019-Electricity-Statement-of-Opportunities.pdf.

[5] B.K. Kazi, Catalytic Gasification and Assessment of Dimethyl Ether Synthesis from Victorian Brown Coal, Monash University, 2014.

[6] Australian_Water_Association. (2012). Hydroelectricity factsheet. Retrieved 5 July 2022 from https://www.awa.asn.au/Documents/Hydro-Fact-Sheet-An-Overview-of-Hydroelectricity-in-Australia.pdf.

[7] M.P. Bahrman, Overview of HVDC transmission, in: Proceedings of the IEEE PES Power Systems Conference and Exposition, 2006.

[8] AEMO. (2022). AMEO infrastructure map. Retrieved 5 July 2022 from https://www.aemo.com.au/aemo/apps/visualisations/map.html.

[9] G. Currie, Australia's Energy Transition, Springer, 2020, doi:10.1007/978-981-15-6145-0.
[10] R. Brazier, E. De Luca, P. de Wit, H. Eklund, C. Gimeno, S. Herbretau, K. Zawadska, Smart Grid Key Performance Indicators. A DSO Perspective, Cedec, EDSO, Geode, Eurelectric, 2020 Retrieved 5 Jan 2022 from https://cdn.eurelectric.org/media/5272/smart_grid_key_performance_indicators__a_dso_perspective-2021-030-0129-01-e-h-B85F16BF.pdf.
[11] Australian_Energy_Infrastructure_Commissioner. (2019). Annual report by the office of the national wind farm commissioner. Retrieved 5 July 2022 from https://www.aeic.gov.au/publications/2019-annual-report.
[12] AER. (2020). Annual benchmarking report. australian government. Retrieved 5 July 2022 from https://www.aer.gov.au/networks-pipelines/guidelines-schemes-models-reviews/annual-benchmarking-reports-2020.
[13] P.E. Hardisty, Environmental and Economic Sustainability, CRC Press, 2010, doi:10.1201/EBK1420059489.
[14] R.C. Thomson, G.P. Harrison, J.P. Chick, Marginal greenhouse gas emissions displacement of wind power in Great Britain, Energy Policy 101 (2017) 201–210, doi:10.1016/j.enpol.2016.11.012.
[15] NRELLife Cycle Assessment Harmonization, US Government, 2022 Retrieved 5 July 2022 from https://www.nrel.gov/analysis/life-cycle-assessment.html.
[16] K. Smith, A. Saxon, M. Keyser, B. Lundstrom, Z. Cao, A. Roc, Life prediction model for grid-connected Li-ion battery energy storage system, in: Proceedings of the American Control Conference (ACC), 2017, pp. 4062–4068, doi:10.23919/ACC.2017.7963578.
[17] International_Energy_Agency, The role of critical minerals in clean energy transitions, IEA (2021) Retrieved 5 Dec 2021 from https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions.
[18] US_Department_of_Energy. (2019). Solar plus storage 101. Retrieved 5 July 2022 from https://www.energy.gov/eere/solar/articles/solar-plus-storage-101.
[19] D. Castelvecchi, Electric cars: the battery challenge, Nature 596 (7872) (2021) 336–339.
[20] T. Flannery, F. Stanley, L. Hanna, Climate council: joint statement of the health effects of coal in Australia, Clim. Counc. (2014) Retrieved 5 Jan 2022 from https://www.climatecouncil.org.au/resources/health-effects-of-coal/.
[21] J. Watson, L. Sonter, & R.K. Valenta (2020, August 2). Renewable energy can save the natural world – but if we're not careful, it will also hurt it. Retrieved 5 Dec 2021 from https://theconversation.com/renewable-energy-can-save-the-natural-world-but-if-were-not-careful-it-will-also-hurt-it-145166.