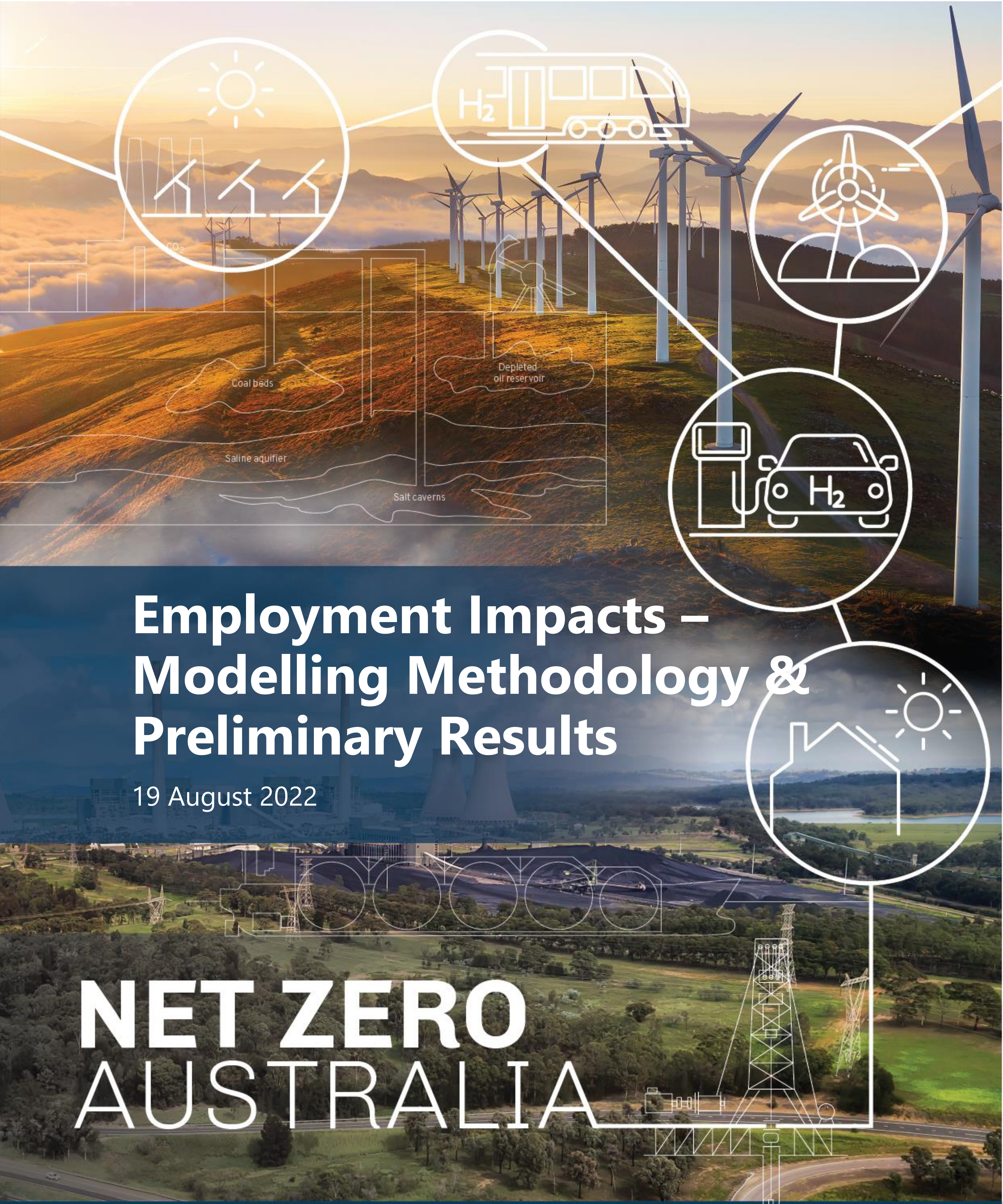

Employment Impacts – Modelling Methodology & Preliminary Results

19 August 2022

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 identifies plausible 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, by 2050.

Employment Impacts – Modelling Methodology & Preliminary Results

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Contents

1 Introduction

A net-zero energy system transition requires profound changes for the sector's labour market. These impacts will vary over time and by region. Existing studies into the employment impacts of decarbonisation in the Australian context tend to focus on domestic energy supply (Climate Council, 2016), specific technologies (Wood et al., 2020; Dean, 2022), medium-term time horizons or on gross job creation (Rutovitz et al. 2020). These constraints may underestimate the scale of workforce transformation required to achieve net zero greenhouse gas emissions in Australia.

The present study seeks to address this gap by assessing direct job creation and associated impacts on occupations, and required education and skills within the energy sector throughout the net-zero energy system transition. This transition includes many different technologies relevant to both the domestic and export energy sectors from 2020 to 2060. Results are fully disaggregated by state geography and will be further disaggregated to more local regions in future work.

2 Conceptual model structure & scope of analysis

The model used in this study is based on the Decarbonization Employment and Energy Systems (DEERS) model developed by Mayfield et al. (2021). This framework is applied to Australia, which enables the estimation of impacts on labour throughout the decarbonisation scenarios modelled in the *Net Zero Australia* project through to 2060. It simulates the labour impacts over time for all energy system technologies and resources modelled in the transition across lifecycle stages outlined below. It also models the impact on employment by occupation, education and skill requirements for both domestic and export sectors by state. The model also incorporates labour productivity as a time-varying factor to account for improvements that will be experienced particularly in emerging technologies as we decarbonise. The DEERS model is structured to produce outputs necessary to inform infrastructure and workforce planning and policymaking in support of transitioning an energy sector to net zero over long temporal horizons (Mayfield et al., 2021).

All technologies and resources included in the employment model, as well as their primary energy activity processes are defined in Table 1 below.

Table 1 | All modelled technologies/resources and their primary energy activities.

Technology/resource	Energy activity process(es)
Aluminium production	Production (i.e., refining alumina and aluminium smelting).
Autothermal reforming	Hydrogen production.
Batteries	Storage (i.e., electricity storage of variable duration (1 – 48 hours)).
Biofuels	Feedstock conversion to biofuels (i.e., conversion of biomass to SNG/H2).
Biomass	Production (i.e., of biomass materials, including crop stubble, native grasses, pulpwood, bagasse and organic municipal solid waste).
Carbon dioxide (CO2) storage	Storage (i.e., CO2 sequestration of emissions captured using carbon capture and storage (CCS)).
CO2 transmission	Transmission (i.e., transport of captured CO2 for sequestration via pipeline).
Coal	Electricity generation (i.e., through combustion of coal) and extraction (i.e., coal mining).
Direct air capture	Operation (i.e., capture of CO2 from the atmosphere for transmission and sequestration).

Technology/resource	Energy activity process(es)
Electricity distribution	Distribution (i.e., operation of low voltage electricity distribution systems, including lines, poles, meters and wiring that deliver electricity to final consumers (ABS, 2006)).
Electricity export	Electricity transmission (i.e., from utility solar for the purposes of export via undersea cable to Southeast Asia).
Electricity transmission	Transmission (i.e., operation of high voltage electricity transmission systems including lines and transformer stations (ABS, 2006)).
Electrolysis	Hydrogen production.
Fischer-Tropsch	Synthetic fuel production.
Haber-Bosch	Ammonia production.
Hydroelectricity (Hydro)	Electricity generation.
Hydrogen storage	Storage (i.e., large-scale underground storage in salt caverns).
Hydrogen transmission	Transmission (i.e., transport of hydrogen for storage or conversion via pipeline).
Direct reduced iron production (Iron DRI)	Production (i.e., refining of iron ore into sponge iron).
Liquified natural gas (LNG)	LNG production (i.e., liquid fuel produced by the liquefication of petroleum gases (ABS, 2006)).
Methanation	Synthetic fuel production.
Natural gas	Electricity generation (i.e., through combustion of natural gas) and extraction of natural gas.
Natural gas transmission	Transmission (i.e., transport of pipeline gas to mid-stream fuel conversion)
Offshore wind	Electricity generation.
Oil refinery	Refining heavy and light component crude oil, manufacturing and/or blending materials into petroleum fuels (ABS, 2006).
Onshore wind	Electricity generation.
Pumped hydroelectric storage (PHES)	Storage (i.e., electricity storage of variable duration (1 – 48 hours)).
Rooftop solar	Electricity generation.
Steam Methane Reforming (SMR)	Hydrogen production.
Utility solar	Electricity generation.

Employment impacts of energy activity within these technology and resource categories are modelled discretely across the following lifecycle stages:

- **Manufacturing (M)** – these jobs encompass the activities required to produce a unit of power generation (e.g., the manufacturing of solar panels or towers for wind turbines), energy storage or production capacity. Manufacturing employment constitutes temporary employment in the context of the technical lifetime of the relevant equipment. Jobs may employ domestic or offshore labour. Adjustments have been made to account for the current capacity of Australian manufacturing, noting that this may change in future. Manufacturing jobs are then derived from annual capacity additions to the energy sector in a given year.
- **Construction and installation (C&I)** – these jobs encompass the activities required to build a unit of power generation, energy storage or production capacity. Like manufacturing, C&I jobs are temporary

employment, but unlike manufacturing all C&I jobs are necessarily onshore. However, whether the roles are filled by local workers or a transient workforce is determined by local capacity and capabilities needed to deliver large-scale energy system construction. C&I jobs are also derived from annual capacity additions to the energy sector over time.

- **Production (P)** – these jobs encompass primary production, including the extraction of fossil fuels, the production of biomass, as well as the production of aluminium and direct reduced iron. They are expressed in terms of jobs per petajoule or kilotonne.
- **Operations and maintenance (O&M)** – these jobs encompass the ongoing activities required to ensure the plant functions throughout its technical lifetime. Compared with manufacturing and C&I, O&M jobs occur over a longer time horizon and are typically presented as jobs per unit capacity of energy generated, stored, or converted. Like C&I jobs, these are local roles. They are derived from the cumulative operating capacity of the energy sector.
- **Decommissioning (D)** – these jobs encompass the work activities generated by the end of a plant's operational lifetime, including dismantling, recycling and rehabilitation of land. While decommissioning jobs can occur over varying time horizons depending on the technology (Ram et al., 2022), they are modelled in a similar way to C&I jobs, being derived from annualised early and end-of-life retirements from the energy sector in a given year.

Lifecycle stages are modelled for each technology and resource based on suitability, substitutability, and the availability of EFs. For some technologies and resources, a given lifecycle stage may not be suitable; for example, as CO2 storage utilises geological formations, there is no associated manufacturing EF. Furthermore, decommissioning jobs may not be modelled where there are no retirements modelled for a given technology, such as aluminium production. Substitution occurs when operational jobs involved in processes of feedstock conversion, such as biofuel, electrolysis or Haber-Bosch plants are counted towards the O&M lifecycle stage rather than production, as calculations occur against nameplate capacity rather than quantified output. Finally, some technology lifecycle stages lack available EFs, such as manufacturing for iron DRI or natural gas transmission. All modelled energy sector technologies, resources and lifecycle stages covered in the employment model are summarised in Table 2 below.

Table 2 | Coverage of lifecycle stages by modelled energy sector technology/resource.

Technology/resource	M	C&I	P	O&M	D
Aluminium production		✓	✓		
Autothermal reforming	✓	✓		✓	✓
Batteries	✓	✓		✓	✓
Biofuels	✓	✓		✓	✓
Biomass	✓	✓	✓	✓	✓
CO_2 storage				✓	
CO_2 transmission		✓		✓	
Coal	✓	✓	✓	✓	✓
Direct air capture	✓	✓		✓	✓
Electricity distribution				✓	
Electricity export		✓		✓	
Electricity transmission				✓	
Electrolysis	✓	✓		✓	✓
Fischer-Tropsch	✓	✓		✓	✓
Haber-Bosch	✓	✓		✓	✓
Hydroelectricity	✓	✓		✓	✓

Technology/resource	M	C&I	P	O&M	D
Hydrogen storage		✓		✓	
Hydrogen transmission		✓		✓	
Iron DRI		✓	✓		
LNG	✓	✓		✓	✓
Methanation	✓	✓		✓	✓
Natural gas	✓	✓	✓	✓	✓
Natural gas transmission		✓		✓	
Offshore wind	✓	✓		✓	✓
Oil refinery	✓	✓		✓	✓
Onshore wind	✓	✓		✓	✓
PHES	✓	✓		✓	✓
Rooftop solar	✓	✓		✓	✓
SMR	✓	✓		✓	✓
Utility solar	✓	✓		✓	✓

The distribution of labour impacts is modelled by state from 2020 to 2060, disaggregated by the domestic and export sector, and across multiple industries, including agriculture, mining, manufacturing, construction, electricity generation and transport. The DEERS model focuses on direct job creation within sectors relevant to the energy supply, being those associated with primary activity such as extraction or electricity generation, and mid- or downstream activities within the value chain such as fuel conversion. It does not include induced jobs, i.e. those created from the economic activity generated by the spending of direct job income. It also does not include the labour impacts from the transition to net zero that are associated with energy efficiency, appliances, vehicles, transport and downstream industrial processes, such as cement or steel manufacturing.

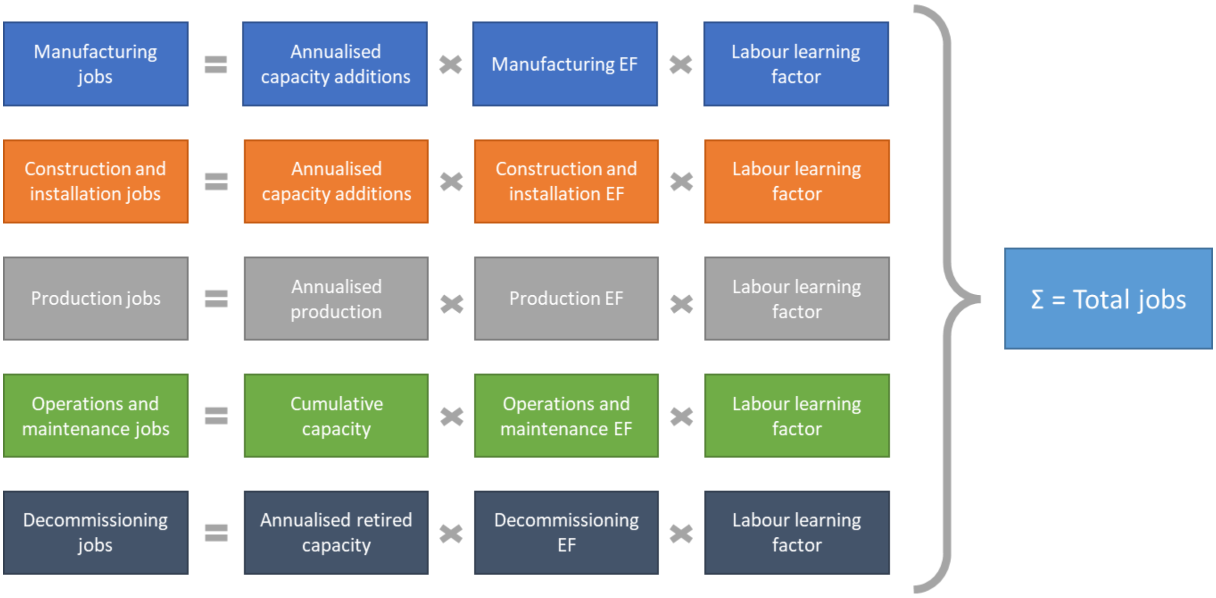
When describing employment outcomes, this study uses the metric *job*, which describe full-time equivalent jobs required over a single year, rather than jobs sustained over multiple years. Alternatively, job-years is used as a time-weighted metric to describe cumulative employment that occurs over longer time horizons (Mayfield et al., 2021).

3 Modelling

3.1 Employment model specification

Gross job creation during the decarbonisation of the energy sector is estimated using equations that relate energy activity outputs by technology/resource from energy system modelling and lifecycle stage with an Employment Factor (EF) and a labour learning factor, as shown in Figure 1. The sum of jobs across each modelled lifecycle stage outlined in Table 2 then provides total employment for a given technology/resource.

Figure 1 | Overview of total employment calculation. Adapted from Rutovitz et al. (2015)



3.2 Energy activity data

A primary input into the employment model is energy activity by technology/resource, lifecycle stage, spatial unit and year. All energy activity data used to assess employment impacts are provided by *Net Zero Australia*'s (NZAu) macro-scale energy system modelling, and specifically, the Regional Investments & Operations (RIO) modelling tool. This data reports cumulative generation, storage and conversion capacity, capacity additions, capacity retirements, production and extraction, and generated electricity in quinquennial increments. All energy activity data by technology/resource and lifecycle stage is detailed below in Figure 3 and Figure 4. Furthermore, RIO modelling incorporates 15 domestic regions, shown in Figure 2, each with its own energy service demand, initial stock of energy infrastructure and resources (NZAu, 2022), as well as additional regions within each state that are designated to produce energy exports. CAPEX and OPEX are reported for each region and technology/resource in annual increments. These inputs have been further aggregated, annualised and converted where relevant in order to inform employment modelling as outlined in Table 3.

Modelling occurs across six core Scenarios: a Reference Scenario with no emissions constraint, and six Scenarios with a net zero emissions constraint, as summarised in Table 4. Further information regarding each scenario is available in the *Net Zero Australia* Methods, Assumptions, Scenarios & Sensitivities document (NZAu, 2022).

Table 3 | Overview of how *Net Zero Australia* energy activity data is used to calculate employment.

Energy activity data	Stages	How it is used
Changes in installed capacity	M, C&I, D	Data distinguishes between new installations, end-of-life retirements and premature retirements; new installations are used to calculate manufacturing and C&I employment, while all retirements are combined to calculate decommissioning employment. Data is reported quinquennially and is annualised to ensure jobs are reported for a given year. As aluminium and iron DRI production is reported as a displacement of energy required to meet the export constraint outlined in the *Net Zero Australia* Methods, Assumptions, Scenarios & Sensitivities, these units are converted from GW to kilotonnes using the displacement formula described in NZAu, 2022. Whether energy activity supports the export or domestic sector is determined by the region where the technology is installed. Note: One tonne of aluminium displaces 107.7 GJ of exported energy. One tonne of iron DRI displaces 11.66 GJ of exported energy.
Cumulative installed capacity	O&M	Units for DAC are converted from kilotonne/hour to annual kilotonnes of CO2. Whether energy activity supports the export or domestic sector is determined by the region where the technology is installed.
Energy production and flows within and between modelled regions	P, O&M	Data is mainly used to calculate production employment, and O&M employment for electricity distribution and transmission. Units for biomass, coal and natural gas are converted from gigawatt hours to petajoules. Aluminium and iron DRI production is converted from gigawatt hours to kilotonnes per the above. Total electricity generated is used for electricity generation and transmission. Whether natural gas meets domestic or export demand is determined by the national proportion of extracted gas consumed by the domestic market for each scenario and modelled year. For all other commodities, this is determined by the region to which a given commodity flows, rather than the region from which it originates.
Expenditure	C&I, O&M	Data is used for the C&I stages of CO2 storage, CO2 transmission, electricity export, hydrogen transmission, natural gas transmission, and the O&M stages of CO2 transmission, hydrogen transmission and natural gas transmission. Stage is determined by cost type, which enable the attribution of expenditure to CAPEX and OPEX, the former of which is used to calculate C&I employment and the latter for O&M employment. All units converted to million $AUD. Whether energy activity supports the export or domestic sector is determined by the region where the technology is installed.

Figure 2 | Modelled domestic and export regions with NZAu's macro-energy system model.

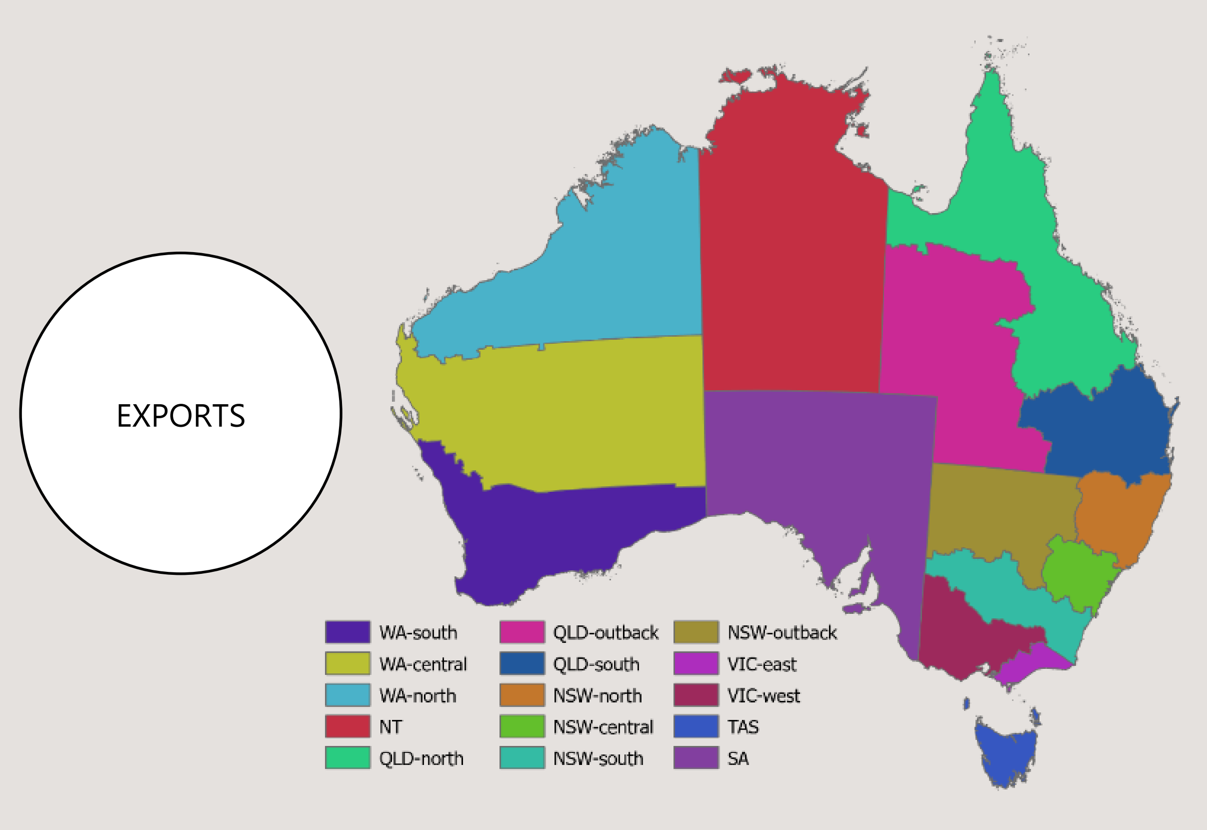
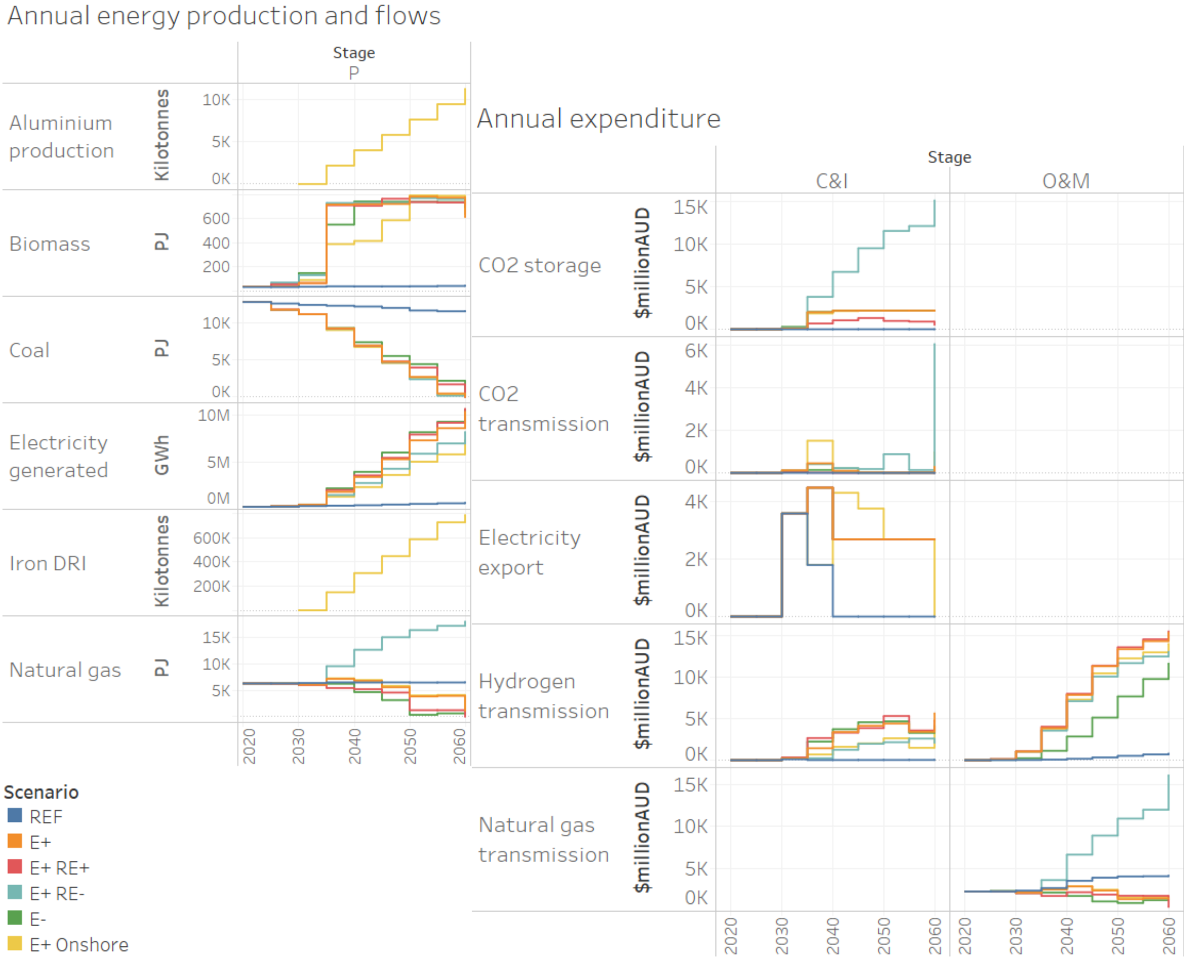


Table 4 | Modelled scenario names and descriptions (NZAu, 2022).

Scenario name	Description
REF	Reference.
E+	Rapid electrification.
E−	Slower electrification.
E+ RE+	Rapid electrification with 100% primary energy from renewables.
E+ RE−	Rapid electrification with the build rate of renewables constrained above historically high levels and the CCS constraint also increased.
E+ Onshoring	Rapid electrification with imposed local production of iron and aluminium for export.

Figure 3 | Energy activity data for changes in installed capacity and cumulative installed capacity of various technologies/resources, by year and scenario for both domestic and export sectors. Positive changes in installed capacity are used for Manufacturing (M) and Construction and installation (C&I) employment lifecycle stages, while negative changes are used for Decommissioning (D) jobs. Cumulative installed capacity data are used for the operations and maintenance (O&M) employment stage.

Figure 4 | Energy activity data for energy production and expenditure by technology/resource and scenario for both domestic and export sectors. Production activity data are used for the Production (P) employment lifecycle stage, and capital expenditure data are used for the Construction and installation (C&I) stage, while operating & maintenance expenditure are used for the O&M employment lifecycle stage.



3.3 Employment Factors

An employment factor (EF) is a measure of average job creation associated with a unit of energy activity, such as the addition of a renewable/storage plant, generation of an amount of electricity or hydrogen, or operation and maintenance of an electricity or gas grid. Each technology/resource and corresponding lifecycle stage has a distinct EF according to their employment intensity, as summarised in Table 5.

In the literature, researchers derive EFs in three ways: by surveying industry professionals, by calculation based on available employment and energy activity data, from the existing literature, or through a combination of these approaches. While the first two approaches are superior within a geographic area, they are more dependent on data availability. For example, the current Australian and New Zealand Standard Industrial Classification (ANZSIC) scheme does not disaggregate employment in electricity generation by renewable technology, instead grouping generation from solar, wind, biomass, geothermal etc. as 'Other Electricity Generation'. Furthermore, employment in early lifecycle stages such as manufacturing and construction is accounted for in other aggregated ANZSIC codes such as 'Other Heavy and Civil Engineering Construction', with no direct connection between these jobs and the energy activities they support.

ABS policies on data suppression to prevent the identification of individuals also affects the availability and reliability of high-resolution time-series data disaggregated by state, industry and occupation (ABS, 2021a). While this data is available for national censuses, the periodic nature of this dataset is a barrier to understanding changes in the rapidly evolving energy sector. For similar reasons, calculating EFs is also difficult for emerging technologies that are yet to be deployed at scale, such as hydrogen electrolysis.

This study therefore primarily relies on surveying EFs from the existing literature, with particular use of those reported by Rutovitz et al. (2020), who utilised both industry surveys and historical data to calculate EFs for the Australian context.

Table 5 presents the EFs used in the present study for each modelled technology/resource by employment lifecycle stage and energy activity basis. Each lifecycle stage has been matched with a relevant ANZSIC code based on description and primary activities (ABS, 2006), which is used for occupation modelling. ANZSIC uses an alphanumeric hierarchy to distinguish between levels of increasing specificity. In the below example, the Electricity, Gas, Water and Waste Services industry is denoted by the character D. The 'Electricity Supply' subdivision is denoted by the number 26, the 'Electricity Generation' group by the number 261, and the 'Fossil Fuel Generation' class by the number 2611.

Level	Example			
Division	D Electricity, Gas, Water and Waste Services			
Subdivision		26 Electricity Supply		
Group			261 Electricity Generation	
Class				2611 Fossil Fuel Generation
				2612 Hydro-Electric Generation
				2619 Other Electricity Generation

In general, the lowest level ANZSIC code has been attributed to the relevant energy activity. In some cases, classes are aggregate categories, such as 2619 Other Electricity Generation which comprises generation from wind, solar, geothermal, and other renewable plants. This highlights the challenge of matching ANZSIC codes for emerging technologies, as the typology reflects current industrial activities and imperfectly matches with emerging technologies. This is a trade-off against using higher level ANZSIC codes that include industrial activities that are clearly misaligned, for example by using 261 Electricity Generation for both fossil fuel and renewable generating technologies. An overview of each ANZSIC code used, including the level and industry can be found in Table 5 and Table 6.

Table 5 | All EFs by technology/resource, including units, sources, ANZSIC code and energy activity basis by lifecycle stage.

Technology/resource	EF	EF unit	Stage	Source	ANZSIC	Energy activity basis
Aluminium production	**0.579***	job-yrs/kilotonnes	C&I	[1]	3109	Annualised production capacity additions
Aluminium production	**2.15***	jobs/kilotonnes	P	[1]	213	Annualised aluminium produced
Autothermal reforming	**170**	job-yrs/GW	M	[2, 3]	249	Annualised conversion capacity additions
Autothermal reforming	**330**	job-yrs/GW	C&I	[2, 3]	3109	Annualised conversion capacity additions
Autothermal reforming	**110**	jobs/GW	O&M	[2, 3]	1811	Cumulative conversion capacity
Autothermal reforming	**330**	job-yrs/GW	D	[2, 3]	3212	Annualised conversion capacity removed
Battery	**331**	job-yrs/GW	M	[4]	243	Annualised storage capacity additions
Battery	**4700**	job-yrs/GW	C&I	[4]	3109	Annualised storage capacity additions
Battery	**1200**	jobs/GW	O&M	[4]	2619	Cumulative storage capacity
Battery	**800**	job-yrs/GW	D	[5]	3212	Annualised storage capacity removed
Biofuels	**2900**	job-yrs/GW	M	[7]	243	Annualised conversion capacity additions
Biofuels	**14000**	job-yrs/GW	C&I	[7]	3109	Annualised conversion capacity additions
Biofuels	**280**	jobs/GW	O&M	[7]	2619	Cumulative conversion capacity
Biofuels	**320**	job-yrs/GW	D	[7]	3212	Annualised conversion capacity removed
Biomass	**2900**	job-yrs/GW	M	[7]	243	Annualised generation capacity additions
Biomass	**14000**	job-yrs/GW	C&I	[7]	3109	Annualised generation capacity additions
Biomass	**29.9**	jobs/PJ	P	[7]	1	Annualised dry biomass produced
Biomass	**280**	jobs/GW	O&M	[7]	2619	Cumulative generation capacity
Biomass	**320**	job-yrs/GW	D	[7]	3212	Annualised generation capacity removed
CO_2 storage	**1.67***	job-yrs/$millionAUD	O&M	[6]	3212	Annualised OPEX spend
CO_2 transmission	**7.46***	job-yrs/$millionAUD	C&I	[6]	3109	Annualised CAPEX spend
CO_2 transmission	**3.31***	jobs/$millionAUD	O&M	[6]	5021	Annualised OPEX spend
Coal	**5400**	job-yrs/GW	M	[7]	243	Annualised generation capacity additions
Coal	**11200**	job-yrs/GW	C&I	[7]	3109	Annualised generation capacity additions
Coal	**3.24***	jobs/PJ	P	[1]	6	Annualised coal extracted
Coal	**140**	jobs/GW	O&M	[7]	2611	Cumulative generation capacity
Coal	**1650**	job-yrs/GW	D	[7]	3212	Annualised generation capacity removed
Direct air capture	**0.09**	job-yrs/kilotonnes	M	[8, 9]	249	Annualised extraction capacity additions
Direct air capture	**1**	job-yrs/kilotonnes	C&I	[8, 9]	3109	Annualised extraction capacity additions
Direct air capture	**0.1**	jobs/kilotonnes	O&M	[8, 9]	9429	Cumulative extraction capacity
Direct air capture	**0.2**	job-yrs/kilotonnes	D	[8, 9]	3212	Annualised extraction capacity removed
Electricity distribution	**0.10***	jobs/GWh	O&M	[1]	263	Annual electricity generated
Electricity export	**3.45***	job-yrs/$millionAUD	C&I	[6]	3109	Annualised CAPEX spend
Electricity export	**440***	jobs/GW	O&M	[6]	262	Cumulative generation capacity
Electricity transmission	**0.01***	jobs/GWh	O&M	[1]	2620	Annual electricity generated
Electrolysis	**218***	job-yrs/GW	M	[1]	249	Annualised conversion capacity additions
Electrolysis	**1300**	job-yrs/GW	C&I	[10]	3109	Annualised conversion capacity additions
Electrolysis	**120**	jobs/GW	O&M	[10]	1811	Cumulative conversion capacity
Electrolysis	**210**	job-yrs/GW	D	[10]	3212	Annualised conversion capacity removed
Fischer-Tropsch	**940**	job-yrs/GW	M	[11]	249	Annualised conversion capacity additions
Fischer-Tropsch	**2180**	job-yrs/GW	C&I	[11]	3109	Annualised conversion capacity additions
Fischer-Tropsch	**170**	jobs/GW	O&M	[11]	1831	Cumulative conversion capacity
Fischer-Tropsch	**870**	job-yrs/GW	D	[11]	3212	Annualised conversion capacity removed
Haber-Bosch	**170***	job-yrs/GW	M	[2, 3]	249	Annualised conversion additions
Haber-Bosch	**330***	job-yrs/GW	C&I	[2, 3]	3109	Annualised conversion additions
Haber-Bosch	**110***	jobs/GW	O&M	[2, 3]	1831	Cumulative conversion capacity
Haber-Bosch	**40***	job-yrs/GW	D	[2, 3]	3212	Annualised conversion capacity removed
Hydro	**699**	job-yrs/GW	M	[4]	243	Annualised generation capacity additions
Hydro	**7400**	job-yrs/GW	C&I	[4]	3109	Annualised generation capacity additions
Hydro	**140**	jobs/GW	O&M	[4]	2612	Cumulative generation capacity
Hydro	**2220**	job-yrs/GW	D	[7]	3212	Annualised generation capacity removed
Hydrogen storage	**30**	job-yrs/GWh	C&I	[16]	3212	Annualised storage capacity additions
Hydrogen storage	**2**	jobs/GW	O&M	[16]	3212	Cumulative storage capacity
Hydrogen transmission	**7.46***	job-yrs/$millionAUD	C&I	[6]	3109	Annualised CAPEX spend
Hydrogen transmission	**3.31***	jobs/$millionAUD	O&M	[6]	5021	Annualised OPEX spend
Iron DRI	**0.58***	job-yrs/kilotonnes	C&I	[1]	3109	Annualised production capacity additions
Iron DRI	**0.09***	jobs/kilotonnes	P	[1]	211	Annualised DRI produced
LNG	**170**	job-yrs/GW	M	[2]	249	Annualised conversion capacity additions
LNG	**330**	job-yrs/GW	C&I	[2]	3109	Annualised conversion capacity additions
LNG	**5**	jobs/GW	O&M	[2]	1701	Cumulative conversion capacity

Technology/resource	EF	EF unit	Stage	Source	ANZSIC	Energy activity basis
LNG	**330**	job-yrs/GW	D	[2]	3212	Annualised conversion capacity removed
Methanation	**570**	job-yrs/GW	M	[12]	249	Annualised conversion capacity additions
Methanation	**190**	job-yrs/GW	C&I	[12]	3109	Annualised conversion capacity additions
Methanation	**130**	jobs/GW	O&M	[12]	1811	Cumulative conversion capacity
Methanation	**210**	job-yrs/GW	D	[12]	3212	Annualised conversion capacity removed
Natural gas	**930**	job-yrs/GW	M	[7]	243	Annualised generation capacity additions
Natural gas	**1300**	job-yrs/GW	C&I	[7]	3109	Annualised generation capacity additions
Natural gas	**3.14***	jobs/PJ	P	[1]	7	Annualised natural gas extracted
Natural gas	**140**	jobs/GW	O&M	[7]	2611	Cumulative generation capacity
Natural gas	**210**	job-yrs/GW	D	[7]	3212	Annualised generation capacity removed
Natural gas transmission	**7.46***	job-yrs/$millionAUD	C&I	[6]	3109	Annualised CAPEX spend
Natural gas transmission	**3.31***	jobs/$millionAUD	O&M	[1]	5021	Annualised OPEX spend
Offshore wind	**377***	job-yrs/GW	M	[4]	243	Annualised generation capacity additions
Offshore wind	**1280**	job-yrs/GW	C&I	[13]	3109	Annualised generation capacity additions
Offshore wind	**140**	jobs/GW	O&M	[13]	2619	Cumulative generation capacity
Offshore wind	**580**	job-yrs/GW	D	[13]	3212	Annualised generation capacity removed
Oil refinery	**870**	job-yrs/GW	M	[2]	249	Annualised conversion capacity additions
Oil refinery	**1650**	job-yrs/GW	C&I	[2]	3109	Annualised conversion capacity additions
Oil refinery	**20**	jobs/GW	O&M	[2]	1701	Cumulative conversion capacity

Note: EFs marked with a * have been calculated based on historical data, derived from similar technologies, or have undergone unit conversion, as detailed below in Table 7. EF sources are as follows:

[1] Own calculation from historical data. See below.

[2] National Renewable Energy Laboratory (NREL), 2016.

[3] International Energy Agency Greenhouse Gas R&D Programme (IEAGHG), 2017.

[4] Rutovitz et al., 2020.

[5] United States Department of Energy, 2017.

[6] Mayfield et al., 2021.

[7] Rutovitz et al., 2015.

[8] Keith et al., 2018.

[9] Peters, 2018.

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Table 6 | ANZSIC codes, levels and industries used to determine occupation projection.

ANZSIC	Level	Industry
01	Subdivision	Agriculture
06	Subdivision	Coal Mining
07	Subdivision	Oil and Gas Extraction
213	Group	Basic Non-Ferrous Metal Manufacturing
243	Group	Electrical Equipment Manufacturing
249	Group	Other Machinery and Equipment Manufacturing
1701	Class	Petroleum Refining and Petroleum Fuel Manufacturing
1811	Class	Industrial Gas Manufacturing
1831	Class	Fertiliser Manufacturing
2110	Class	Iron Smelting and Steel Manufacturing

ANZSIC	Level	Industry
2611	Class	Fossil Fuel Electricity Generation
2612	Class	Hydro-Electricity Generation
2619	Class	Other Electricity Generation
2620	Class	Electricity Transmission
2630	Class	Electricity Distribution
3109	Class	Other Heavy and Civil Engineering Construction
3212	Class	Site Preparation Services
5021	Class	Pipeline Transport
9429	Class	Other Machinery and Equipment Repair and Maintenance

3.3.1 EF derivations and calculations

As noted in Table 5, while most EFs have been sourced directly from key references, some have been adjusted to align with the units of the *Net Zero Australia* energy activity data, while others have been derived from similar technologies or calculated based on recent employment and energy activity data. All calculations, unit conversions and derivations of EFs are detailed in Table 7.

Where EFs have been calculated using historical employment data, this has been sourced from the *ABS Jobs in Australia, 2011-12 to 2018-19* report (2021) for the ANZSIC classes outlined in Table 6. Energy activity and fossil fuel extraction data has been sourced from the Department of Industry, Science, Energy and Resources' *Resources and Energy Quarterly* (2019) and *Australian Energy Update* (2020) reports. Currency conversions from USD to AUD have used the average exchange rate at year-end published by the Australian Taxation Office (ATO, 2021).

Table 7 | Summary of all EFs that have been derived from similar technologies, calculated from historical data or undergone unit conversion.

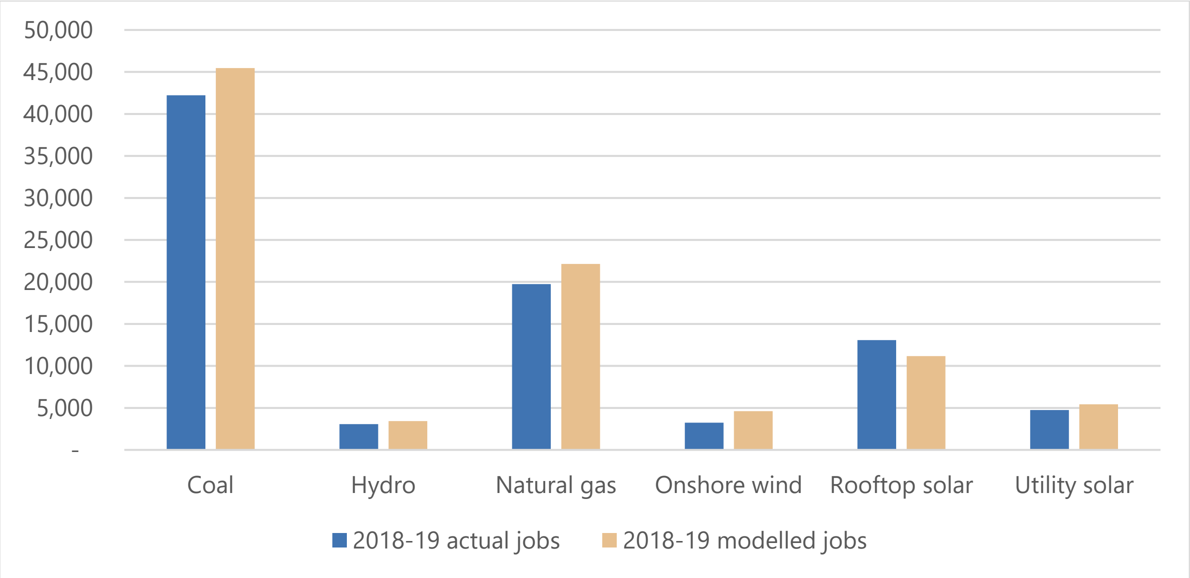
Technology/resource	Stage(s)	Derivation	Notes
Alumina refining	P	Calculated from historical data	Alumina refining EF calculated as the average of EFs over 2016-2020: $EF_{(jobs/kilotonne)} = \Sigma\,(jobs / production_{(kilotonnes)}) / n$
Aluminium production	C&I	Derived from similar technology	From iron DRI production EF.
Aluminium production	P	Calculated from historical data	EF is the sum of alumina refining and aluminium smelting EFs: $EF_{(jobs/kilotonne)} = \Sigma\,(EF\_alumina + EF\_aluminium)$
Aluminium smelting	P	Calculated from historical data	Aluminium smelting EF calculated as the average of EFs over 2016-2020: $EF_{(jobs/kilotonne)} = \Sigma\,(jobs / production_{(kilotonnes)}) / n$
Autothermal reforming	All	Derived from similar technology	From steam methane reforming EFs in Ram et al. (2022).
Coal	P	Calculated from historical data	$EF_{(jobs/PJ)}$ = extraction jobs / total $production_{(PJ)}$
CO_2 storage	C&I	Unit conversion	From CO_2 injection EFs from Mayfield et al. (2021): $EF_{(jobs/\$millionAUD)} = EF_{(jobs/\$millionUSD)} \times$ exchange rate
CO_2 transmission	C&I	Unit conversion	From CO_2 transmission EFs from Mayfield et al. (2021): $EF_{(jobs/\$millionAUD)} = EF_{(jobs/\$millionUSD)} \times$ exchange rate
CO_2 transmission	O&M	Unit conversion	From CO_2 transmission EF from Mayfield et al. (2021): $EF_{(jobs/\$millionAUD)} = EF_{(jobs/\$millionUSD)} \times$ exchange rate
Electrolysis	M	Adjusted to Australian context	From Ram et al. (2022), multiplied by 0.2 to adjust for Australian manufacturing capacity per Rutovitz et al. (2020).
Electricity distribution	O&M	Calculated from historical data	$EF_{(jobs/GWh)}$ = distribution jobs / electricity $generated_{(GWh)}$
Electricity export	C&I	Calculated from historical data	From electricity transmission EF from Mayfield et al. (2021): $EF_{(jobs/\$millionAUD)} = EF_{(jobs/\$millionUSD)} \times$ exchange rate
Electricity export	O&M	Derived from similar technology	From electricity transmission EF from Mayfield et al. (2021).
Electricity transmission	O&M	Calculated from historical data	$EF_{(jobs/GWh)}$ = transmission jobs / electricity $generated_{(GWh)}$

Technology/resource	Stage(s)	Derivation	Notes
Haber-Bosch	All	Derived from similar technology	From steam methane reforming EFs in Ram et al. (2022).
Hydrogen transmission	All	Derived from similar technology	From CO_2 transmission EFs from Mayfield et al. (2021). See above for unit conversions.
Iron DRI	C&I	Calculated from historical data	Based on 2020 construction of Toledo Direct Reduction Plant (Cleveland-Cliffs, 2022): $EF_{(jobs/kilotonnes)}$ = construction jobs / nameplate $capacity_{(kilotonnes)}$
Iron DRI	P	Derived from similar technology	Based on alumina refining EF.
Natural gas	P	Calculated from historical data	$EF_{(jobs/PJ)}$ = extraction jobs / total $production_{(PJ)}$
Natural gas transmission	All	Derived from similar technology	From CO_2 transmission EFs from Mayfield et al. (2021). See above for unit conversions.
Offshore wind	M	Derived from similar technology	From onshore wind manufacturing from Rutovitz et al. (2020).

3.4 Model validation

These employment factors used can be validated by comparing actual with modelled employment for a given year, as is shown in Figure 5. For this purpose, FY 2018-19 was selected as this is the most recent year of publication for key employment data sources, namely *Jobs in Australia* (ABS, 2021b) and *Employment in Renewable Energy Activities, Australia* (ABS, 2020). Installed capacity and capacity changes is sourced from the Australian Energy Market Commission (Reliability Panel, 2021), and extraction data is sourced from the *Australian Energy Update* (Department of Industry, Science, Energy and Resources, 2020). Only resources which utilise EFs that have not solely been calculated based on historical employment have been included for comparison here. For hydro, capacity additions from Snowy 2.0 have been annualised over total construction time.

Figure 5 | Comparison of 2018 actual and modelled employment by resource sector. The total variance across all sectors is 6.8%.



3.5 Labour learning factors

All jobs are assumed to experience improvements in labour productivity over time, producing efficiencies that reduce employment factors. Rates of productivity improvement vary between technologies based on factors that include technological maturity, scale of deployment, workforce experience and skill, potential for automation, etc. Improvements may occur non-linearly and are often pronounced during the emergence of a technology. While the rate of learning improvement is uncertain, projections of cost reductions of emerging technologies can also be used as an analogue for learning improvements (Rutovitz et al. 2020). CSIRO capital cost reductions from the *GenCost 2020-21* High Variable Renewable Energy scenario have therefore been used to calculate learning improvements for batteries, rooftop and utility solar. This source uses variable learning rates based on projected market share and technological maturity, which are initially high and reduce over time (Graham et al., 2021). For these technologies, learning improvements have been calculated to 2050 and then remain constant to 2060.

Cost reductions for batteries are based on CSIRO projections for eight-hour battery storage. For electrolysis, capital cost reductions have been taken from NZAu (2022), with the lowest capital cost technology chosen for each year. For all other technologies, annual learning improvements have been set at either 1% or 2% to account for gradual improvements in each technology, based on their prominence in the future energy sector (Hayward and Graham, 2013). For ease of calculation, a single learning rate has been used for each technology/resource across all scenarios and lifecycle stages, though in principle variations in scale of deployment should produce different learning rates (Ouassou et al., 2021). Learning improvements compound linearly over time and are calculated using the following formula:

$$L = 1 / (1 + D)^{t}$$

Where L is the overall learning improvement, D is the annual decline, and t is the number of years elapsed since 2020. All learning improvements by technology/resource are summarised in Table 8.

Table 8 | Learning improvements by technology/resource and year.

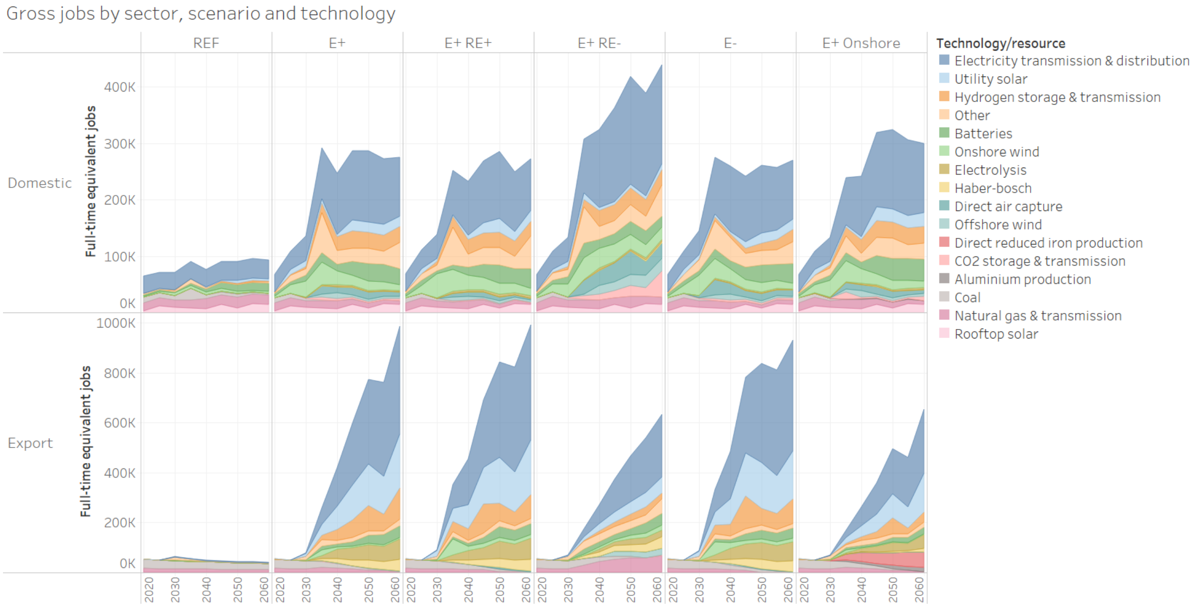
Technology/resource	Annual decline	Calculation	2020	2025	2030	2035	2040	2045	2050	2055	2060
Aluminium production	1.00%	Linear	100%	95%	91%	86%	82%	78%	74%	71%	67%
Autothermal reforming	1.00%	Linear	100%	95%	91%	86%	82%	78%	74%	71%	67%
Batteries	Variable	CSIRO	100%	56%	39%	35%	32%	29%	26%	26%	26%
Biofuels	1.00%	Linear	100%	95%	91%	86%	82%	78%	74%	71%	67%
Biomass	1.00%	Linear	100%	95%	91%	86%	82%	78%	74%	71%	67%
CO_2 storage	1.00%	Linear	100%	95%	91%	86%	82%	78%	74%	71%	67%
CO_2 transmission	1.00%	Linear	100%	95%	91%	86%	82%	78%	74%	71%	67%
Coal	1.00%	Linear	100%	95%	91%	86%	82%	78%	74%	71%	67%
Direct air capture	1.00%	Linear	100%	95%	91%	86%	82%	78%	74%	71%	67%
Electricity distribution	2.00%	Linear	100%	91%	82%	74%	67%	61%	55%	50%	45%
Electricity export	1.00%	Linear	100%	95%	91%	86%	82%	78%	74%	71%	67%
Electricity transmission	2.00%	Linear	100%	91%	82%	74%	67%	61%	55%	50%	45%
Electrolysis	Variable	NZAu (2022)	100%	69%	47%	35%	30%	28%	28%	28%	28%
Fischer-Tropsch	1.00%	Linear	100%	95%	91%	86%	82%	78%	74%	71%	67%
Haber-Bosch	1.00%	Linear	100%	95%	91%	86%	82%	78%	74%	71%	67%
Hydro	1.00%	Linear	100%	95%	91%	86%	82%	78%	74%	71%	67%
Hydrogen storage	1.00%	Linear	100%	95%	91%	86%	82%	78%	74%	71%	67%

Technology/resource	Annual decline	Calculation	2020	2025	2030	2035	2040	2045	2050	2055	2060
Hydrogen transmission	1.00%	Linear	100%	95%	91%	86%	82%	78%	74%	71%	67%
Iron DRI	1.00%	Linear	100%	95%	91%	86%	82%	78%	74%	71%	67%
LNG	1.00%	Linear	100%	95%	91%	86%	82%	78%	74%	71%	67%
Methanation	1.00%	Linear	100%	95%	91%	86%	82%	78%	74%	71%	67%
Natural gas	1.00%	Linear	100%	95%	91%	86%	82%	78%	74%	71%	67%
Natural gas transmission	1.00%	Linear	100%	95%	91%	86%	82%	78%	74%	71%	67%
Offshore wind	1.00%	Linear	100%	95%	91%	86%	82%	78%	74%	71%	67%
Oil refinery	1.00%	Linear	100%	95%	91%	86%	82%	78%	74%	71%	67%
Onshore wind	1.00%	Linear	100%	95%	91%	86%	82%	78%	74%	71%	67%
PHES	1.00%	Linear	100%	95%	91%	86%	82%	78%	74%	71%	67%
Rooftop solar	Variable	CSIRO	100%	60%	52%	46%	39%	38%	36%	36%	36%
SMR	1.00%	Linear	100%	95%	91%	86%	82%	78%	74%	71%	67%
Utility solar	Variable	CSIRO	100%	58%	51%	45%	38%	37%	35%	35%	35%

4 Preliminary results

Figure 6 presents the modelled gross Australian jobs employed within the energy sector for all technologies/resources and for *Net Zero Australia*'s Scenarios. These *gross jobs* figures represent the total number of jobs in each year employed in the energy sector and are calculated using the equations stated in Figure 1. As the modelled energy activity includes existing generation infrastructure and extraction processes, gross employment includes currently existing jobs.

Figure 6 | Gross jobs by scenario and sector for each modelled technology/resource. Note that technologies with fewer jobs have been aggregated as 'Other'

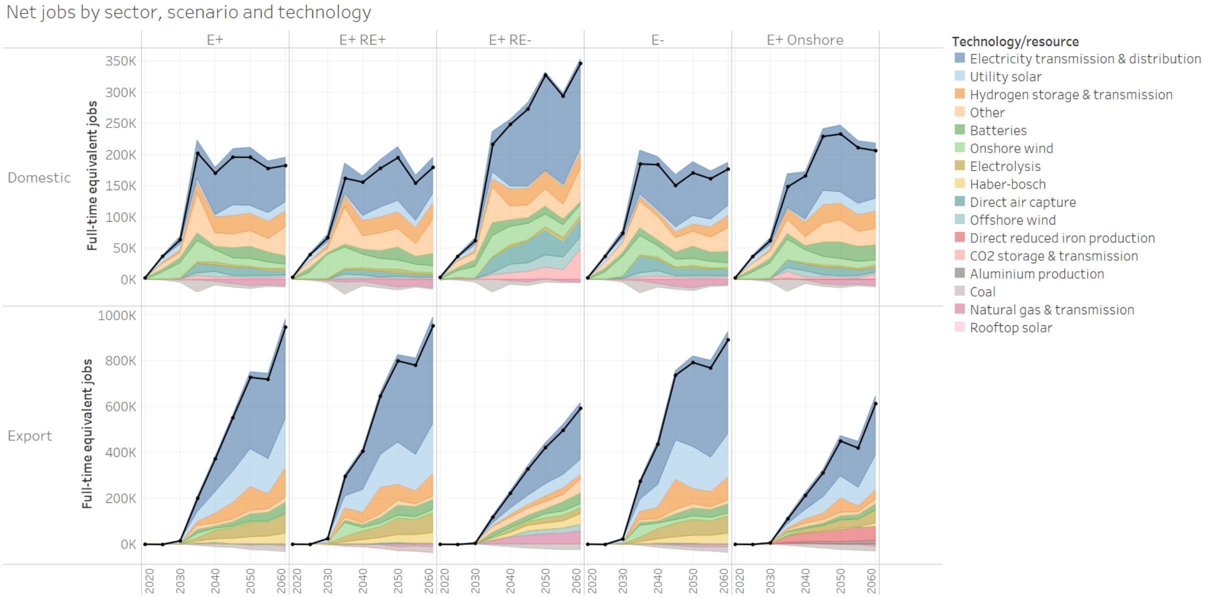


Gross domestic employment has a relatively small variation between the net zero Scenarios, with between 270-450k jobs in 2050-2060, all of which are a significant increase from the roughly 100k jobs in the Reference Scenario in 2050-2060. Greater variation occurs in the export sector, with total modelled jobs varying between 600k-1m in 2060. This is a major increase on this sector's 40k workers in the Reference Scenario in 2060.

Figure 7 presents the net employment of the modelled net-zero scenarios for all of Australia and the modelled technologies/resources. Here, *net jobs* represent the difference in gross employment between a given net-zero Scenario and the Reference Scenario, and therefore the large positive values can be considered *additional* jobs in the energy sector workforce as a result of the net-zero transition.

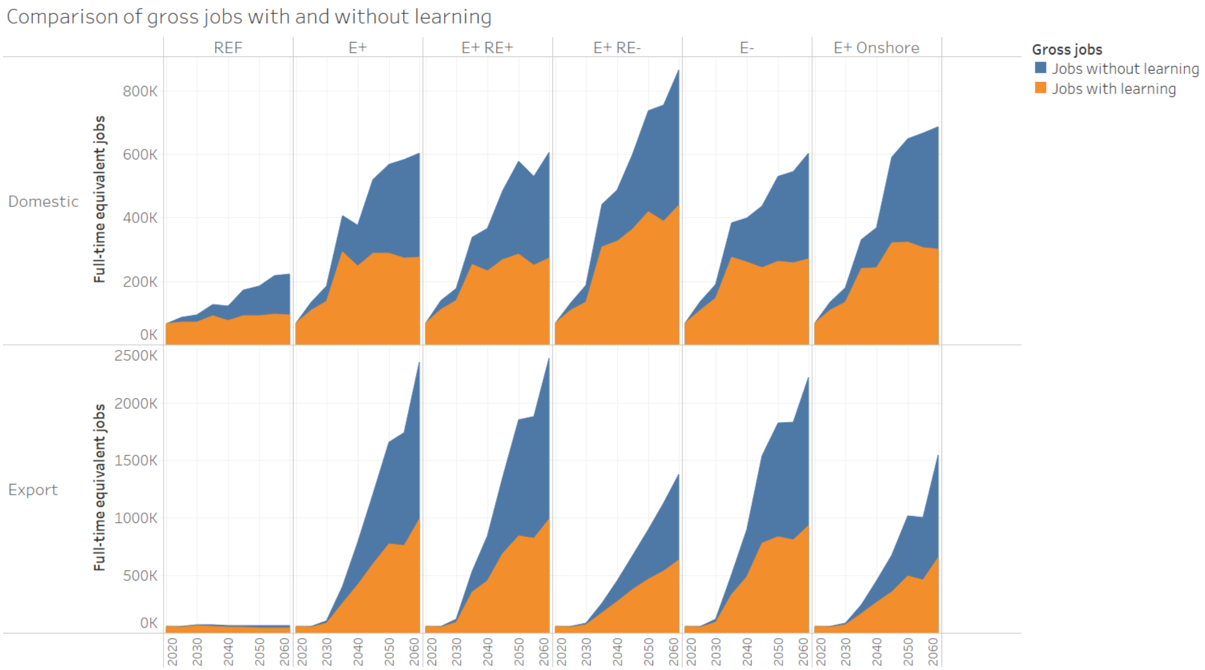
The net employment results demonstrate that job losses are largely restricted to coal and natural gas on the order of 50k jobs across the domestic and export systems by 2060. While there is net positive job creation for every modelled year, jobs losses will be concentrated in coal and natural gas sectors in fossil-fuel dependent regions, which may occur in different regions to created jobs. The extent to which affected communities may be affected will be further examined during the downscaling part of this project.

Figure 7 | Net employment by scenario and sector for each modelled technology/resource. Note technologies with low individual employment have been aggregated as 'Other'. Total jobs across all technologies are indicated by the black line.



As noted, while learning improvements affect all technologies, emerging technologies are modelled to experience a profound reduction in labour intensity of up to 60-75% over time. For technologies and sectors projected to experience rapid deployment, these declines produce significant reductions in labour demand. Figure 8 presents a comparison of gross jobs with and without learning improvements. Total employment *without learning* by Scenario varies between 2.2-3 million total jobs, which more than doubles the gross employment with labour learning improvements from Figure 6.

Figure 8 | Comparison of gross jobs with and learning improvements.

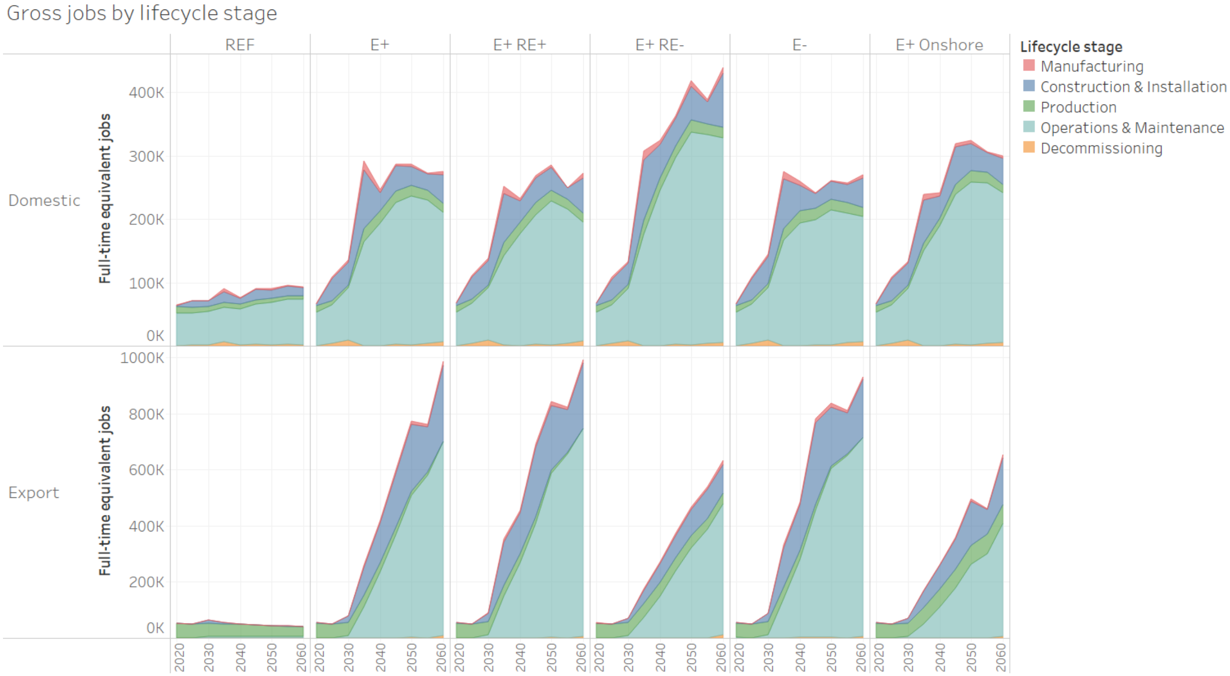


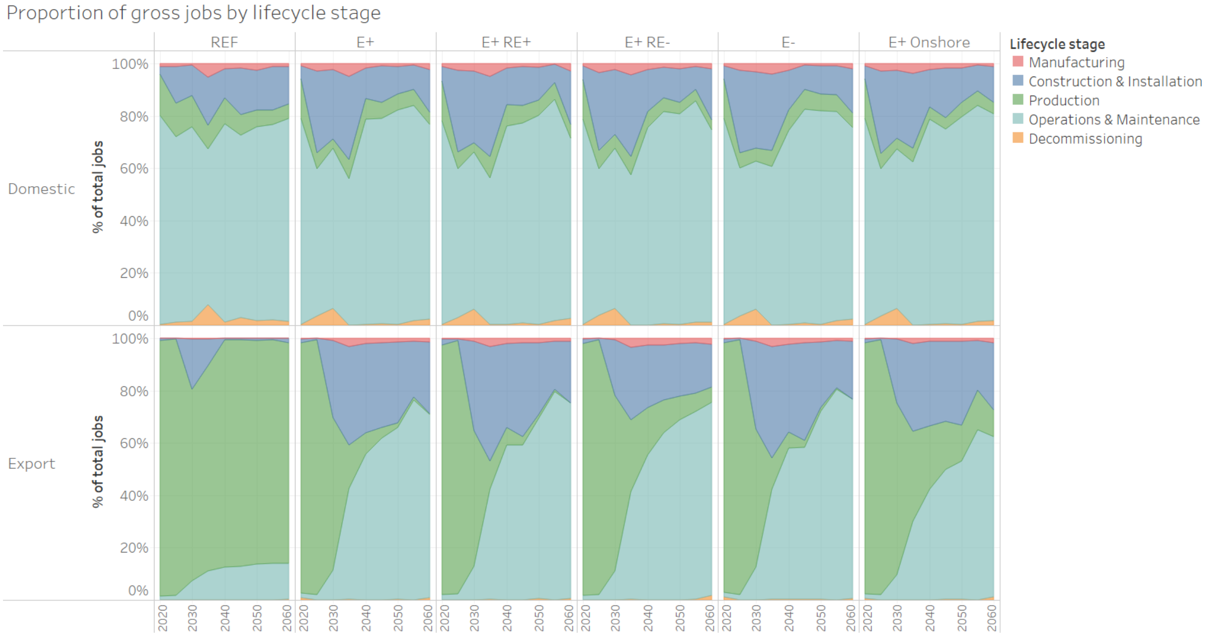
4.1 Lifecycle stage

Figure 9 shows that while manufacturing and decommissioning account for a relatively minor proportion of domestic energy sector employment to 2060, C&I increases to 30% of employment between 2025-2035 before decreasing to around 10% for the remainder of the modelled period. O&M experiences growing prevalence, increasing from 50% of energy sector employment to 80% towards the end of the modelled period. As domestic sector jobs in coal mining and natural gas extraction are lost, production jobs diminish from 30% of total employment in 2020 to just 5% by 2060. The early and end-of-life retirement of coal and oil refining assets between 2030-2035, and the end-of-life retirement of utility and rooftop solar, onshore wind and battery storage infrastructure in 2055-2060 produces small spikes of decommissioning jobs for those years.

As the export sector starts to decarbonise from 2030, there is significant change in the employment lifecycle stage, with production jobs reducing significantly from the majority to between 0.1-9.6% of total employment, depending on Scenario. Unsurprisingly, C&I booms from 2030, accounting for between 31-45% of total employment before diminishing to around 20% by 2060. O&M occupies a growing proportion of total employment, increasing from 14% in 2030 to around 75% by 2060. This result demonstrates that while there is a medium-term boom in construction pronounced between 2025-2045, this gives way to a growing proportion of ongoing jobs in O&M towards the end of the modelled period. Decommissioning jobs in the export sector are largely confined to end-of-life retirements of LNG production infrastructure between 2040-2060, and some utility solar and autothermal reforming capacity in 2060.

Figure 9 | Gross jobs by lifecycle stage and scenario (top), and proportion of gross jobs by lifecycle stage and scenario (bottom).





4.2 Workforce projections

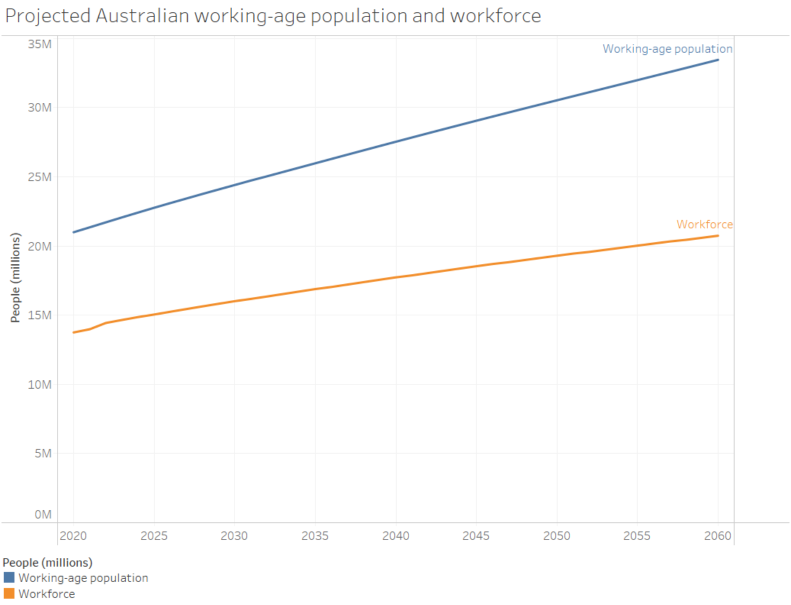
Workforce projections combine working-age (15 and over) population projections with a workforce participation rate projection to assess the future size of the workforce by state. Working-age population data by state is sourced from the Medium Scenario of the ABS *Australia Population Projections* (2018). The projected workforce participation rate is provided by The Australian Government Treasury (2021). The workforce participation rate describes the percentage of the working-age population that is either working or actively looking for work (Gustafson, 2021). Treasury forecasts a decline in participation of 3.3% between 2020 and 2060. This has been calculated linearly over 38 years from the 2022 peak participation rate of 66.5% to 62%. The projected population for each year is then multiplied by the participation rate to calculate the projected workforce at national and state levels, as shown in Figure 10.

Figure 11 then shows the proportion of the overall workforce projected to be occupied by energy sector jobs, as well as gross energy sector jobs by state. Figure 12 shows the proportionate breakdown of modelled energy sector employment against projected workforce by state. Totals exceed 100% where modelled energy sector jobs exceed total projected workforce.

Figure 11 shows that the absolute proportion of the energy workforce increases from under 1% in 2020 to between 4.5-6% by 2060 depending on the scenario. The present results show that these jobs are concentrated across the sunbelt of Western Australia, the Northern Territory and Queensland. Western Australia has the largest projected sectoral workforce, with Queensland and the Northern Territory having comparable sectoral workforces. However, Figure 12 indicates that the projected proportion of each region's workforce comprised by the energy sector varies greatly. In the Northern Territory, the energy sector workforce is projected to exceed the total projected workforce by roughly 1.5 times.

Whilst these results demonstrate the limitations of this modelling, they also underscore that labour availability will be a very major consideration and the importance of long-term planning and policy to ensure that decarbonisation is not compromised by labour shortages. Indeed, it is plausible that labour availability could be a major driver of where export investments are located, tending to move them from the northern sunbelt to more populous regions across the south and east; regions which these interim findings – that do not factor in labour availability – suggest are not as competitive as export regions. Such results will be examined further in the forthcoming downscaling effort to determine where these jobs are likely to be located in a more granular way.

Figure 10 | Working-age population and workforce projections over time (left), and workforce projection (million people) by state in 2020 and 2060 (right).



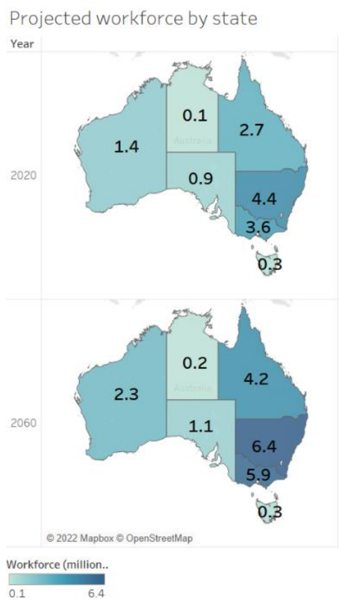


Figure 11 | Energy sector jobs as a percentage of projected workforce for each scenario over time (left), and gross energy sector jobs (thousands of jobs) for the E+ scenario in 2020 and 2060, by state/territory (right). Energy sector jobs combine both the domestic and export sectors.

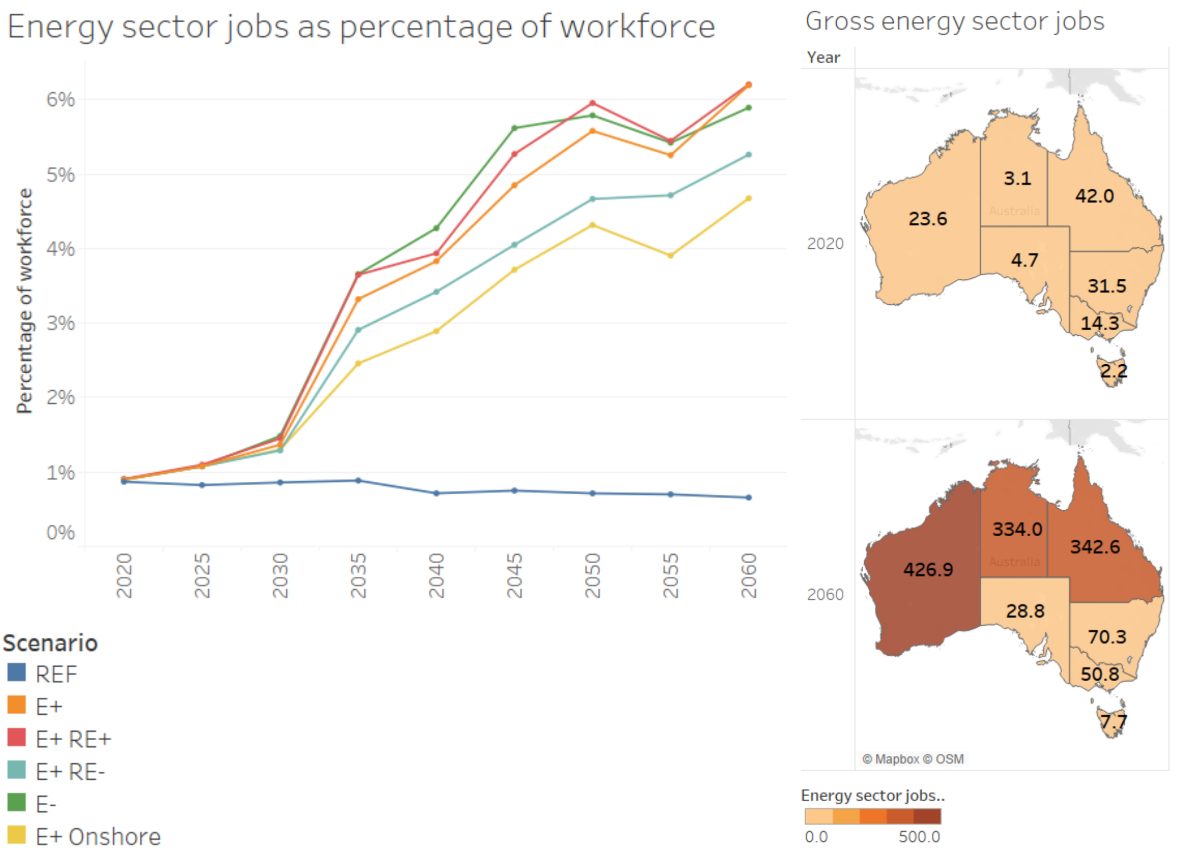
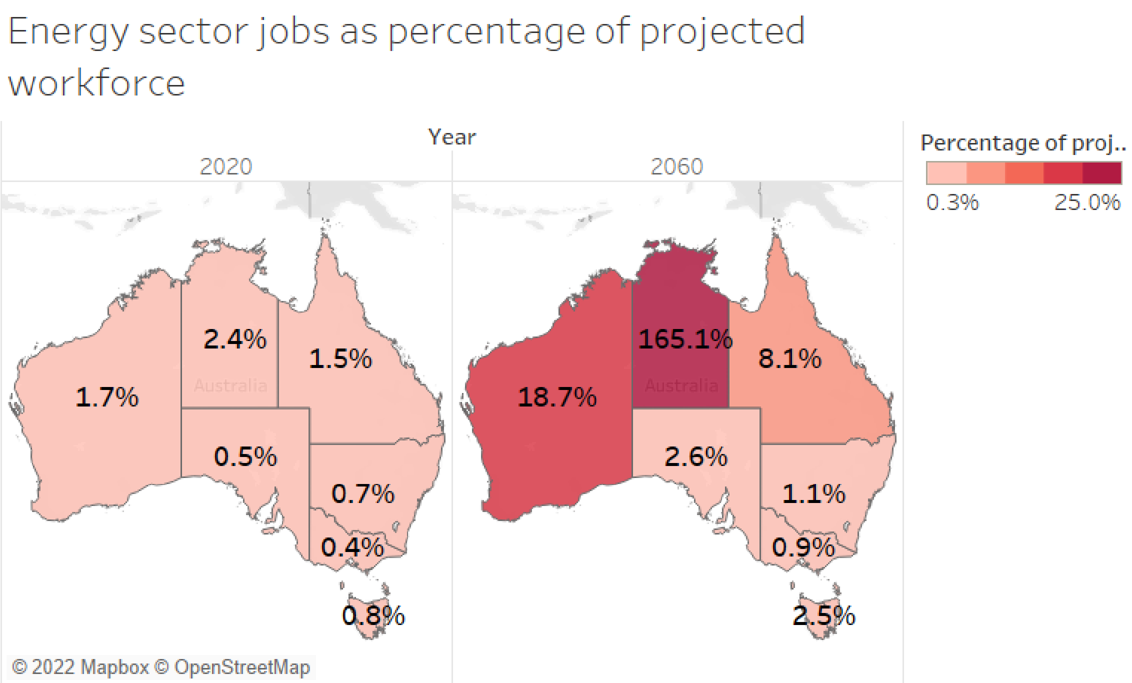


Figure 12 | Proportion of projected workforce for the E+ scenario in 2020 and 2060, by state/territory. Note totals exceed 100% where modelled energy sector employment exceeds the projected workforce.



4.3 Occupation projection

As seen in Table 5, each technology/resource and stage has been assigned a relevant ANZSIC code. Using 2016 Census data, a breakdown of employment by occupation for each ANZSIC code was generated. Occupations follow the Australian and New Zealand Standard Classification of Occupations (ANZSCO). ANZSCO uses numeric codes to differentiate between hierarchic levels.

Level	Example
Major group (n = 8)	2 Professionals
Sub-major group (n = 43)	23 Design, Engineering, Science and Transport Professionals
Minor group (n = 99)	233 Engineering Professionals
Unit group (n = 364)	2333 Electrical Engineers

Occupational data was extracted for 477 occupations at the unit group level. The unit group data extraction included higher-level occupational groups that are not further defined (nfd) in the 2016 Census data; for example 2330 Engineering Professionals nfd. The proportion of employment in each occupation within the relevant ANZSIC industry code was calculated, which forms the basis of the projection of employment by occupation.

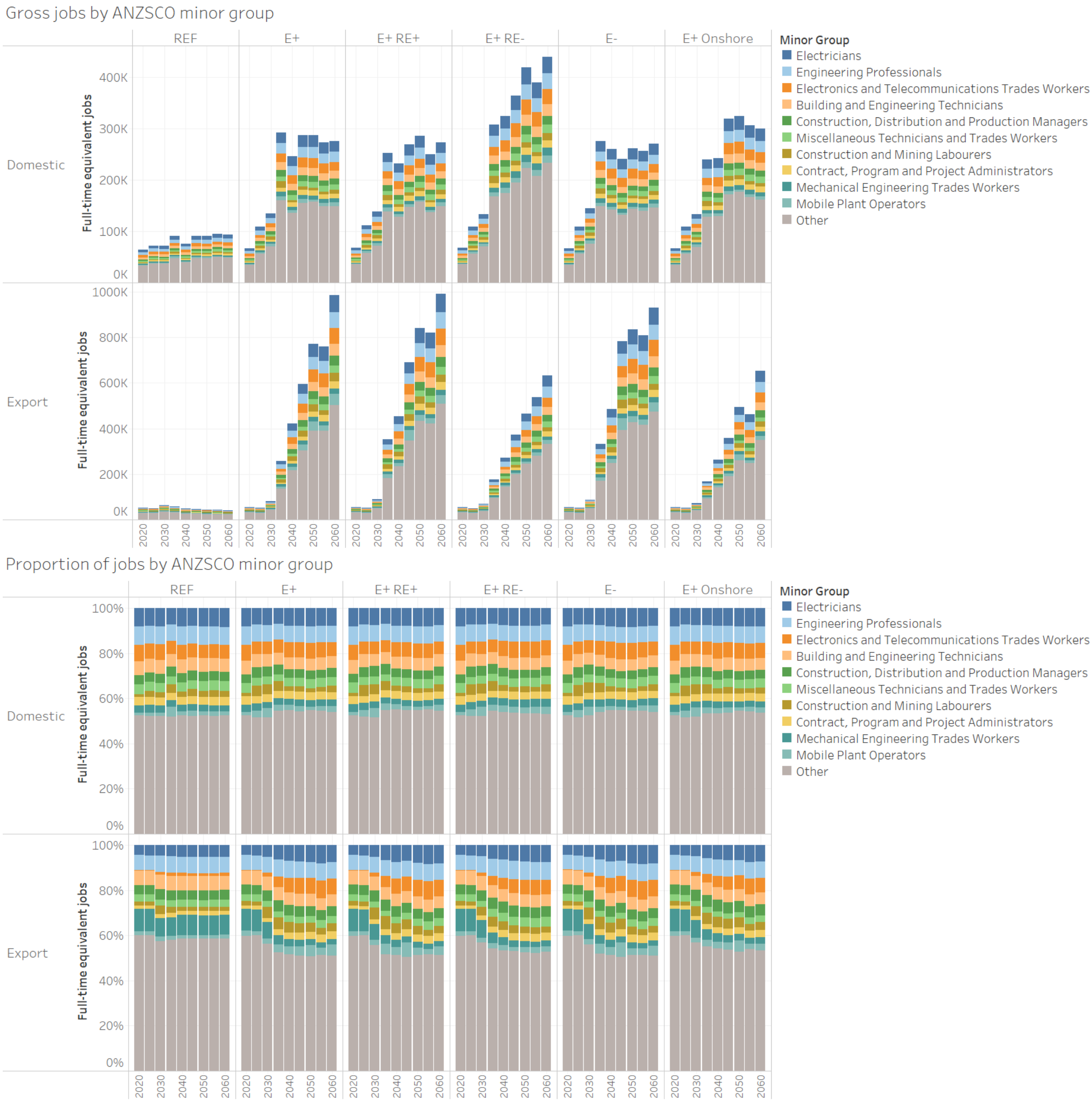
The occupation projection multiplies the proportional occupation breakdown by gross employment by energy activity associated with each ANZSIC code. The product is then summarised by occupation. As this projection is based on 2016 Census data, it does not consider occupational makeup changes that should occur within industries over the coming decades. Indeed, the characteristics of a given occupation today and in 30 years should be significantly different, particularly for those occupations related to emerging technologies such as electrolysis and battery storage. As a result, this projection is more reliable at higher ANZSCO levels, and the rapidly evolving nature of energy technology and the workforce that support it must be kept in mind.

Figure 13 nonetheless presents gross and proportional jobs over time by ANZSCO major group. With the decarbonisation of the export sector from 2030, proportional employment for machinery operators and drivers decreases significantly. Unsurprisingly, the growth in C&I employment in Figure 9 significantly increases absolute and proportional jobs for labourers, as well as clerical and administrative workers. The domestic sector is more stable, with most professions fluctuating a few percentage points throughout 2020-2060. However, as with the export sector, labourers enjoy a substantial increase in alignment with the increase in C&I jobs from 2025.

Figure 13 | Gross and proportional jobs in each ANZSCO major group by scenario over time.

Lower ANZSCO levels can nonetheless provide valuable insights into occupational groups that will experience substantial growth during decarbonisation. Figure 14 presents gross and proportional jobs over time by ANZSCO minor group, with the top 10 occupations by number of jobs identified and all other occupations grouped as 'Other'. These occupations account for up to approximately 45% of domestic sectoral employment over time. Perhaps unsurprisingly, roles relating to electrification and engineering dominate these jobs, with significant numbers in construction and project administration roles as well.

Figure 14 | Gross and proportional jobs by top 10 ANZSCO minor groups by scenario over time.



4.4 Skill level projection

Each occupation is assigned a skill level, which reflects the level of complexity and range of tasks undertaken in the occupation. The skill level of an occupation measures the level of formal education and training, previous experience and the amount of on-the-job training needed to successfully complete the tasks undertaken by that occupation. Table 9 provides a breakdown of ANZSCO skill levels.

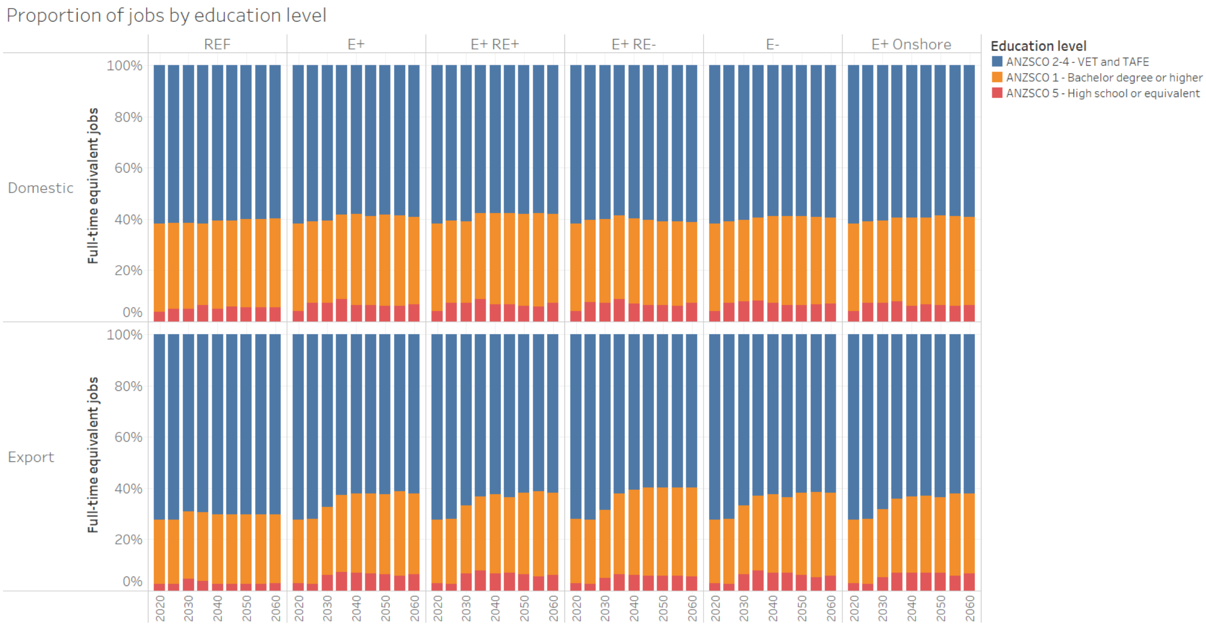
Table 9 | Breakdown of requirements for each ANZSCO skill level (ABS, 2021c).

Skill level	Description
1	• Occupations that have a level of skill commensurate with a bachelor degree or higher qualification. • At least five years of relevant experience may substitute for formal qualifications.
2	• Occupations that have a level of skill commensurate with an Australian Qualifications Framework (AQF) Associate degree, Advanced Diploma or Diploma. • At least three years of relevant experience may substitute for formal qualifications.
3	• Occupations that have a level of skill commensurate with an AQF Certificate IV or Certificate III including at least two years of on-the-job training. • At least three years of relevant experience may substitute for formal qualifications.
4	• Occupations that have a level of skill commensurate with an AQF Certificate II or Certificate III. • At least one year of relevant experience may substitute for formal qualifications.
5	• Occupations that have a level of skill commensurate with an AQF Certificate I or compulsory secondary education. • For some occupations a short period of on-the-job training may be required in addition to or instead of formal qualification.

Some aggregated occupations are assigned multiple skills. For example, 599 Miscellaneous Clerical and Administrative Workers may be of skill level 2, 3 or 4. For the purposes of generating a projection of future employment by skill, employment in these occupations is evenly divided between each skill level.

Despite the significant increases in gross employment seen in Figure 6, the proportional employment by skill level in the domestic sector is largely static over time, as seen in Figure 15. The exception to this trend is the export sector, as lower-skilled jobs in coal mining and natural gas extraction currently occupy a larger proportion of the overall workforce. Over time, these jobs give way to occupations with ANZSCO skill levels of 1 and 5.

Figure 15 | Gross and proportional jobs by education level for each scenario over time.



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