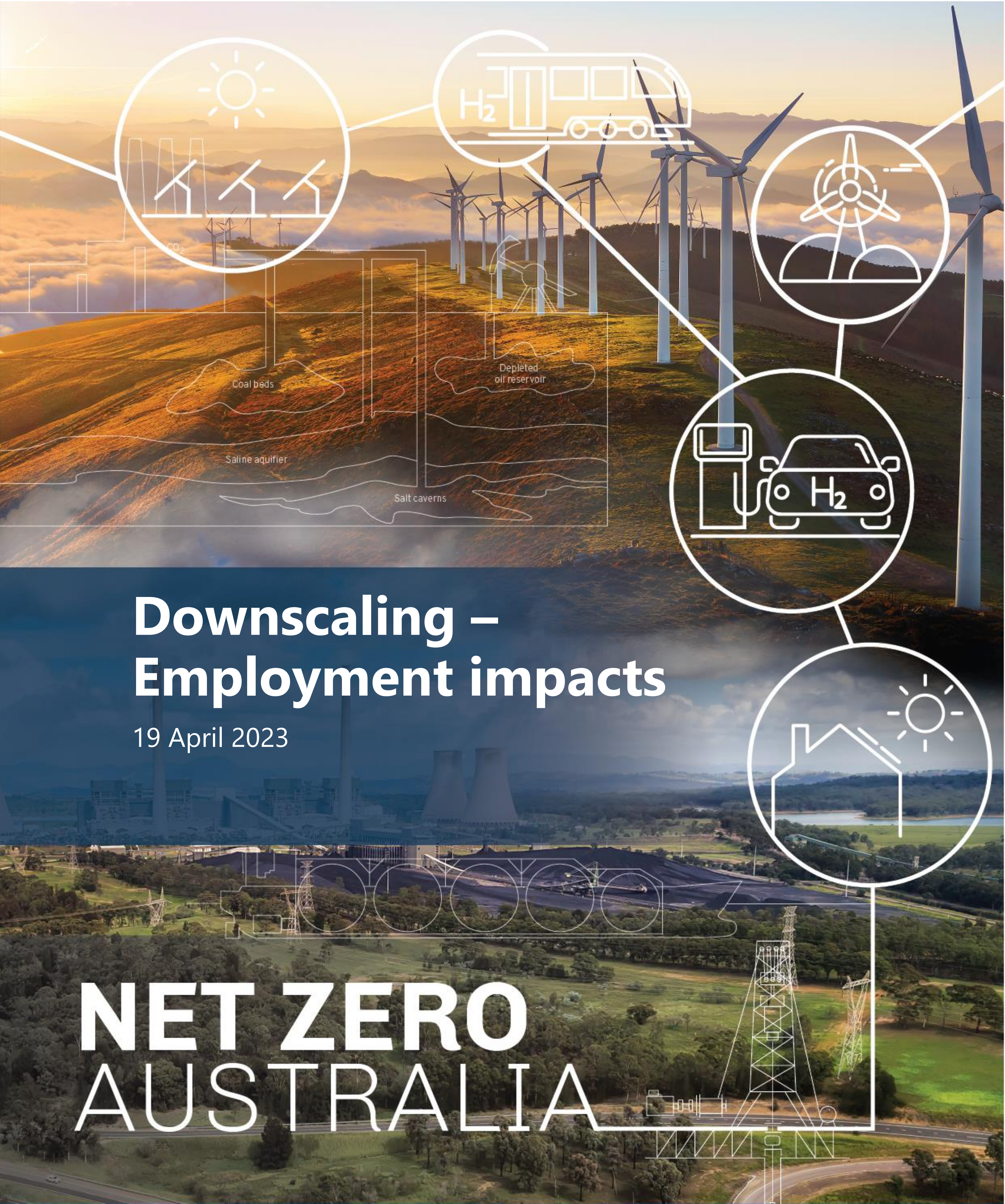

Downscaling – Employment impacts

19 April 2023

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

Net Zero Australia

Downscaling – Employment impacts

19 April 2023

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Contents

Summary

This study estimates the labour impacts of decarbonisation in Australia over the coming decades to 2060. Its novel contribution to the research in this field is the consideration of a wide range of technologies required for decarbonisation, across four decades, and for both domestic and export sector emissions in every Australian state and territory. Using the DEERS model from Mayfield et al. (2021), we have been able to project the impacts on gross and net jobs, as well as the changing makeup of the workforce. This includes the occupations, skills and education required.

Across all Scenarios, by mid-century, the total gross jobs created for the domestic and export sectors vary between 210-490 thousand and 350-510 thousand, respectively. While there are periodic C&I booms, there is also a growing demand for a large ongoing workforce. Net jobs are found to be approximately 15 thousand lower in the domestic sector than gross jobs, and 50 thousand in the export sector, due to declining employment in coal and natural gas as the energy sector decarbonises. Overall, the number of people employed in the energy sector is projected to increase from less than 1% of the total workforce in 2020 to between 3-4% by 2060.

Domestic sector jobs are more evenly distributed, with consistent growth in all states across most Scenarios, primarily in utility solar PV, batteries and electricity transmission and distribution. Export sector jobs are more unevenly distributed, with job growth in most Scenarios being concentrated in Western Australia, the Northern Territory and Queensland in the hydrogen supply chain, which includes utility solar PV, batteries, electrolysis, hydrogen transmission and storage, and Haber-Bosch synthesis of ammonia. However, export sector jobs will also be sensitive to several important factors that are external to this analysis. This includes the need for contracted supply to export customers to underpin export investment before any construction starts. Also, our Sensitivities have shown that the impacts of regional cost variations and other regional constraints will impact export system investment significantly. As such, our export jobs modelling needs to be interpreted with some care.

Significantly, all states and territories experience net job growth across each decade to 2060, with one exception. Net job losses occur in the export sector in NSW and Queensland, primarily driven by declining employment in coal mining, and to a lesser extent, natural gas extraction and transmission. Also, job creation is disproportionate to population projections that anticipate workforce growth in existing population centres, which highlights a limitation in the modelling concerning regional cost modifiers.

Occupation projections demonstrate significant increases in absolute jobs for many different types of worker. The most represented occupations include electricians, engineering professionals, project managers, associated trades workers and construction labourers.

While the projected jobs growth of the energy sector is lower in absolute terms than has been experienced by several other Australian industries over the last 30-40 years, in relative terms the sector is required to grow between five- to six-fold in this period, which is without precedent. Furthermore, most jobs will be in regional communities, which are a potential source of revitalisation, but also pose social, infrastructural, planning and investment challenges. This is also another, important reason to engage with different Indigenous communities. Government involvement at state and federal levels is also essential to minimising the current and future potential for local unemployment or diminished employment conditions (in terms of both wages and job security), education needs, labour shortages due to internal competition between domestic and export sectors and states and territories, and potentially for facilitating the use of temporary and permanent skilled migration to mitigate labour capacity shortfalls. Considerable further research is required to evaluate such impacts further.

1 Introduction

Many existing studies into the labour impacts of decarbonisation in Australia have focussed on the transition for the domestic energy sector, as net-zero targets are typically based on emissions from domestic consumption rather than total production. However, Australia is the largest global exporter of metallurgical coal, the second largest exporter of thermal coal, and the largest exporter of liquefied natural gas (LNG). Furthermore, planning for the potential growth of the energy sector workforce across both domestic and export sectors and within states and territories should be prioritised, as each will primarily draw from the same pool of workers (Electrical Trades Union, 2022). Effective policy and decision-making are essential to meeting the skill and education requirements of the workforce necessary to achieve decarbonisation at the anticipated pace, without being stalled by labour constraints and inflating costs (Mayfield et al., 2021).

Existing studies of labour impacts also tend to either consider a more limited time horizon or a more limited range of technologies than the transition to net zero will likely require. Some studies focus on horizons to the early- to mid-2030s (e.g., Rutovitz et al., 2020), or specific technologies (e.g., Wood et al., 2020). Furthermore, while greater uncertainties are inherent when projecting labour impacts over longer horizons, particularly regarding cost and learning improvements that affect labour intensity, understanding scale of labour requirements throughout the decarbonisation task is essential in informing effective policy interventions and government planning. This is particularly important when considering the education demands of the emerging energy sector workforce, as establishing new qualifications for nascent sectors can take up to six years from design concept to producing the first graduates. Furthermore, Australia is already experiencing skill shortages in critical renewable generation and storage jobs, which requires timely intervention to mitigate further shortages in the context of growing labour demand (Clean Energy Council, 2022).

Finally, it is critical for policymakers to understand the spatial impacts of decarbonisation (Cass et al., 2022). Job losses are likely to occur in communities around industries that extract, process and use fossil fuels. Government planning and intervention is therefore likely essential to achieving a just transition for affected workers. This involves upskilling and reskilling workers, decision-making regarding the location of new renewable infrastructure, and the establishment of just transition policies to compensate for lost wages or relocations (Mayfield et al., 2021). While communities are increasingly calling for certainty, spatial disaggregation is missed in many existing studies (Cass et al., 2022).

Table 1 catalogues existing research into the labour impacts of decarbonisation in Australia, including the technologies studied, the time horizon applied, the consideration of occupations, skills and education, as well as the spatial disaggregation of impacts. The present study seeks to address the research gaps highlighted above by assessing direct, gross and net job impacts, including associated impacts on occupations, and the education and skills required by the energy sector throughout the net-zero energy system transition from 2020 to 2060. This transition includes a broad suite of different technologies and resources relevant to both the domestic and export energy sectors, with all results disaggregated by state.

Table 1 | Summary of existing research into the labour impacts of decarbonisation in Australia.

Author(s)	Technologies	Time horizon	Sector(s)	Occupations, skills, education	Spatially disaggregated
Climate Council, 2016	Wind, solar, hydro, biomass, coal and gas	To 2030	Domestic	No	Yes
Beyond Zero Emissions, 2020	Renewable generation and transmission, heating, ventilation and air conditioning, manufacturing, mining, recycling, transport, land restoration and carbon and education	Five years	Domestic	No	No
Briggs et al., 2020	Solar, wind, hydro and batteries	2020-2035	Domestic	Yes	By state
Stanford, 2020	Coal and gas, solar, wind	Short term	Domestic, export	No	No
Wood et al., 2020	Hydrogen, steel, direct reduced iron, aluminium, ammonia	To 2050	Export	Yes	Yes
RepuTex, 2021	Electricity grid, batteries, rooftop solar	To 2030	Domestic	No	No
Briggs et al., 2021	Large scale RE, coal and gas, rooftop solar, batteries, transmission construction	2021-2036	Domestic	Yes	By state
Construction Skills Queensland, 2022	Wind, solar, batteries, transmission construction, hydrogen	2020-2050	Domestic, export	Yes	Sub-regions of Queensland
Jackson and Ibrahim, 2022	Wind, solar, electricity grid, batteries	To 2050	Domestic	Yes	No
Rutovitz et al., 2023	Electricity system (generation & storage technologies, and transmission construction	To 2050	Domestic (& hydrogen superpower export sensitivity)	Yes	By state
Chau et al., 2023	Wind, solar, batteries, hydrogen, electricity grid	To 2050	Domestic (& export sensitivity)	Yes	No

2 Conceptual model and scope of analysis

The model used in this study is a form of 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 energy system technologies and resources modelled in the transition across relevant lifecycle stages. 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 throughout decarbonisation. 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 emissions over long temporal horizons (Mayfield et al., 2021).

All technologies and resources included in the employment model, as well as their associated energy activity processes are defined in Table 2 below. Employment impacts of energy activity within these technology and resource categories are modelled in lifecycle stages summarised in Table 3.

Table 2 | All modelled technologies/resources and their associated energy activities.

Technology/resource	Energy activities
Aluminium production (onshored)	Production (i.e., refining alumina and aluminium smelting)
Autothermal reforming	Hydrogen (H_2) production
Batteries	Storage (i.e., electricity storage of variable duration)
Biofuels	Feedstock conversion to biofuels (i.e., conversion of biomass to synthetic natural gas/H_2)
Biomass	Production (i.e., of biomass feedstock for biofuel production, including crop stubble, native grasses, pulpwood, bagasse and organic municipal solid waste)
Carbon dioxide (CO_2) storage	Storage (i.e., permanent sequestration of captured CO_2)
CO_2 transmission	Transmission (i.e., transport of captured CO_2 for sequestration/use via pipeline)
Coal	Electricity generation (i.e., through combustion of coal) and extraction (i.e., coal mining)
Direct air capture (DAC)	Operation (i.e., capture of CO_2 from the atmosphere for transmission and sequestration)
Electricity distribution	Distribution (i.e., operation, maintenance and augmentation 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 (onshored 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))

Technology/resource	Energy activities
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 PV	Electricity generation
Steam methane reforming (SMR)	Hydrogen production
Utility solar PV	Electricity generation

Table 3 | Summary and description of all modelled lifecycle stages.

Lifecycle stage	Description
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. In the context of the technical lifecycle of a given technology or resource, manufacturing work constitutes temporary employment. However, from a workforce perspective, manufacturing jobs are often tied to significant infrastructure and investment which may expand significantly over the decades-long transition, so should be considered ongoing jobs. 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 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. C&I jobs are temporary, onshore employment. 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 C&I, O&M jobs occur over a longer time horizon and are typically presented as jobs per unit 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 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 suitable Employment Factors (EF). For some technologies and resources, a given lifecycle stage may not be suitable; for example, as CO_2 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 are not based on quantified output. Finally, some technology lifecycle stages such as manufacturing for iron DRI and natural gas transmission, or decommissioning for many technologies, are not modelled due to lack of verified EFs. All modelled energy sector technologies, resources and lifecycle stages covered in the employment model are summarised in Table 4 below.

Table 4 | Coverage of lifecycle stages by modelled energy sector technology/resource.

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

The distribution of labour impacts is modelled from 2020 to 2060, disaggregated by 15 defined sub-regions and those serving domestic and export energy demands, across multiple industries, including agriculture, mining, manufacturing, construction, electricity generation and transport. We note, in particular, that throughout this report we distinguish between employment associated with serving *domestic* and *export* energy demands. This is in alignment the overall NZAu project approach to modelling domestic and export energy system decarbonisation with separate net-zero emissions constraints, but as one interconnected energy system. While domestic and export energy sector activities are related, the distinction shown in results below provides a reasonable illustration of sectoral trends.

We model with the DEERS model only direct job creation within sectors relevant to the energy supply. That is, those associated with primary energy activities such as extraction or electricity generation, and mid- or downstream energy activities within the value chain such as fuel conversion. We do not account for induced jobs, i.e. those created from the economic activity generated by the spending of direct job incomes. We also do 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.

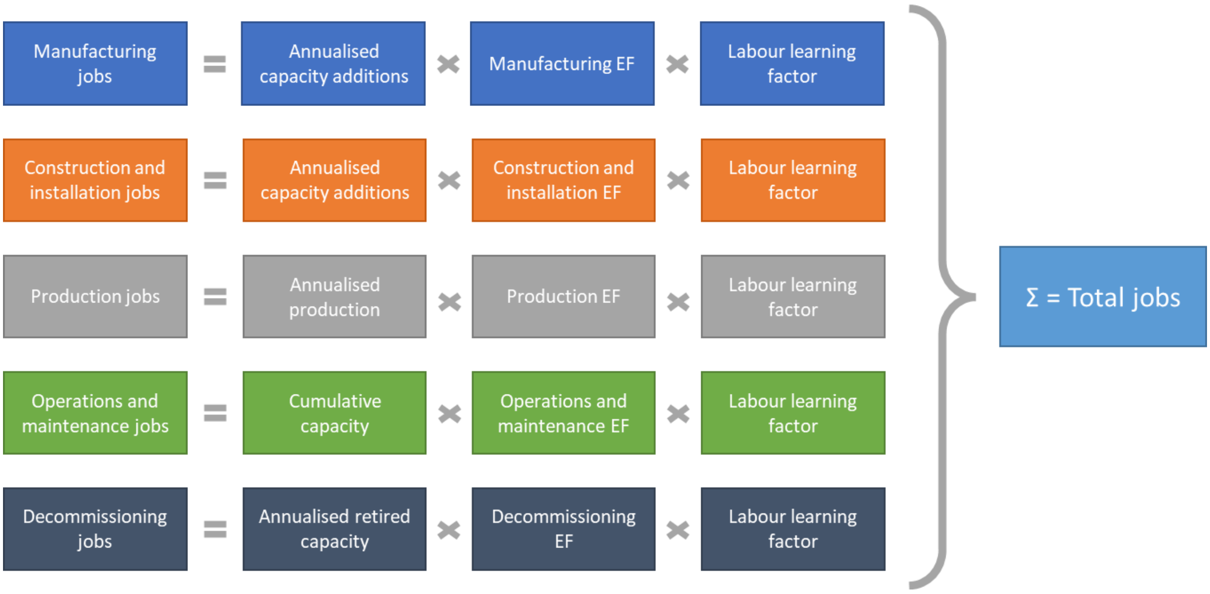
When describing employment outcomes, this study uses the metric *job*, which describes full-time equivalent jobs required over a single year, rather than jobs sustained over multiple years. Alternatively, job-years is used as a time-weighted metric to describe cumulative employment that occurs over longer 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 4 then provides total employment for a given technology/resource.

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



3.1.1 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 macro-scale energy system modelling, and specifically, the Regional Investments & Operations (RIO) modelling tool (Williams et al., 2021). This data reports cumulative generation, storage and conversion capacity, capacity additions, capacity retirements, production and extraction, and generated electricity in five-year increments. All energy activity data by technology/resource and lifecycle stage is detailed below in Figure 3, Figure 4, Figure 5, and Figure 6. Furthermore, RIO modelling incorporates the 15 Australian domestic regions, shown in Figure 2, each with its own energy and energy-service demand, initial stock of energy infrastructure and resources (NZAu, 2022a). In addition, RIO modelling incorporates regions that are designated to the potential production of energy for exports. Capital expenditure (CAPEX) and operational expenditure (OPEX) are reported for each region and technology/resource in annual increments. These inputs have been further aggregated, annualised and converted, where relevant, to inform employment modelling, as outlined in Table 5.

Modelling occurs across the six Core Scenarios defined for the Net Zero Australia Project: a Reference Scenario with no emissions constraint, and six Scenarios with a net zero emissions constraint, as summarised in Table 6. Further information regarding each Scenario is available in the Net Zero Australia Methods, Assumptions, Scenarios & Sensitivities document (NZAu, 2022a).

Table 5 | Usage of *Net Zero Australia* energy activity data to calculate employment.

Energy activity data	Lifecycle stages	How it is used
Changes in installed capacity	M, C&I, D	Data distinguishes between new installations, end-of-life retirements, and early retirements; new installations are used to calculate manufacturing and C&I employment, while all retirements are combined to calculate decommissioning employment. Data is reported in five-year timesteps, which is annualised to ensure jobs are reported for a given year. As onshored production of aluminium and iron DRI is reported in NZAu as a displacement of energy required to meet the export constraint outlined in the Net Zero Australia Methods, Assumptions, Scenarios & Sensitivities (2022a), these units are converted from GW to kilotonnes/year of actual production using the displacement formula described in that document. Whether energy activity supports the export or domestic sector is determined by the region where the technology is installed. Notes: - One tonne of aluminium displaces 107.7 GJ of exported energy. One tonne of iron DRI displaces 11.66 GJ of exported energy. - Capacity installations occurring during the years 2020-2025 are attributed as changes observed in 2025. As a result, the 2020 modelled C&I employment in utility solar, rooftop solar, onshore wind and PHES will be lower than actual observed employment.
Cumulative installed capacity	O&M	Units for DAC are converted from kilotonne/hour to annual kilotonnes of CO_2. 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. Onshored production of aluminium and iron DRI is converted from GWh 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 CO_2 storage, CO_2 transmission, electricity export, hydrogen transmission, natural gas transmission, and the O&M stages of CO_2 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 2020 AU$. Whether energy activity supports the export or domestic sector is determined by the region where the technology is installed.

Table 6 | Modelled Scenario names and descriptions (NZAu, 2022a).

Scenario name	Description
REF	Reference: - Projects historical trends, does not model cost impacts of fossil fuel supply constraints; - No new greenhouse gas emission constraints imposed domestically or on exports; - Policy settings frozen from 2020 onwards.
E+	Rapid electrification: - Nearly full electrification of transport and buildings by 2050; - No limit on renewable rollout; - Lower cap on underground carbon storage.
E−	Slower electrification: - Slower electrification of transport and buildings compared to E+; - No limit on renewable rollout rate; - Lower cap on underground carbon storage rate.
E+RE+	Full renewable rollout: - No fossil fuel use by 2050; - No limit on renewable rollout rate; - Lower cap on underground carbon storage rate, which is only used for non-fossil fuel sources (e.g., cement production).
E+RE−	Constrained renewable rollout: - Renewable rollout rate limited to several times historical levels (to examine supply chain and social license constraints); - Much higher cap on underground carbon storage (to make net zero achievable).
E+ONS	Onshoring: - Local production of iron and aluminum using clean energy; - Progressively displaces exports of iron ore, bauxite, alumina and fossil fuels.

Figure 2 | Modelled domestic regions with NZAu's macro-energy system model (2022a).

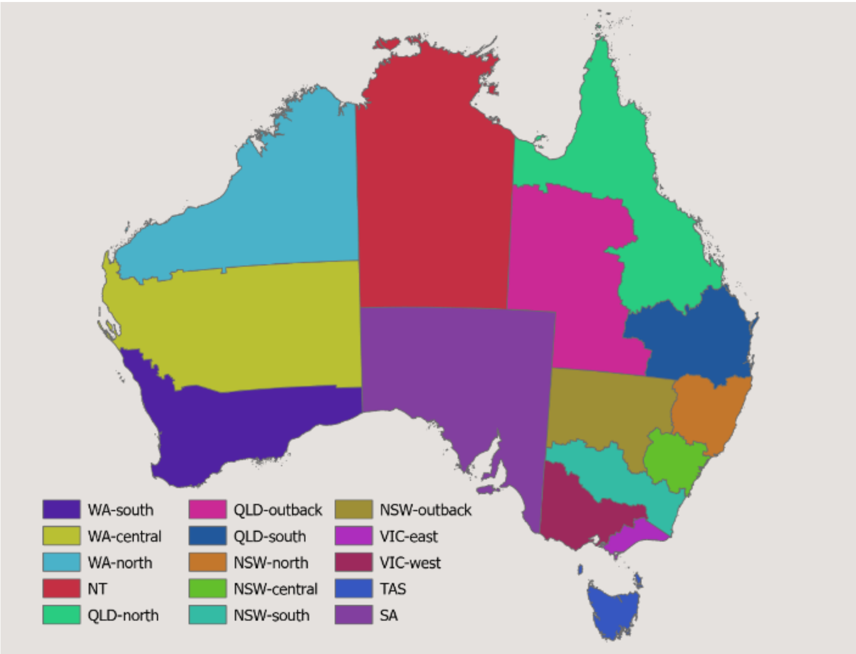


Figure 3 | Energy activity data for changes in installed capacity of various technologies/resources, by year and Scenario for both domestic and export sectors. Positive changes in installed capacity are used for Manufacturing (M) and Construction and installation (C&I) employment lifecycle stages, while negative changes are used for Decommissioning (D) jobs. Note vertical axis scales vary by technology/resource.

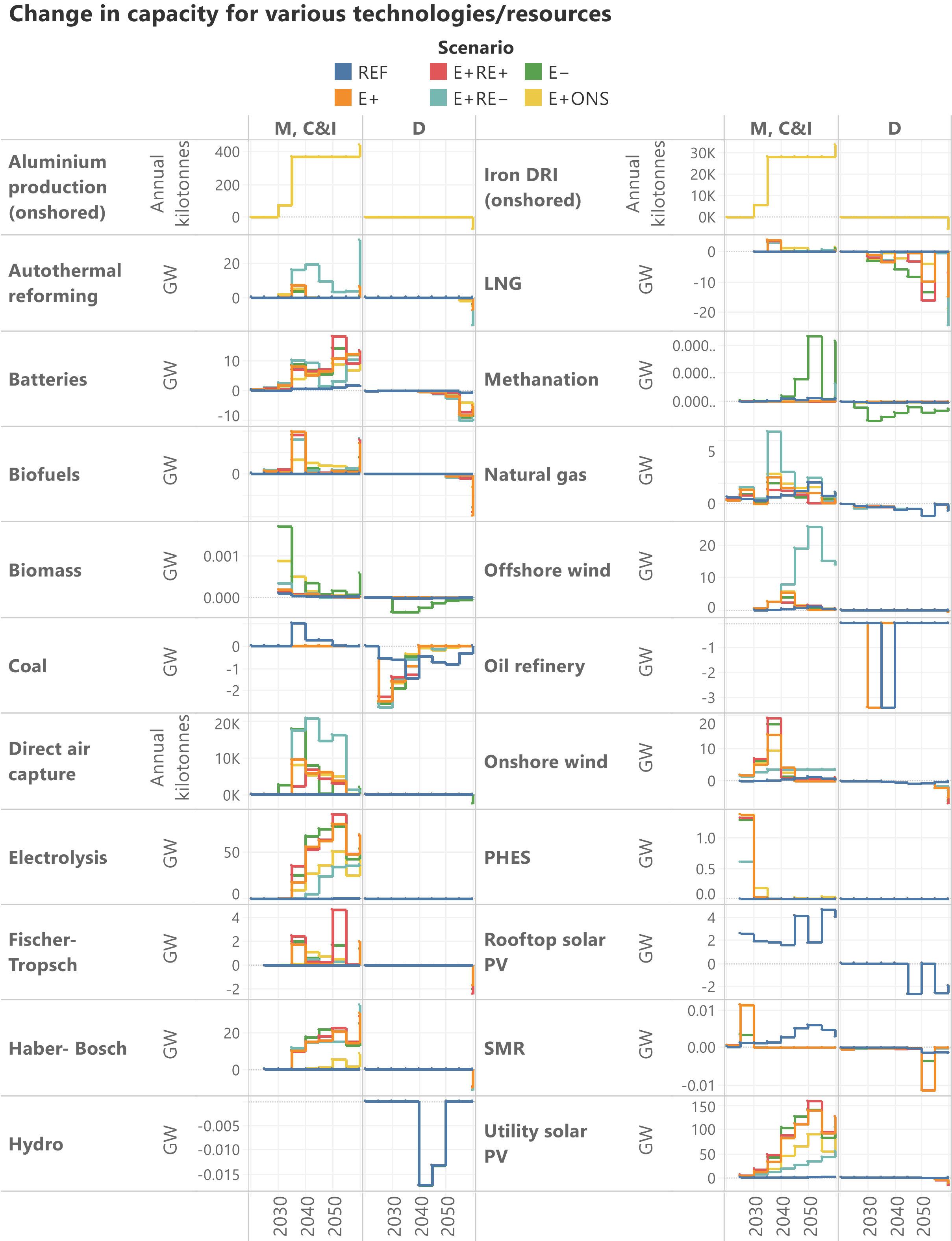


Figure 4 | Energy activity data for cumulative capacity of various technologies/resources, by year and Scenario for both domestic and export sectors. Cumulative installed capacity data are used for the operations and maintenance (O&M) employment stage. Note y-axis scale varies by technology/resource.

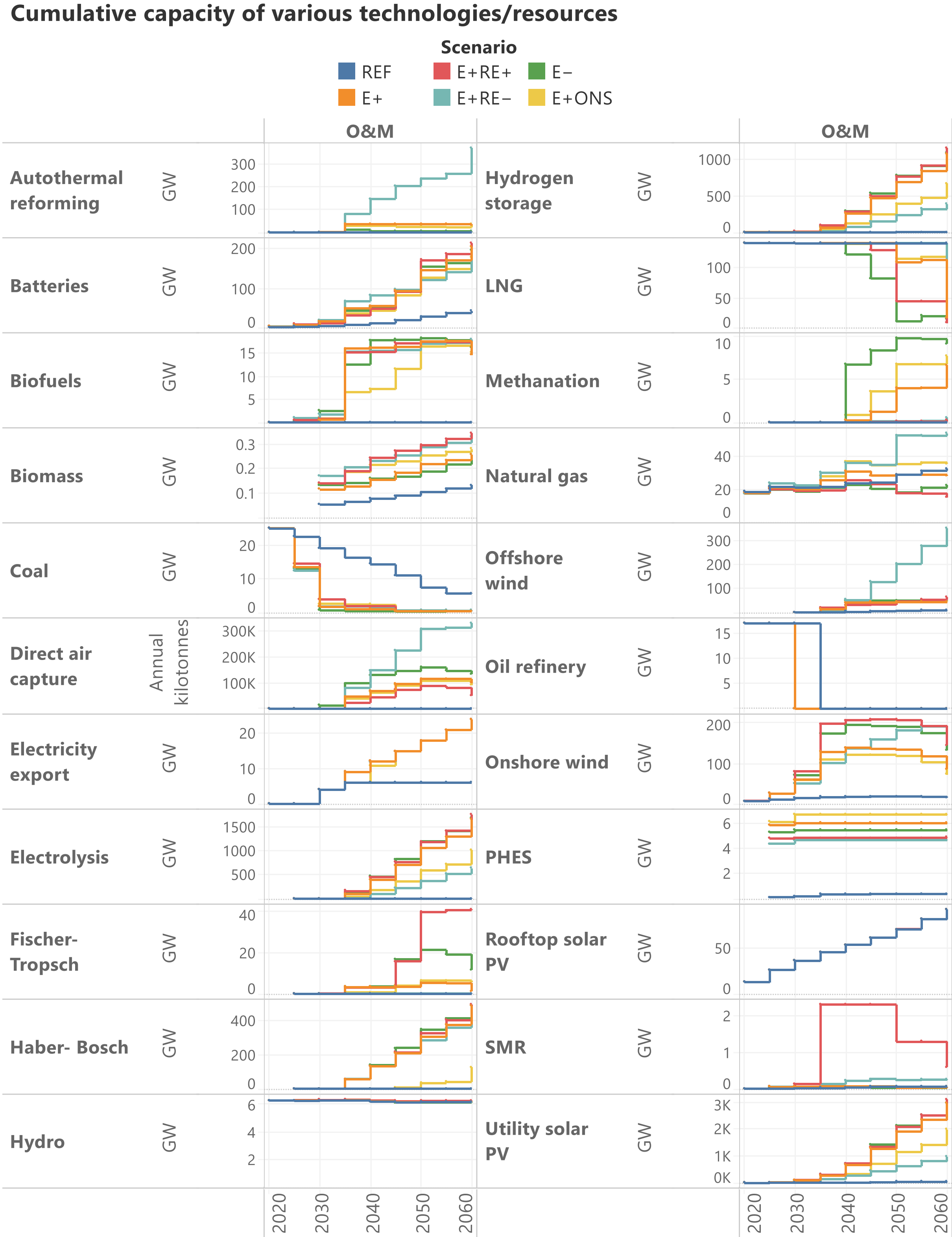


Figure 5 | Energy activity data for production by technology/resource, by year (x-axis) and Scenario for both domestic and export sectors. Production activity data are used for the Production (P) employment lifecycle stage. Note vertical axis scales vary by technology/resource.

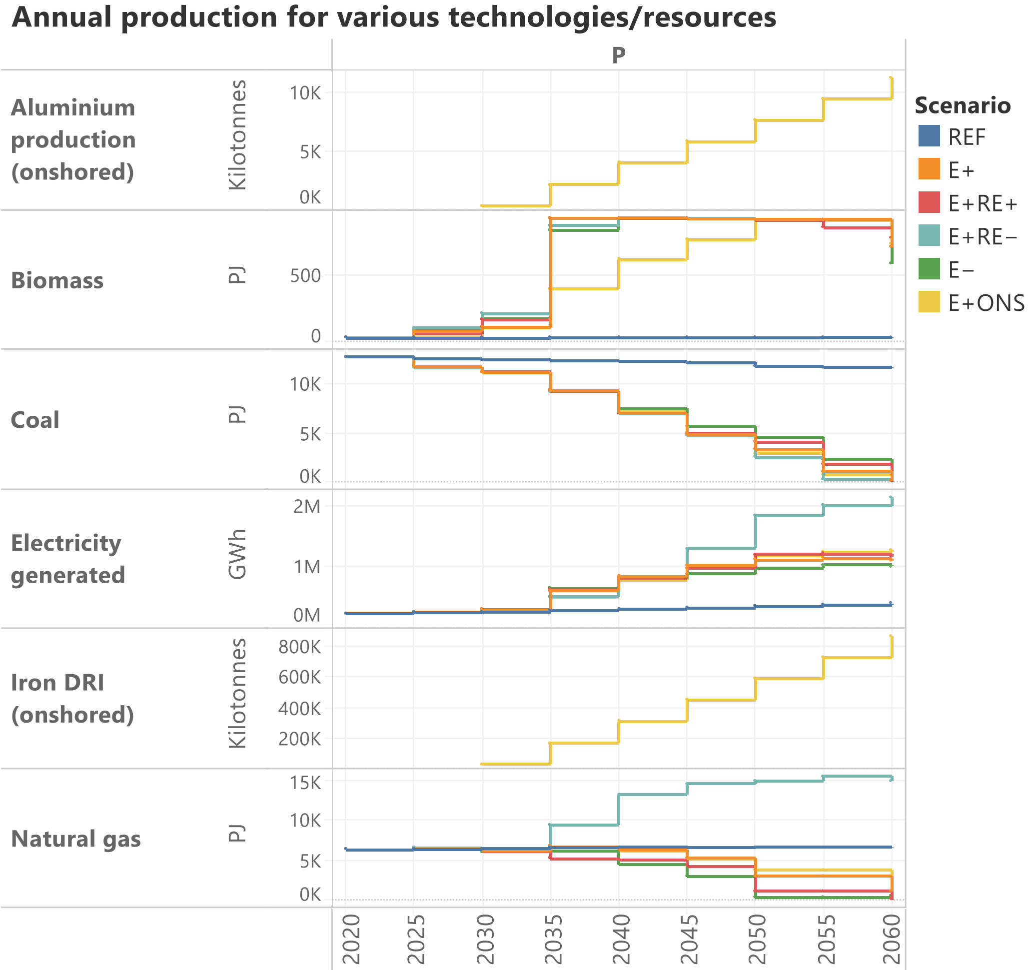
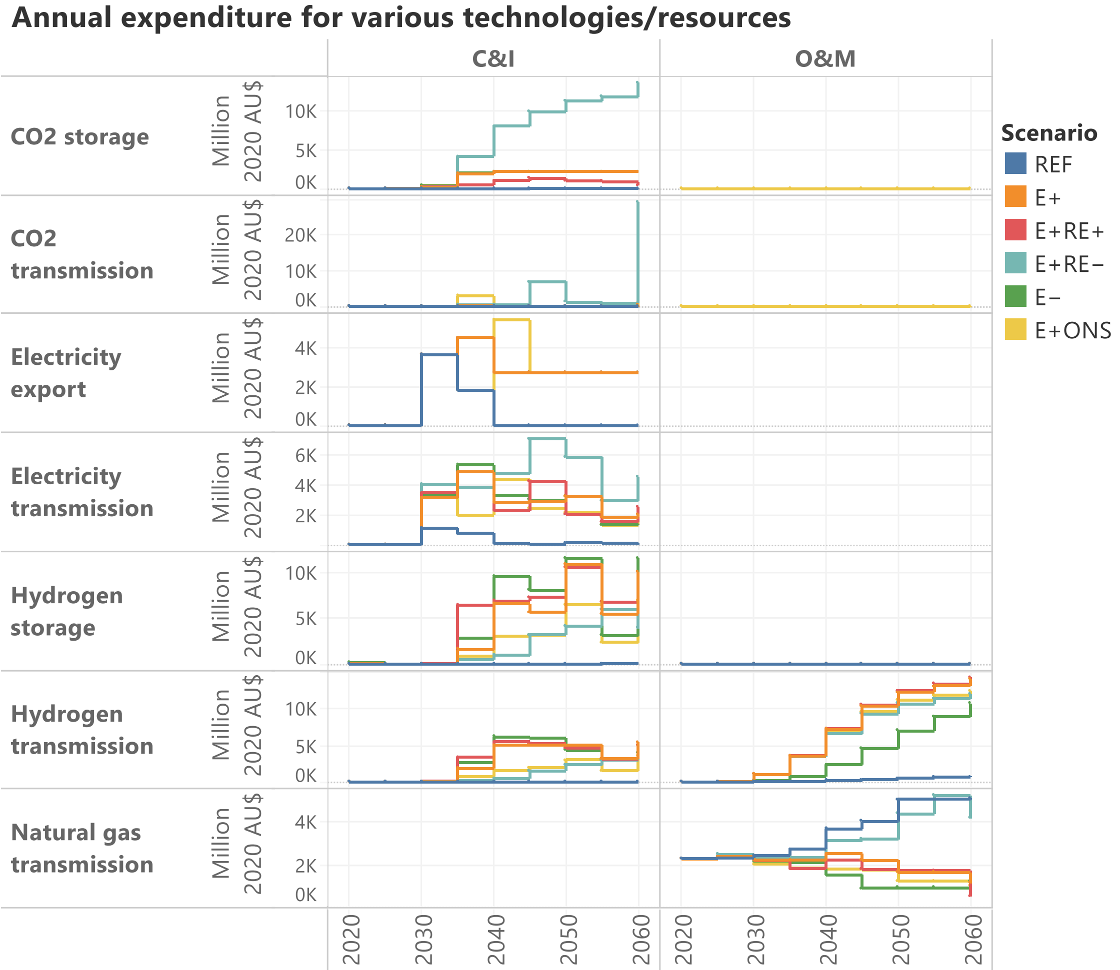


Figure 6 | Energy activity data for expenditure by technology/resource, by year and Scenario for both domestic and export sectors. Capital expenditure data are used for the Construction and installation (C&I) stage, while operating and maintenance expenditure are used for the O&M employment lifecycle stage. Note vertical axis scales vary by technology/resource.



3.1.2 Employment Factors

An Employment Factor (EF) is a measure of average or marginal 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 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 7.

In the literature, researchers derive EFs in three ways: by surveying industry professionals; by calculation based on available employment and energy activity data; and from the existing literature. A combination of these approaches may also be used. While the first two approaches are superior within a geographic area, as they ensure relevance to the context of study, they are 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 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.

Australian Bureau of Statistics (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 derived by Rutovitz et al. (2020) and Rutovitz et al. (2023), which utilised both industry surveys and historical data to calculate EFs for the Australian context.

Table 7 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 Australian and New Zealand Standard Industrial Classification (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. However, in some cases, such as *06 Coal Mining*, subdivisions or groups do not disaggregate further, and the higher level is used. An overview of each attributed ANZSIC code, including the level and industry can be found in Table 7 and Table 8.

Table 7 | All employment factors (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	**196***	job-yrs/GW	M	[2]	249	Annualised plant capacity additions
Autothermal reforming	**368***	job-yrs/GW	C&I	[2]	3109	Annualised plant capacity additions
Autothermal reforming	**121**	jobs/GW	O&M	[3]	1811	Cumulative plant capacity
Battery	**90**	job-yrs/GW	M	[16]	243	Annualised storage capacity additions
Battery	**600**	job-yrs/GW	C&I	[16]	3109	Annualised storage capacity additions
Battery	**40**	jobs/GW	O&M	[16]	2619	Cumulative storage capacity

Technology/resource	EF	EF unit	Stage	Source	ANZSIC	Energy activity basis
Biofuels	196*	job-yrs/GW	M	[2]	243	Annualised plant capacity additions
Biofuels	368*	job-yrs/GW	C&I	[2]	3109	Annualised plant capacity additions
Biofuels	121*	jobs/GW	O&M	[3]	1701	Cumulative plant capacity
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	1500	jobs/GW	O&M	[7]	2619	Cumulative generation capacity
Biomass	1588	jobs-yrs/GW	D	[6]	3212	Annualised generation capacify 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/$millionAUD	O&M	[6]	5021	Annualised OPEX spend
Coal	3320	job-yrs/GW	M	[16]	243	Annualised generation capacity additions
Coal	11100	job-yrs/GW	C&I	[16]	3109	Annualised generation capacity additions
Coal	3.24*	jobs/PJ	P	[1]	6	Annualised coal extracted
Coal	220	jobs/GW	O&M	[16]	2611	Cumulative generation capacity
Coal	690	job-yrs/GW	D	[6]	3212	Annualised generation capacity removed
Direct air capture	1.54	job-yrs/kilotonnes	M	[8]	249	Annualised extraction capacity additions
Direct air capture	1.38	job-yrs/kilotonnes	C&I	[8]	3109	Annualised extraction capacity additions
Direct air capture	0.28	jobs/kilotonnes	O&M	[8]	9429	Cumulative extraction capacity
Electricity distribution	0.10*	jobs/GWh	O&M#	[1]	263	Annual electricity generated
Electricity export	3.07*	job-yrs/$millionAUD	C&I	[6]	3109	Annualised CAPEX spend
Electricity export	440*	jobs/GW	O&M	[6]	262	Cumulative generation capacity
Electricity transmission	1.9	job-yrs/$millionAUD	C&I	[9]	3224	Annualised CAPEX spend
Electricity transmission	0.01*	jobs/GWh	O&M	[1]	262	Annual electricity generated
Electrolysis	111	job-yrs/GW	M	[10]	249	Annualised plant capacity additions^
Electrolysis	225	job-yrs/GW	C&I	[11]	3109	Annualised plant capacity additions^
Electrolysis	172	jobs/GW	O&M	[11]	1811	Cumulative plant capacity^
Fischer-Tropsch	196*	job-yrs/GW	M	[2]	249	Annualised plant capacity additions
Fischer-Tropsch	368*	job-yrs/GW	C&I	[2]	3109	Annualised plant capacity additions
Fischer-Tropsch	21*	jobs/GW	O&M	[2]	1831	Cumulative plant capacity
Haber-Bosch	196*	job-yrs/GW	M	[2]	249	Annualised plant additions
Haber-Bosch	368*	job-yrs/GW	C&I	[2]	3109	Annualised plant additions
Haber-Bosch	21*	jobs/GW	O&M	[2]	1831	Cumulative plant capacity
Hydro	2210	job-yrs/GW	M	[16]	243	Annualised generation capacity additions
Hydro	7400	job-yrs/GW	C&I	[4]	3109	Annualised generation capacity additions
Hydro	140	jobs/GW	O&M	[4]	2612	Cumulative generation capacity
Hydrogen storage	1.67*	job-yrs/$millionAUD	C&I	[6]	3212	Annualised storage capacity additions
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 (onshored)	0.58*	job-yrs/kilotonnes	C&I	[1]	3109	Annualised production capacity additions
Iron DRI (onshored)	0.09*	jobs/kilotonnes	P	[1]	211	Annualised DRI produced
LNG	196*	job-yrs/GW	M	[2]	249	Annualised plant capacity additions
LNG	368*	job-yrs/GW	C&I	[2]	3109	Annualised plant capacity additions
LNG	21*	jobs/GW	O&M	[2]	1701	Cumulative plant capacity
Methanation	788	job-yrs/GW	C&I	[12]	3109	Annualised plant capacity additions
Methanation	788	jobs/GW	O&M	[12]	1811	Cumulative plant capacity
Natural gas	380	job-yrs/GW	M	[16]	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	1588	job-yrs/GW	D	[6]	3212	Annualised generation capacity removed
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	1400	job-yrs/GW	C&I	[16]	3109	Annualised generation capacity additions
Offshore wind	80	jobs/GW	O&M	[16]	2619	Cumulative generation capacity
Offshore wind	580	job-yrs/GW	D	[13]	3212	Annualised generation capacity removed
Oil refinery	196*	job-yrs/GW	M	[2]	249	Annualised plant capacity additions

Technology/resource	EF	EF unit	Stage	Source	ANZSIC	Energy activity basis
Oil refinery	**368***	job-yrs/GW	C&I	[2]	3109	Annualised plant capacity additions
Oil refinery	**21***	jobs/GW	O&M	[2]	1701	Cumulative plant capacity
Onshore wind	**377**	job-yrs/GW	M	[4]	243	Annualised generation capacity additions
Onshore wind	**2700**	job-yrs/GW	C&I	[16]	3109	Annualised generation capacity additions
Onshore wind	**220**	jobs/GW	O&M	[4]	2619	Cumulative generation capacity
Onshore wind	**460**	job-yrs/GW	D	[14]	3212	Annualised generation capacity removed
PHES	**699**	job-yrs/GW	M	[4]	243	Annualised generation capacity additions
PHES	**7200**	job-yrs/GW	C&I	[4]	3109	Annualised generation capacity additions
PHES	**80**	jobs/GW	O&M	[4]	2612	Cumulative generation capacity
Rooftop solar PV	**153**	job-yrs/GW	M	[4]	243	Annualised generation capacity additions
Rooftop solar PV	**5200**	job-yrs/GW	C&I	[16]	3109	Annualised generation capacity additions
Rooftop solar PV	**160**	jobs/GW	O&M	[4]	2619	Cumulative generation capacity
SMR	**196***	job-yrs/GW	M	[2]	249	Annualised plant capacity additions
SMR	**368***	job-yrs/GW	C&I	[2]	3109	Annualised plant capacity additions
SMR	**121***	jobs/GW	O&M	[3]	1811	Cumulative plant capacity
Utility solar PV	**90**	job-yrs/GW	M	[16]	243	Annualised generation capacity additions
Utility solar PV	**2100**	job-yrs/GW	C&I	[16]	3109	Annualised generation capacity additions
Utility solar PV	**110**	jobs/GW	O&M	[4]	2619	Cumulative generation capacity
Utility solar PV	**282**	job-yrs/GW	D	[15]	3212	Annualised generation capacity removed

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 9. 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] Larson et al., 2020.
[9] Briggs et al., 2021.
[10] Nel ASA, 2018.
[11] Leguijt et al., 2021.
[12] Navigant Netherlands B.V., 2019.
[13] International Renewable Energy Agency (IRENA), 2018.
[14] IRENA, 2017a.
[15] IRENA 2017b.
[16] Rutovitz et al., 2023.
Note electricity distribution jobs are assumed to include both C&I and O&M, but have been allocated to O&M.
^ The energy activity basis for electrolysis use plant capacity in terms of heating value of hydrogen produced per unit time, rather than nameplate electrical capacity. Electrolysis EFs are adjusted according to the conversion efficiencies outlined in NZAu (2022a), increasing linearly from 69-74% by 1% every five years from 2020.

Table 8 | 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
2611	Class	Fossil Fuel Electricity Generation
2612	Class	Hydro-Electricity Generation

ANZSIC	Level	Industry
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
3224	Class	Structural Steel Erection Services
5021	Class	Pipeline Transport
9429	Class	Other Machinery and Equipment Repair and Maintenance

3.1.3 EF derivations and calculations

As noted in Table 7, 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 9.

Where EFs have been calculated using historical employment data, this has been sourced from the *ABS Jobs in Australia, 2011-12 to 2018-19* (2021b) report for the ANZSIC classes outlined in Table 8. 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 9 | Summary of all EFs that have been derived from similar technologies, calculated from historical data or undergone unit conversion.

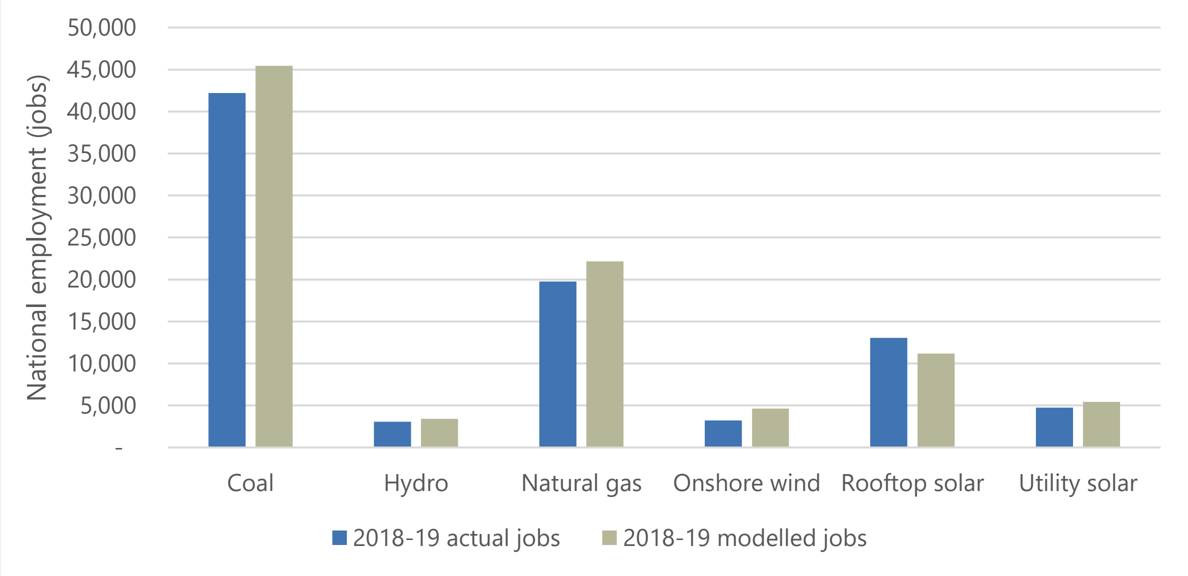
Technology/resource	Stage(s)	Derivation	Notes
Aluminium production (onshored)	C&I	Derived from similar technology	From onshored iron DRI production EF.
Aluminium production (onshored)	P	Calculated from historical data	EF is the sum of alumina refining and aluminium smelting EFs: $EF_{(jobs/kilotonne)} = \Sigma\ (EF\_alumina + EF\_aluminium)$
Alumina refining	P	Calculated from historical data	Alumina refining EF calculated as the average of EFs over 2016-2020: $EF_{(jobs/kilotonne)} = \Sigma\ (jobs / production_{(kilotonnes)}) / \text{no. years}$
Aluminium smelting	P	Calculated from historical data	Aluminium smelting EF calculated as the average of EFs over 2016-2020: $EF_{(jobs/kilotonne)} = \Sigma\ (jobs / production_{(kilotonnes)}) / \text{no. years}$
Autothermal reforming	M, C&I	Derived from similar technology	Using inputs for a simple refinery with an output of 30,000 barrels per day
Biofuels	All	Derived from similar technology	From autothermal reforming EFs.
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 in Mayfield et al. (2021): $EF_{(jobs/\$millionAUD)} = EF_{(jobs/\$millionUSD)} \times \text{exchange rate}$
CO_2 transmission	C&I	Unit conversion	From CO_2 transmission EFs in Mayfield et al. (2021): $EF_{(jobs/\$millionAUD)} = EF_{(jobs/\$millionUSD)} \times \text{exchange rate}$
CO_2 transmission	O&M	Unit conversion	From CO_2 transmission EF in Mayfield et al. (2021): $EF_{(jobs/\$millionAUD)} = EF_{(jobs/\$millionUSD)} \times \text{exchange rate}$

Technology/resource	Stage(s)	Derivation	Notes
Electricity distribution	O&M	Calculated from historical data	$EF_{(jobs/GWh)}$ = distribution jobs / electricity $generated_{(GWh)}$
Electricity export	C&I	Derived from similar technology	From electricity transmission EF in 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 in Mayfield et al. (2021).
Electricity transmission	O&M	Calculated from historical data	$EF_{(jobs/GWh)}$ = transmission jobs / electricity $generated_{(GWh)}$
Fischer-Tropsch	All	Derived from similar technology	Using inputs for a simple refinery with an output of 30,000 barrels per day.
Haber-Bosch	All	Derived from similar technology	Using inputs for a simple refinery with an output of 30,000 barrels per day.
Hydrogen storage	C&I	Derived from similar technology	From CO_2 injection EFs in Mayfield et al. (2021). See above for unit conversions.
Hydrogen transmission	All	Derived from similar technology	From CO_2 transmission EFs in Mayfield et al. (2021). See above for unit conversions.
Iron DRI (onshored)	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 (onshored)	P	Derived from similar technology	Based on alumina refining EF.
LNG	All	Derived from similar technology	Using inputs for a simple refinery with an output of 30,000 barrels per day.
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 in Mayfield et al. (2021). See above for unit conversions.
Offshore wind	M	Derived from similar technology	From onshore wind manufacturing in Rutovitz et al. (2020).
Oil refinery	All	Derived from similar technology	Using inputs for a simple refinery with an output of 30,000 barrels per day.
SMR	All	Derived from similar technology	From autothermal reforming EFs.

3.1.4 Model validation

These employment factors used can be validated by comparing actual with modelled employment for a given year, as is shown in Figure 7. For this purpose, Financial Year 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 7 | Comparison of 2018 actual and modelled employment by resource sector. The relative total difference across all sectors is 7.2%, the mean absolute error is 17%, and the median absolute error is 13%.



3.1.5 Labour learning factors

All jobs are assumed to experience improvements in labour productivity over time, producing efficiencies that reduce employment intensity. 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). Commonwealth Scientific Industrial Research Organisation (CSIRO) capital cost reductions from the *GenCost 2020-21* High Variable Renewable Energy scenario have therefore been used to calculate learning factors for available technologies. 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 factors 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 (2022a), with the lowest capital cost technology chosen for each year.

For technologies not covered by the GenCost projections, learning rates have been based on calculations for a comparable developed, industrialised economy, using a lower-bound estimate of 1.2% per annum, or a learning rate of 2.5% per annum for electrical grid technologies (United Nations Industrial Development Organization and Global Green Growth Institute, 2015). For ease of modelling, 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).

All learning factors by technology/resource are summarised in Table 10.

Table 10 | Learning factors by technology/resource and year, as a proportion of the initial (2020) EF.

Technology/resource	Annual decline	Source	2020	2025	2030	2035	2040	2045	2050	2055	2060
Aluminium production (onshored)	1.2%	Assumed	100%	94%	89%	84%	79%	74%	70%	66%	62%
Autothermal reforming	1.2%	Assumed	100%	94%	89%	84%	79%	74%	70%	66%	62%
Batteries	Variable	CSIRO (2021)	100%	56%	39%	35%	32%	29%	26%	26%	26%
Biofuels	1.2%	Assumed	100%	94%	89%	84%	79%	74%	70%	66%	62%
Biomass	Variable	CSIRO (2021)	100%	99%	98%	97%	97%	96%	95%	95%	95%
CO_2 storage	1.2%	Assumed	100%	94%	89%	84%	79%	74%	70%	66%	62%
CO_2 transmission	1.2%	Assumed	100%	94%	89%	84%	79%	74%	70%	66%	62%
Coal	Variable	CSIRO (2021)	100%	99%	98%	97%	96%	95%	94%	94%	94%
Direct air capture	1.2%	Assumed	100%	94%	89%	84%	79%	74%	70%	66%	62%
Electricity distribution	2.5%	Assumed	100%	88%	78%	69%	61%	54%	48%	42%	37%
Electricity export	2.5%	Assumed	100%	88%	78%	69%	61%	54%	48%	42%	37%
Electricity transmission	2.5%	Assumed	100%	88%	78%	69%	61%	54%	48%	42%	37%
Electrolysis	Variable	NZAu (2022a)	100%	69%	47%	35%	30%	28%	28%	28%	28%
Fischer-Tropsch	1.2%	Assumed	100%	94%	89%	84%	79%	74%	70%	66%	62%
Haber-Bosch	1.2%	Assumed	100%	94%	89%	84%	79%	74%	70%	66%	62%
Hydro	Variable	CSIRO (2021)	100%	99%	98%	97%	97%	96%	95%	95%	95%
Hydrogen storage	1.2%	Assumed	100%	94%	89%	84%	79%	74%	70%	66%	62%
Hydrogen transmission	1.2%	Assumed	100%	94%	89%	84%	79%	74%	70%	66%	62%
Iron DRI (onshored)	1.2%	Assumed	100%	94%	89%	84%	79%	74%	70%	66%	62%
LNG	1.2%	Assumed	100%	94%	89%	84%	79%	74%	70%	66%	62%
Methanation	1.2%	Assumed	100%	94%	89%	84%	79%	74%	70%	66%	62%
Natural gas	Variable	CSIRO (2021)	100%	99%	98%	97%	96%	95%	94%	94%	94%
Natural gas transmission	1.2%	Assumed	100%	94%	89%	84%	79%	74%	70%	66%	62%
Offshore wind	Variable	CSIRO (2021)	100%	94%	91%	88%	86%	83%	80%	80%	80%
Oil refinery	1.2%	Assumed	100%	94%	89%	84%	79%	74%	70%	66%	62%
Onshore wind	Variable	CSIRO (2021)	100%	98%	95%	94%	93%	91%	91%	91%	91%
PHES	Variable	CSIRO (2021)	100%	99%	98%	97%	97%	96%	95%	95%	95%
Rooftop solar PV	Variable	CSIRO (2021)	100%	60%	52%	46%	39%	38%	36%	36%	36%
SMR	1.2%	Assumed	100%	94%	89%	84%	79%	74%	70%	66%	62%
Utility solar PV	Variable	CSIRO (2021)	100%	58%	51%	45%	38%	37%	35%	35%	35%

3.2 Workforce projection

Workforce projections combine working-age (15 and over) population projections with a workforce participation rate projection to estimate the future size of the workforce by Australian state/territory. 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 8. This indicates that the states with the largest projected workforce growth are Victoria, New South Wales (NSW), and Queensland.

Figure 8 | Australian population and workforce projections (above); and workforce projections disaggregated by state/territory per decade to 2060 (below).

3.3 Occupation projection

As seen in Table 7, each technology/resource and stage has been assigned a relevant ANZSIC code. Using 2021 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 2021 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 of energy activity associated with each ANZSIC code. The product is then summarised by occupation.

3.4 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 11 provides a breakdown of ANZSCO skill levels.

Some aggregated occupations are assigned multiple skills. For example, workers in *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.

Table 11 | 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.

4 Results

4.1 National levels of employment in the energy system

4.1.1 Gross jobs

Figure 9 presents modelled gross Australian jobs employed within the energy sector for all technologies/resources in Table 2 and for *Net Zero Australia*'s Core Scenarios. *Gross jobs* represent the total number of jobs in each year employed in the energy sector and are calculated using the equations shown in Figure 1. As the modelled energy activity includes existing generation infrastructure and extraction processes, gross employment includes currently existing jobs.

Gross domestic sector employment has relatively small variation between most net zero Scenarios, requiring between 216-262 thousand jobs in 2050 for the E+ rapid electrification, E+ RE+ full renewables, E− slower electrification and E+ONS onshoring Scenarios. Gross domestic sector jobs in the E+RE− constrained renewables Scenario is significantly higher, at 415 thousand jobs in 2050. All of these results represent significantly greater employment than the roughly 74 thousand domestic sector jobs modelled for the Reference Scenario in 2050. Gross export jobs are also subject to relatively limited variation, with between 348-511 thousand jobs modelled for all net zero Scenarios in 2060. These are greater by an order of magnitude on the Reference Scenario, which has 57 thousand workers in 2060.

Further detail is presented in Figure 10, which provides a breakdown of gross jobs by technology/resource and for the domestic and export energy sectors. Variation in employment between Scenarios is due to energy-system modelling optimising for different technologies to meet different Scenario constraints, which have varying levels of labour intensity. For example, the E+RE− constrained renewables Scenario expands extraction of natural gas for export through conversion to H_2 via autothermal reforming. Also, constrained build rates for utility solar PV in E+RE− require the substitution of more offshore wind across both domestic and export sectors. Due to the expanded use of fossil fuels, greater deployment of direct air capture and CO_2 storage and transmission is required to meet the net zero emissions constraint.

Figure 9 | Gross jobs by domestic (left) and export (right) sectors and Scenario. Values have units of full-time equivalent jobs.

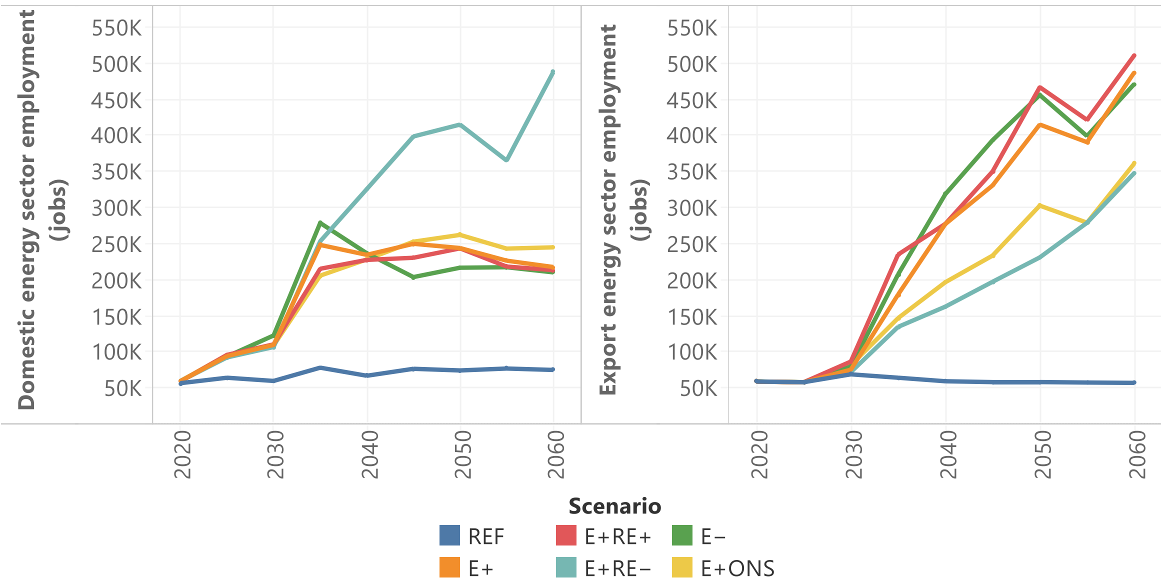


Figure 10 | Gross jobs by Scenario and domestic (above) and export (below) sectors, for each modelled technology/resource. Results are in full-time equivalent jobs. Technologies with low individual employment have been aggregated as 'Other'.

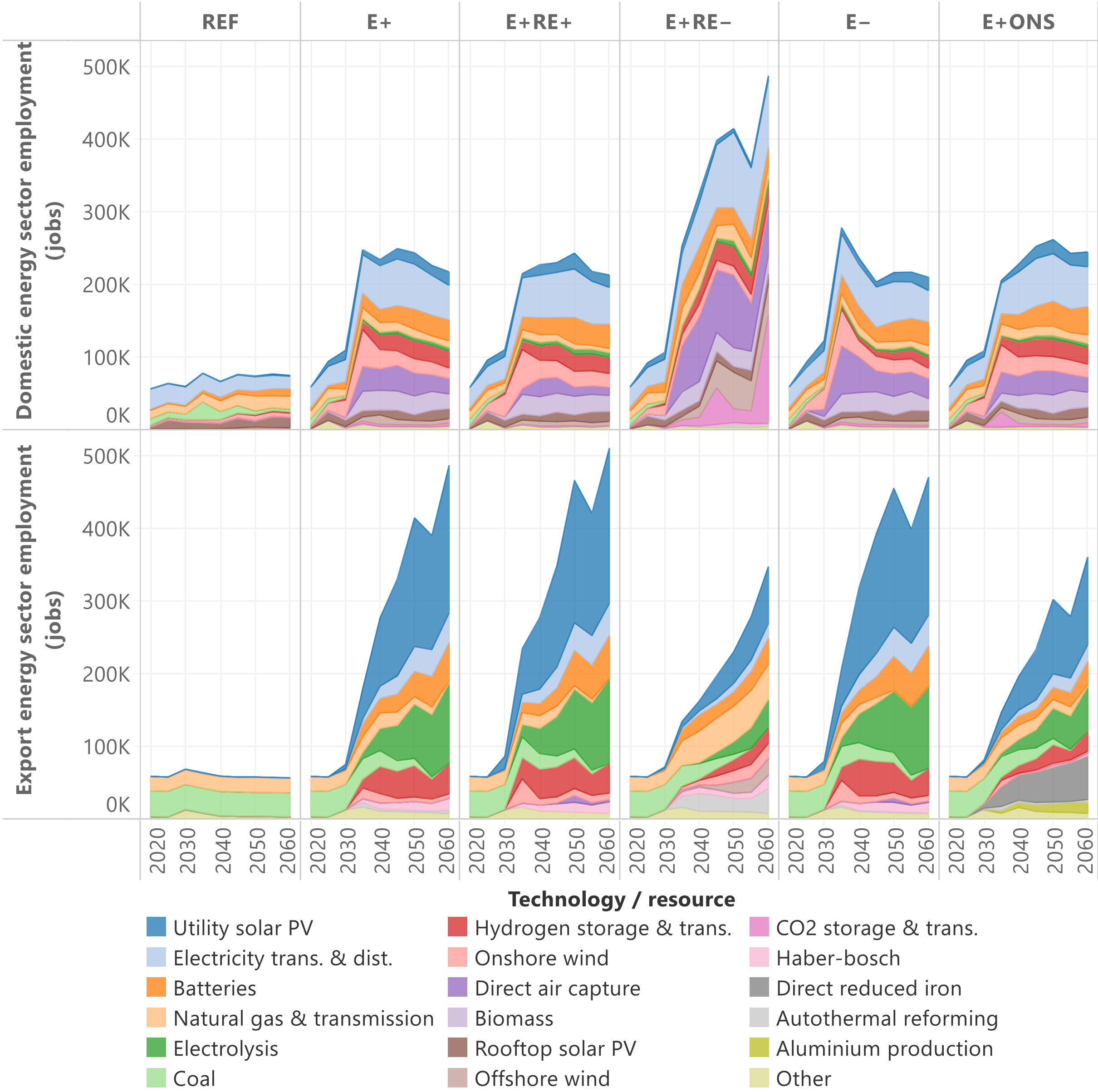
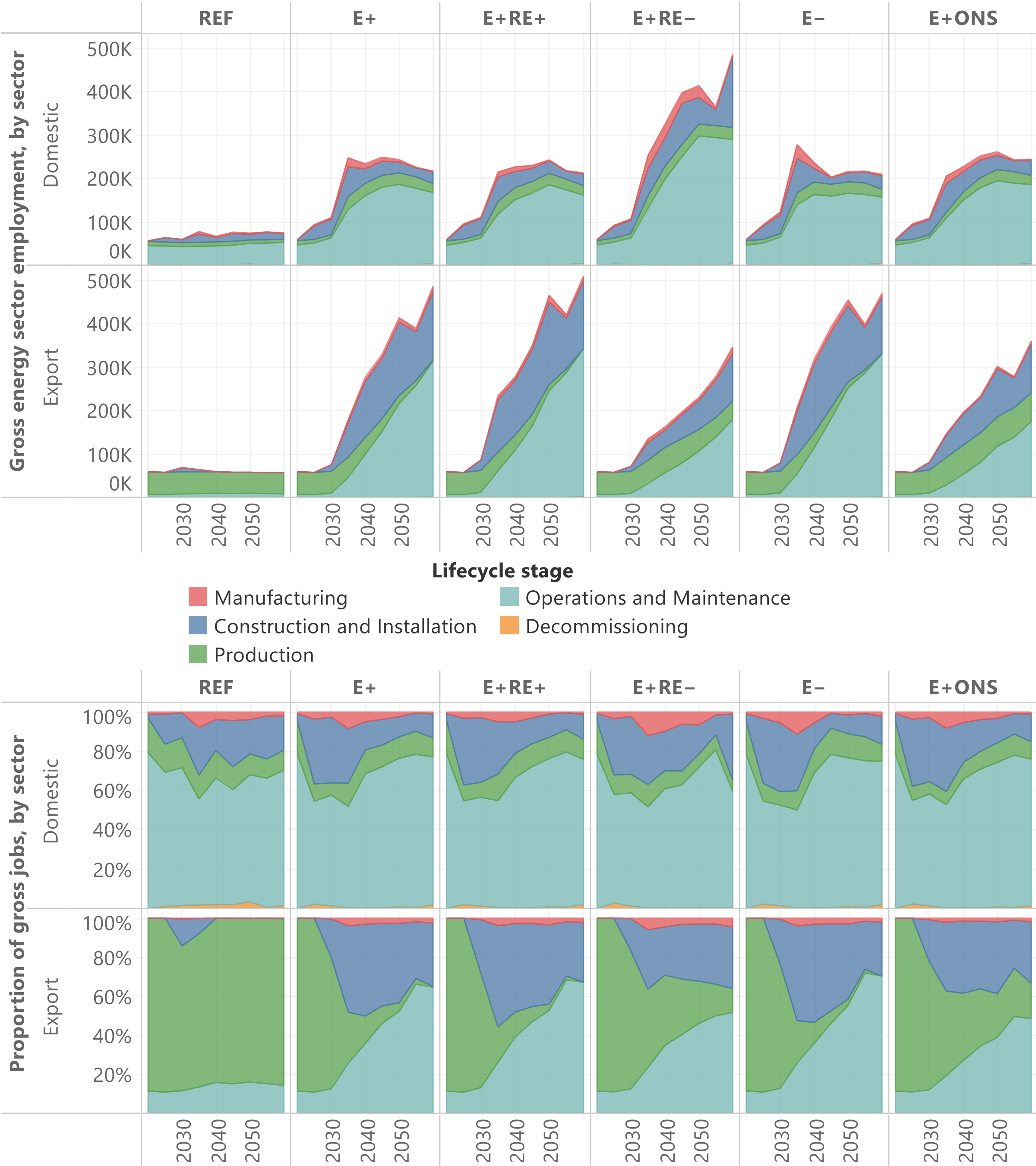


Figure 11 presents employment by lifecycle stage for each Scenario and sector over time. In the domestic sector, manufacturing peaks at ~10% of total jobs, but generally fluctuates at or below 5% across the modelled period. C&I peaks at ~35% of employment between 2025-2035 before decreasing to between 10-14% for the remainder of the modelled period. O&M experiences growing prevalence, increasing from ~50% of energy sector employment to ~75% by 2050-60. As production jobs in coal mining and natural gas extraction decrease, jobs in biomass increase, resulting in a proportionate decrease in production from 15% of total employment in 2020 to between 5-10% 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, though these remain a negligible share of total jobs.

As the export sector starts to decarbonise from 2030, there are more pronounced changes in the proportional makeup of employment by lifecycle stage, with production jobs reducing sharply from ~90%

to less than 10% of total jobs by 2060. Unsurprisingly, C&I increases substantially from 2030, peaking at between 30-50% of total employment before diminishing to between 25-35% by 2060. O&M occupies a growing proportion of total employment, increasing from 5% in 2030 to peak at 50-72% in 2060. Manufacturing jobs consistently contribute between 1-3% of total jobs throughout 2030-2060. The potential job impacts of expanding domestic manufacturing capacity is discussed in further detail below. This result demonstrates that while there is a medium-term boom in construction demand between 2025-2045, this gives way to a large workforce of ongoing O&M jobs towards the end of the modelled period.

Figure 11 | Gross jobs by lifecycle stage, Scenario and disaggregated by Domestic and Export sectors (top), and proportion of gross jobs by lifecycle stage and Scenario (bottom). Values in units of full-time equivalent jobs.

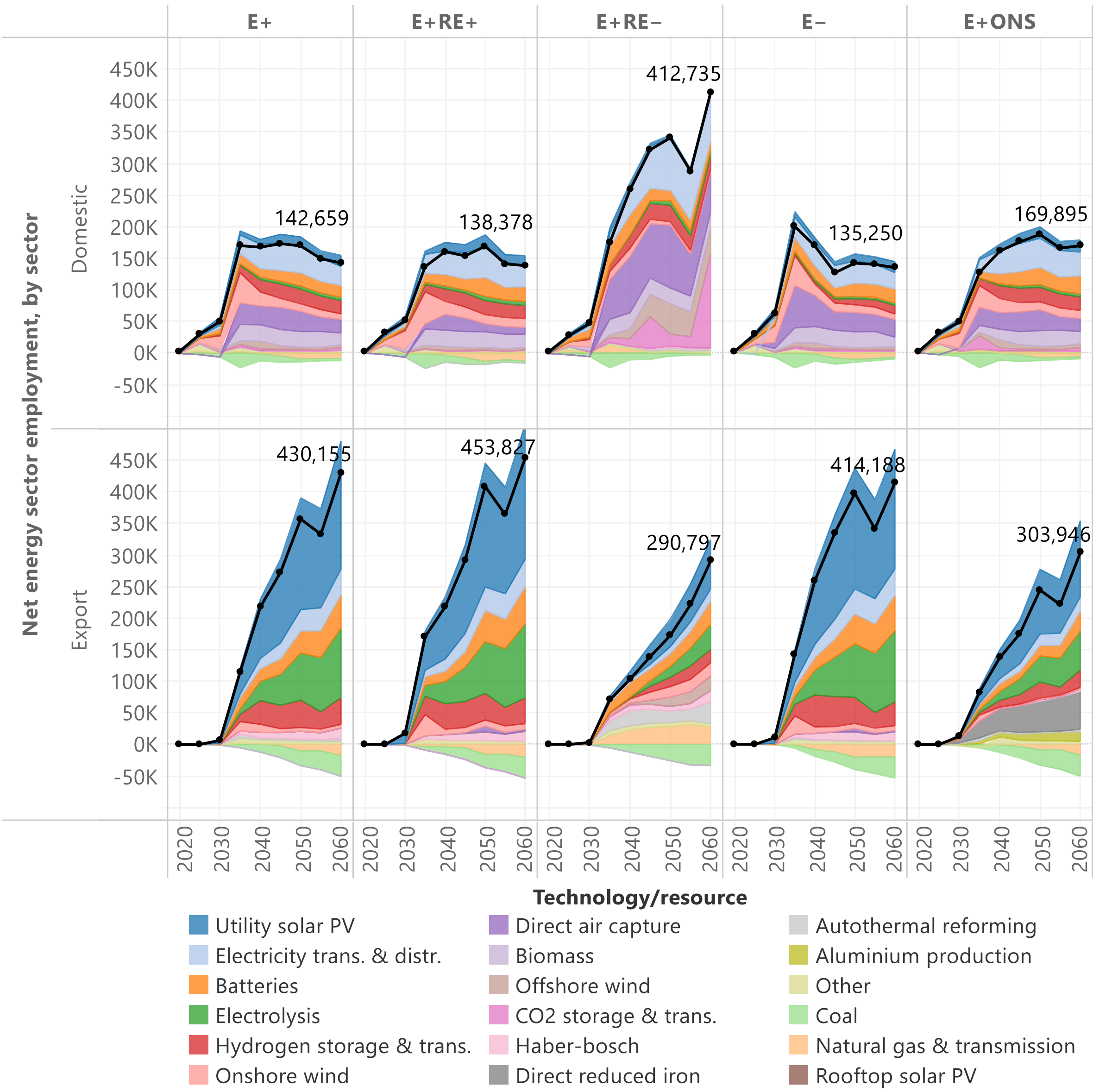


4.1.2 Net jobs

Figure 12 presents net jobs of each modelled net-zero Scenario by technology/resource. Here, *net jobs* describe the difference in gross employment between a given net-zero Scenario and the Reference Scenario, and is therefore a measure of jobs that will be both created and lost because of the net-zero transition.

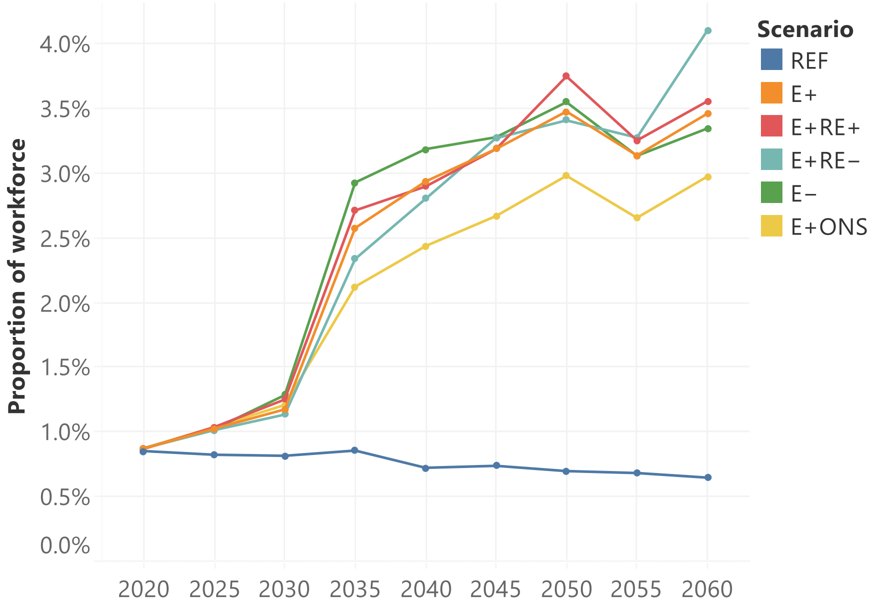
The net employment results demonstrate that job losses are largely restricted to coal and natural gas, and are approximately 15 thousand jobs in the domestic energy sector and 50 thousand jobs in the export energy sector by 2060. While there is net positive job creation for every modelled year, jobs losses will be concentrated in coal and natural gas sectors in fossil-fuel dependent regions, which may occur in different regions to those with the new jobs. As discussed, spatial mapping of net job losses results provides key insights into the impacts on local communities, and will be explored in greater detail below (Cass et al., 2022).

Figure 12 | Net jobs by Scenario and domestic and export sectors, for each modelled technology/ resource. Values are in units of full-time equivalent jobs and are relative to the Reference Scenario in each year. Total net jobs across all technologies/resources are indicated by the black line, with labels for 2020 and 2060.



Finally, Figure 13 shows the proportion of the overall workforce projected to be occupied by energy sector jobs. This indicates that the absolute proportion of the energy workforce increases from under 1% in 2020 to between 3-4% by 2060, depending on the Scenario.

Figure 13 | Proportion of projected workforce occupied by the energy sector in each Scenario.



4.2 Spatial distribution of energy system employment

4.2.1 Gross jobs

Jobs are spatially distributed across each modelled domestic region and designated zones for the export system. Figure 14 depicts gross energy sector jobs by state and territory for each decade to 2060 according to this domestic and export split, and Figure 15 graphs the evolution of gross jobs by state and territory. While each state and territory undergoes an increase in employment to 2060, this growth is unevenly distributed across geography and Scenario. The domestic sector is relatively stable, with most states fluctuating a few percentage points over time. The exception is the E+RE− constrained renewables Scenario, which sees growth in the relative prominence of the Northern Territory and Victoria, which offsets relative reductions in NSW and Queensland.

The export sector undergoes more significant change in the spatial distribution of employment. A clear pattern emerges across the E+ rapid electrification, E− slower electrification and E+ RE+ full renewables, in which most growth is concentrated in the sunbelt of Western Australia, the Northern Territory and Queensland. At the same time the role of NSW in export sector employment rapidly diminishes to zero by 2045. In the E+RE− constrained renewables and the E+ONS onshoring Scenario, there are fewer export jobs in Queensland, and considerably more in Western Australia.

Figure 14 | Gross jobs by state/territory and sector for each decade to 2060.

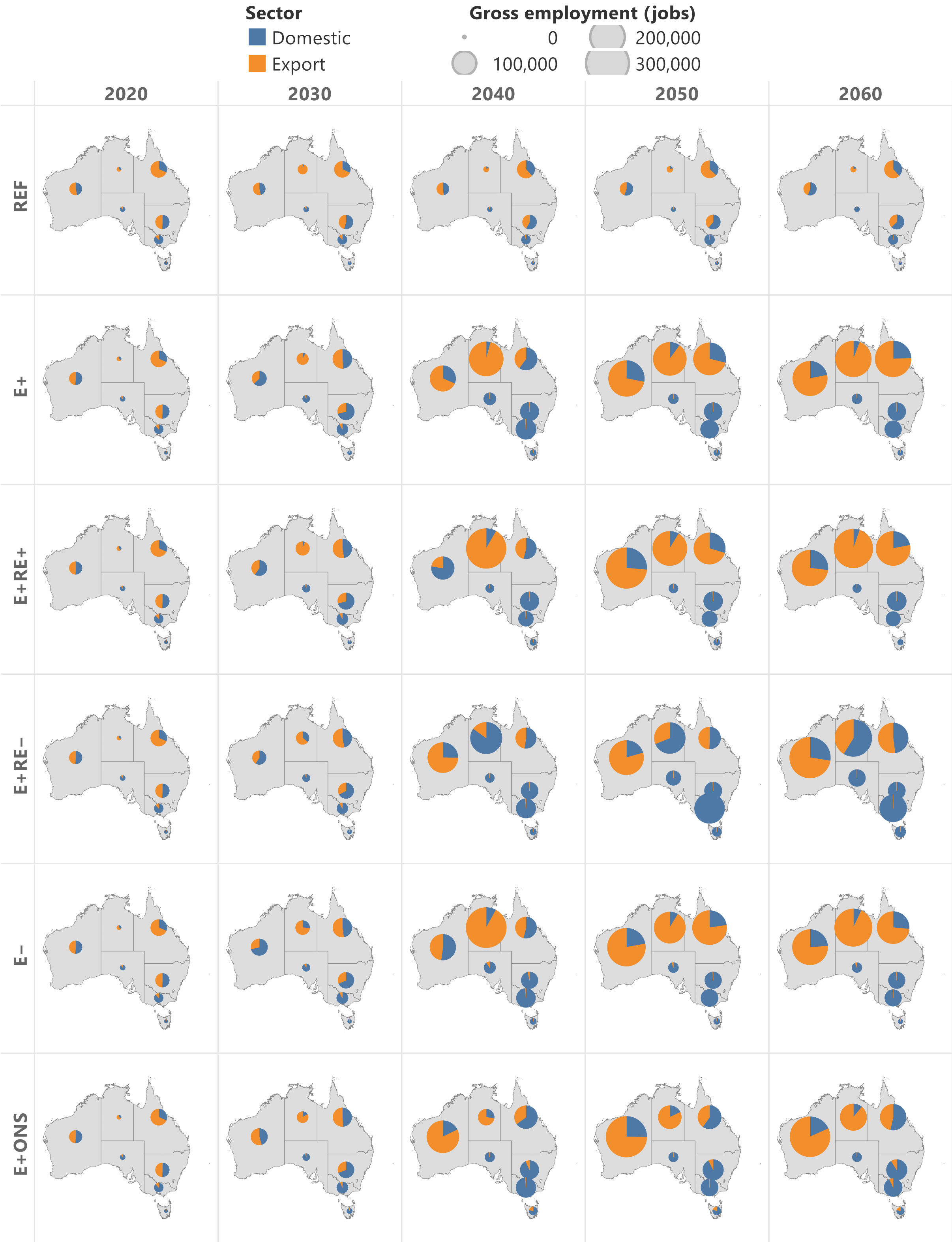


Figure 15 | Gross jobs by sector and state/territory to 2060. We note that NSW here includes the ACT.

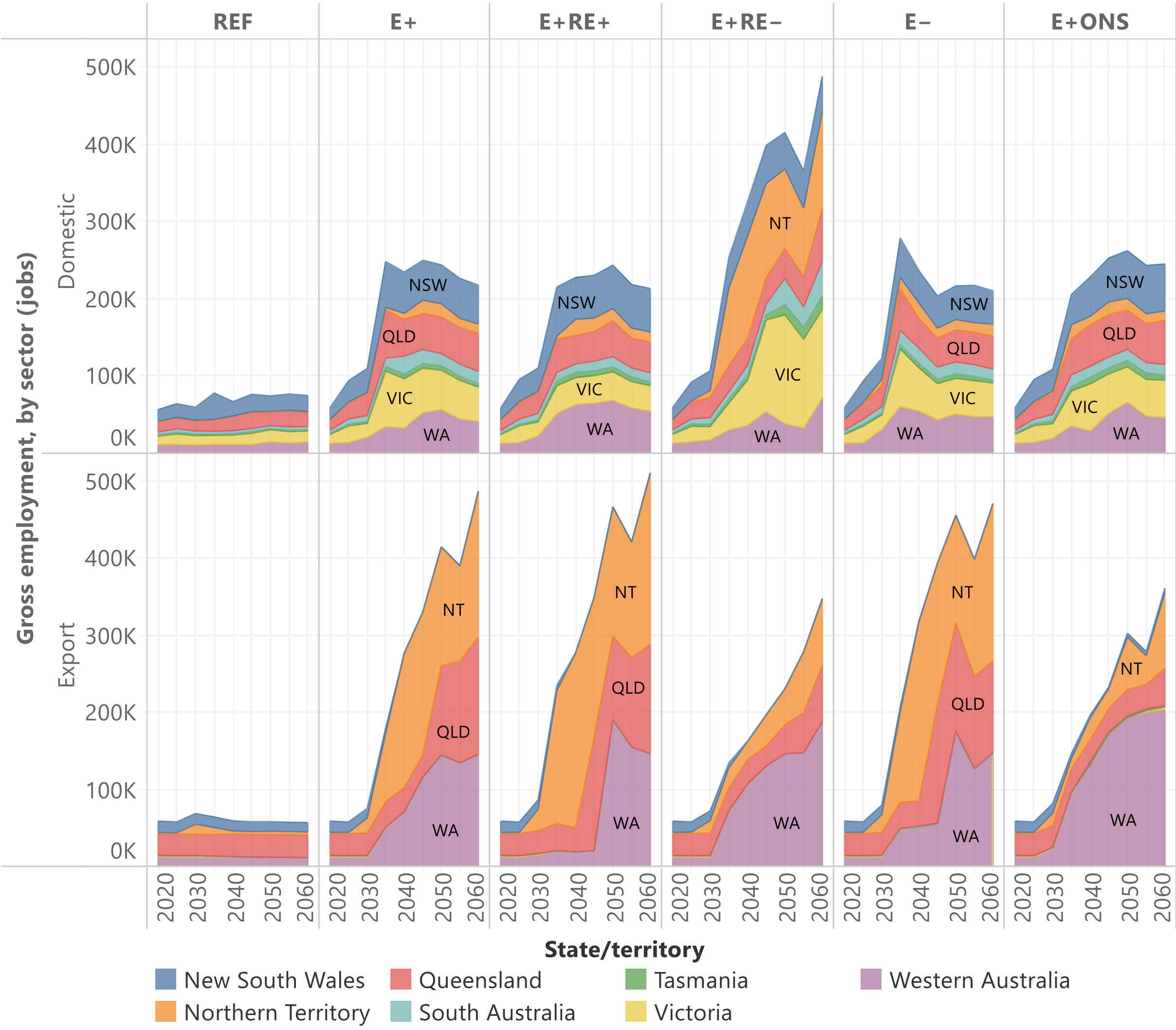
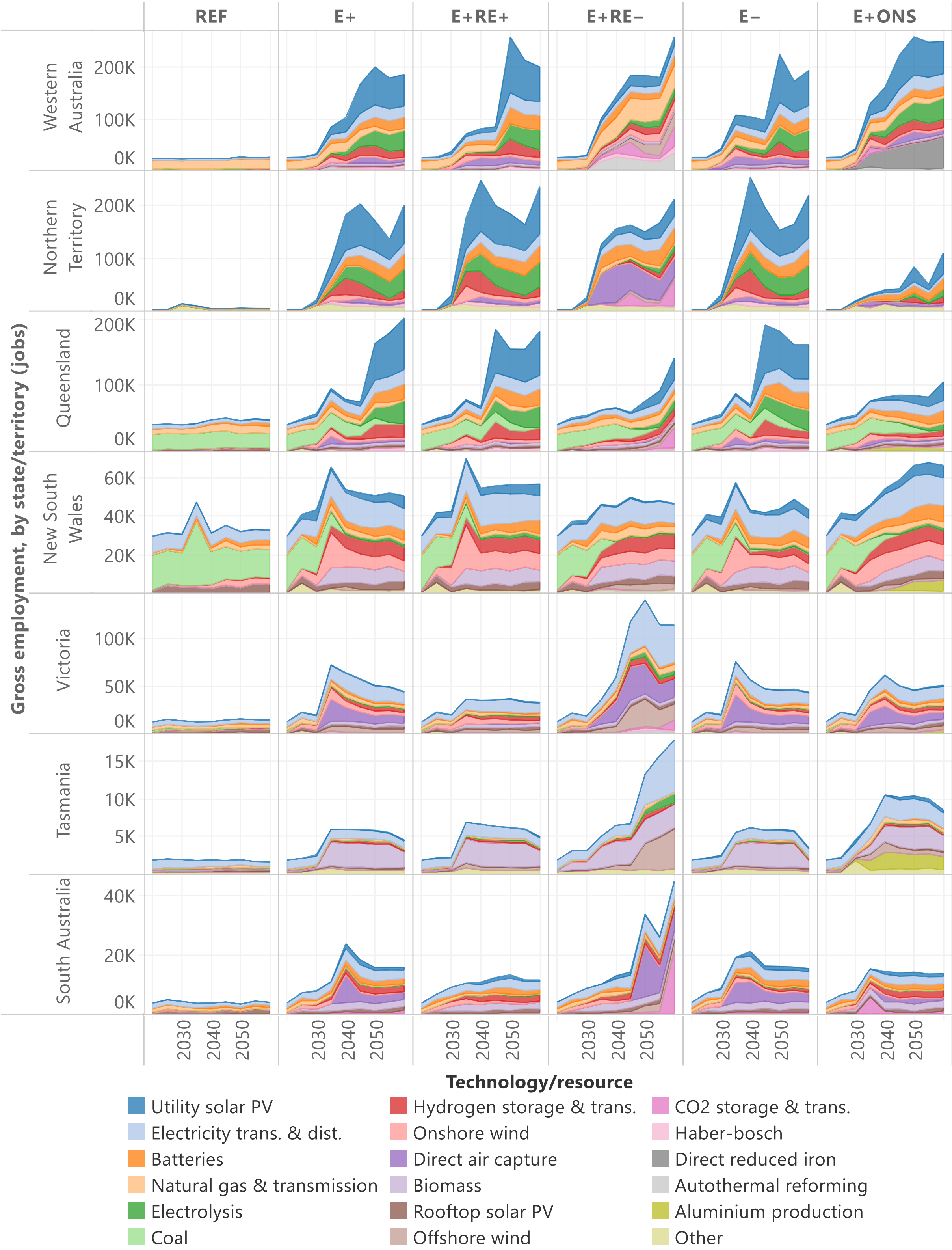


Figure 16 presents gross jobs by Scenario, technology/resource, and state/territory, without the domestic export sector split. This provides insights into the causes of growth between each Scenario, and how the makeup of the energy sector changes over time in each state/territory.

In the domestic sector, most states and territories experience large-scale deployment of utility solar, batteries, and electricity transmission and distribution, offsetting the dominant role occupied by coal and natural gas at present. The proportional makeup of each state is then relatively stable. Direct air capture and CO_2 transmission and storage, particularly in the E+RE− constrained renewables Scenario induce significant growth in employment across regions with CO_2 sequestration resource. We note, however that direct air capture has a particularly high manufacturing EF, which we have not reduced for the Australian context.

In most Scenarios the relative importance of coal and natural gas in the export sector are rapidly displaced by major growth in hydrogen supply chain technologies, including utility solar, electrolysis, Haber-Bosch and hydrogen storage and transmission. However, as noted, this growth is disproportionately located in the sunbelt of Western Australia, the Northern Territory and Queensland. In NSW, all export coal jobs are largely displaced by 2040-45, and by 2055-60 in Queensland. Natural gas export jobs are more variable, being largely eliminated in Western Australia by 2050 in the E+RE+ full renewables and E− slower electrification Scenarios, persisting to 2060 in the E+ rapid electrification and E+ONS onshoring Scenario, and increasing five-fold from 2030-2060 in the E+RE− constrained renewables Scenario. In Queensland, natural gas export jobs are more stable, only reducing from 2055-2060 in the E+ rapid electrification, E+RE+ full renewables, and E+ONS onshoring Scenarios. Jobs reduce considerably from 2040 in the E− slower electrification Scenario and increase two- to three-fold from 2040-60 in the E+RE− constrained renewables Scenario.

Figure 16 | Gross jobs by Scenario, technology, and state/territory (for both domestic and export sectors). Units are full-time equivalent jobs. Note that vertical axis range varies between states/territory.



4.2.2 Net jobs

Figure 17 presents net jobs by state/territory across both the domestic and export sectors for selected years to 2060. This demonstrates that all states and territories experience net positive energy jobs growth as a result of the modelled energy system transition in each decade and Scenario. Furthermore, examining those jobs associated with serving domestic energy demand in isolation and at the more granular 15 NZAu domestic zone level shows the same result of net positive jobs throughout the transition, with the exception of very small net negative jobs in 2030 for eastern Victoria, associated with closures of brown coal assets (Figure 18).

Figure 19 then presents the net jobs associated with serving energy export demand in isolation, showing greater spatial variation and net job losses in certain states/territories. NSW experiences job losses consistently across all Scenarios from the 2030s. These job losses are primarily caused by reduction in demand for coal mining and natural gas extraction.

Further detail on the nature of the spatial distribution of net jobs in the E+ rapid electrification Scenario in 2030 and 2060 is then presented in Figure 20. This shows that in 2030, job losses are primarily associated with closures of coal mining and power generation assets in central NSW, across Queensland, and in eastern Victoria. Job losses can also be observed in WA, associated with reductions in natural gas activity. We note that in 2030 – the first year of applying the export energy emissions constraint – growth in renewable energy exports is yet to occur and so the huge growth in export sector employment is yet to offset jobs losses in some regions. In 2030, the increase in net jobs is driven by a build out of renewable electricity and grid assets, which is not entirely coincident with the regions in which coal and gas jobs are lost.

Figure 20shows that by 2060 growth in export jobs more than offset any job losses in most regions, while significant domestic sector job growth occurs in all regions. We note that in 2060 the reduction in brown coal jobs in eastern Victoria are no longer considered a net job loss due to the counterfactual reference Scenario also modelling closures of those brown coal assets.

Figure 21 presents net jobs for the coal and natural gas industries only (across both domestic and export energy sectors). This demonstrates that NSW from the 2030s and Queensland from the 2040s experience job losses across all Scenarios. Western Australia also experiences job losses in most Scenarios due to declining natural gas extraction employment, except for the E+RE- constrained renewables Scenario, in which natural gas jobs increase substantially to meet hydrogen demand through autothermal reforming with CCS. However, as has been shown already, these losses in coal and natural gas industries are more than offset by explosive growth in other export technologies/resources.

Figure 17 | Total (domestic and export sector) net jobs by state and Scenario every ten years of the transition. Net positive jobs are in blue, net negative jobs are in red.

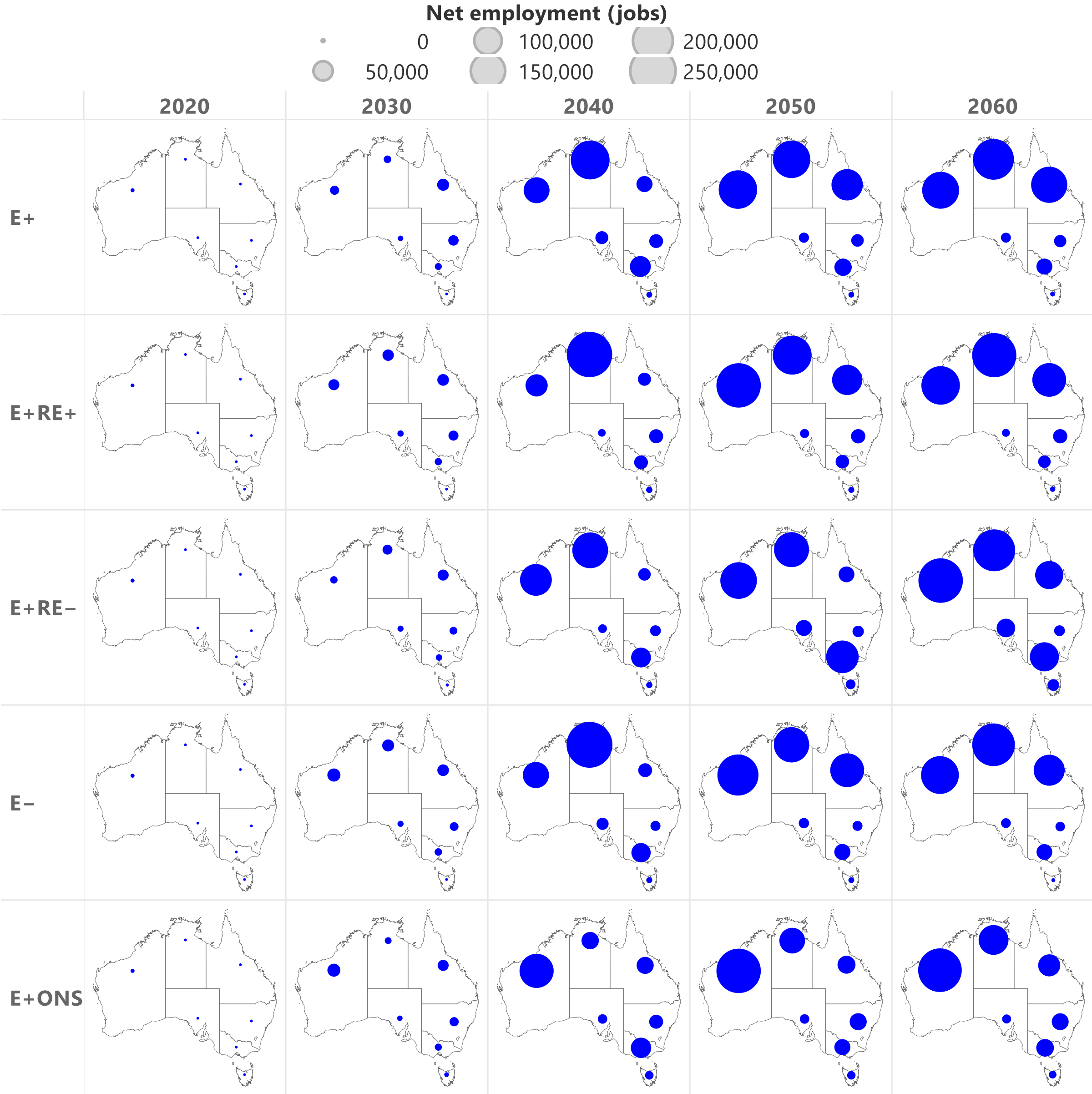


Figure 18 | Net domestic sector jobs by the 15 NZAu regions and selected Scenarios every ten years from 2030 to 2050. Net positive jobs are in blue, net negative jobs are in red.

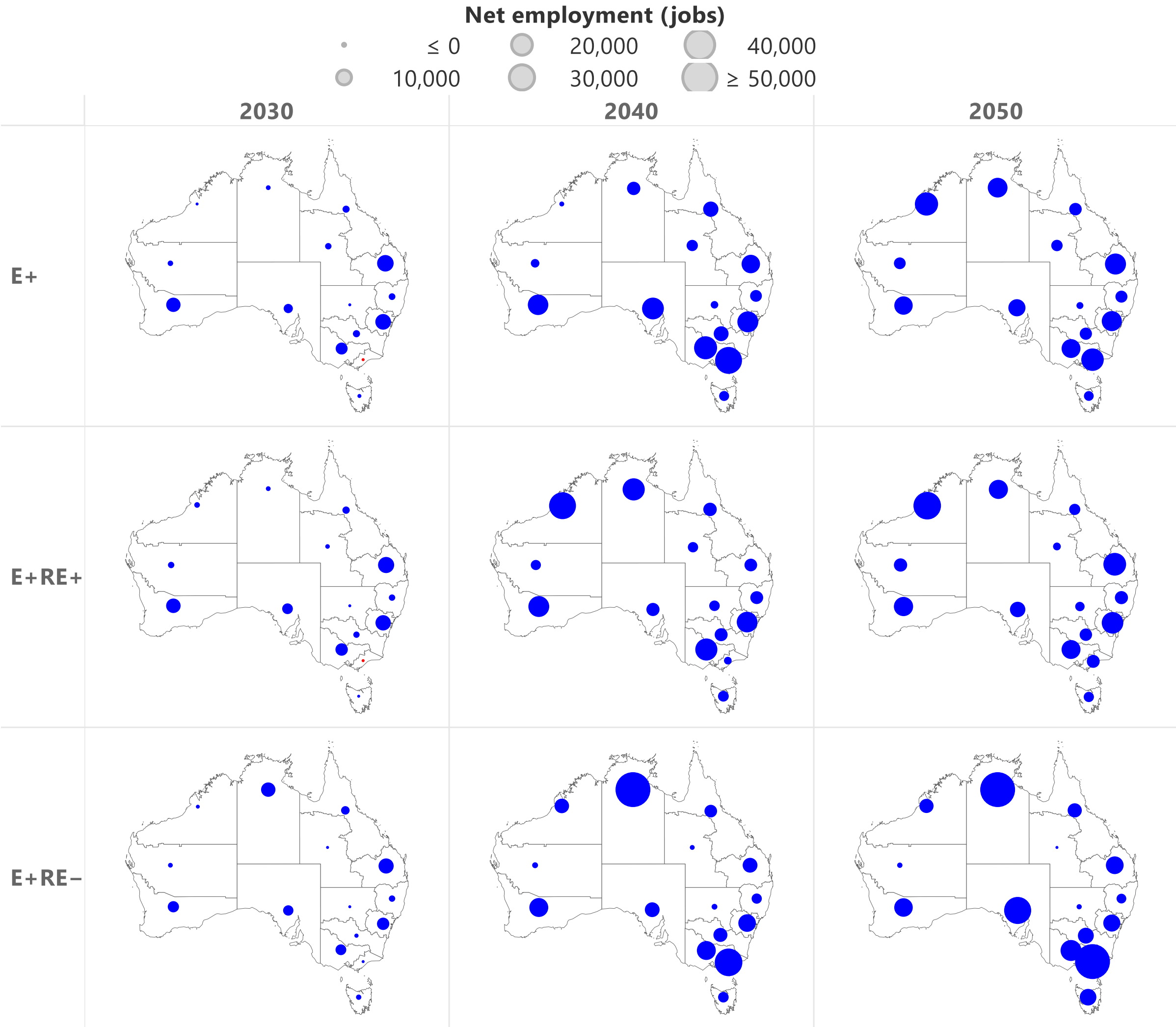


Figure 19 | Net export sector jobs by state and Scenario every ten years from 2030 to 2060. Net positive jobs are in blue, net negative jobs are in red.

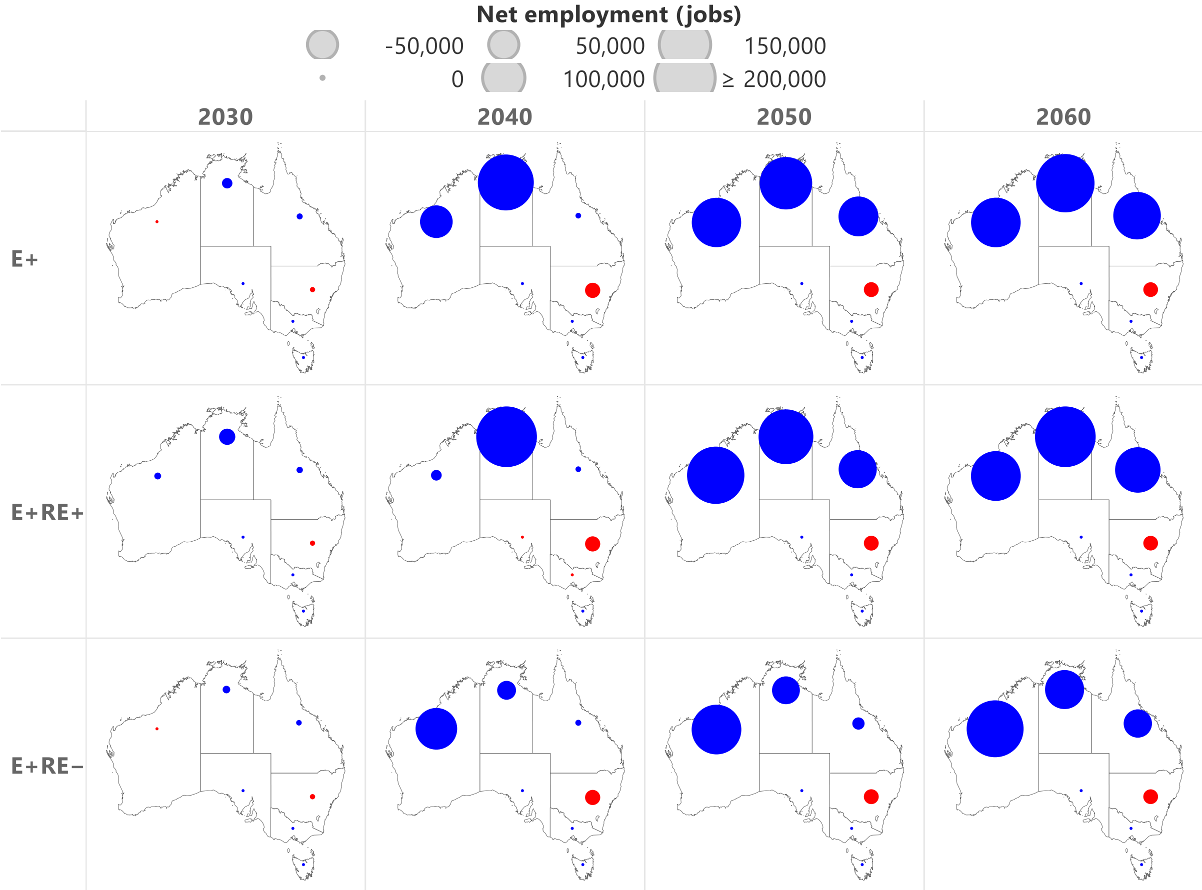


Figure 20 | Net jobs, by technology/resource across the 15 NZAu domestic zones and the defined export zones in 2030 and 2060, for the E+ Scenario. The net jobs in each region aggregated over all considered technologies/resources is shown with the black circle.

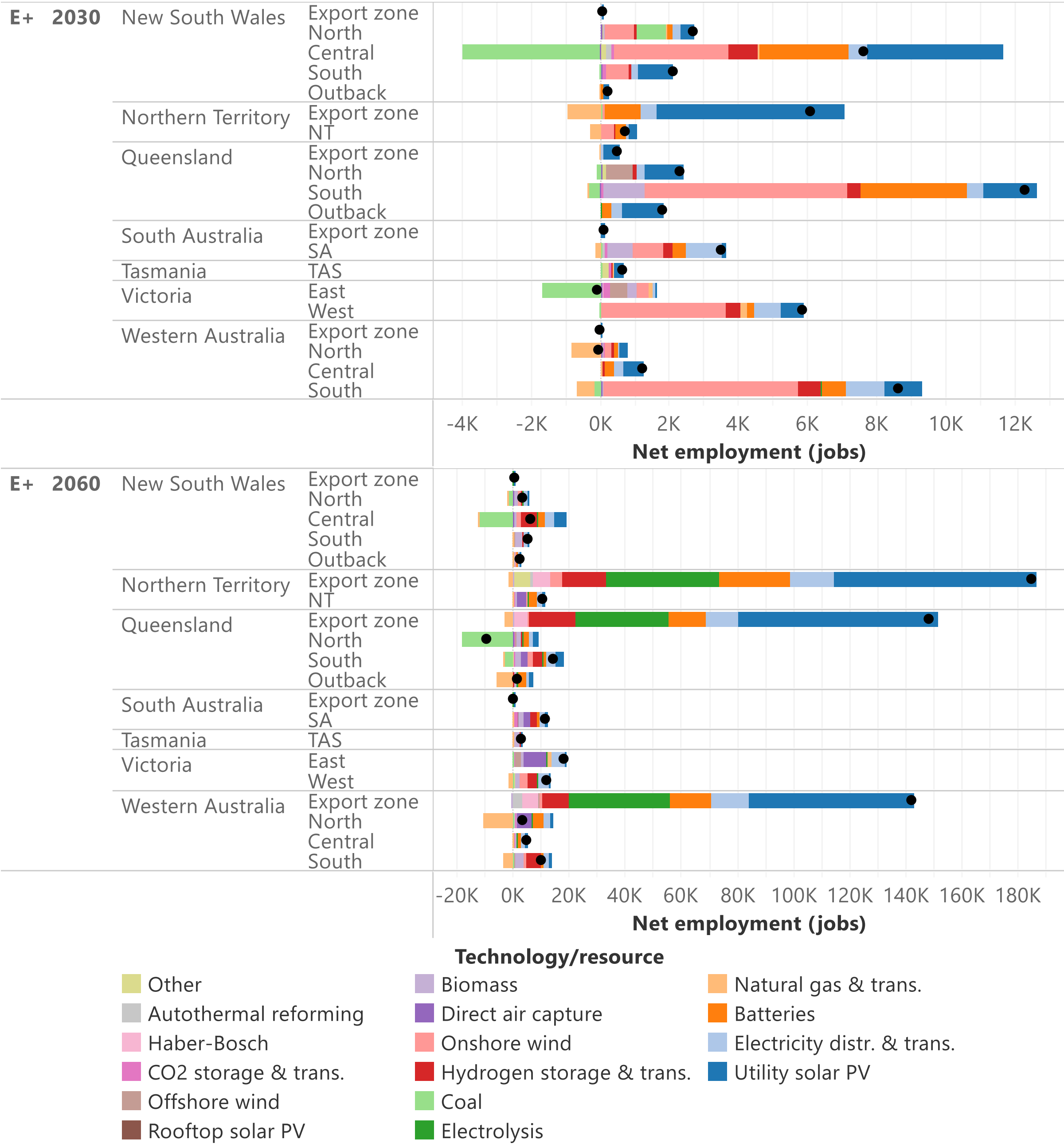
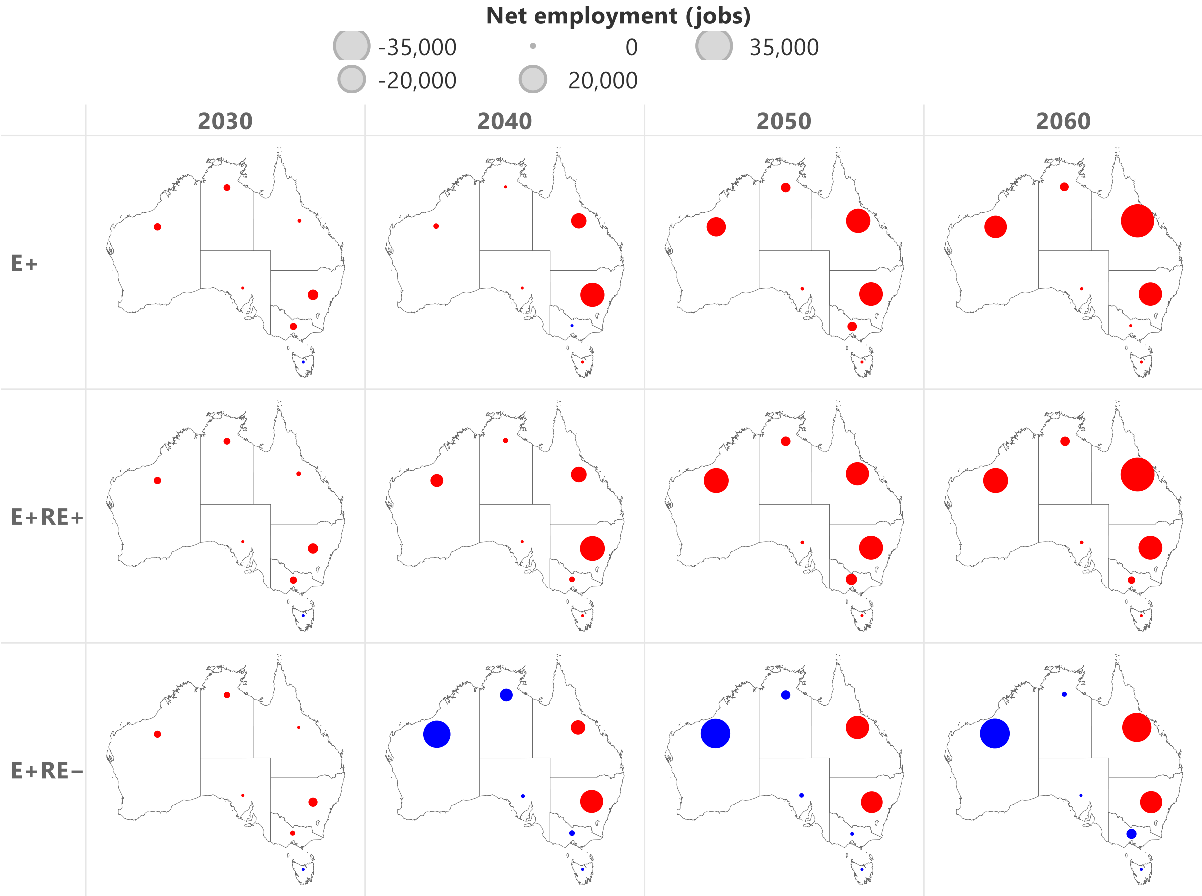


Figure 21 | Net jobs in coal and natural gas (for both domestic and export sectors) by state and Scenario every ten years from 2030 to 2060. Net positive jobs are in blue, net negative jobs are in red.



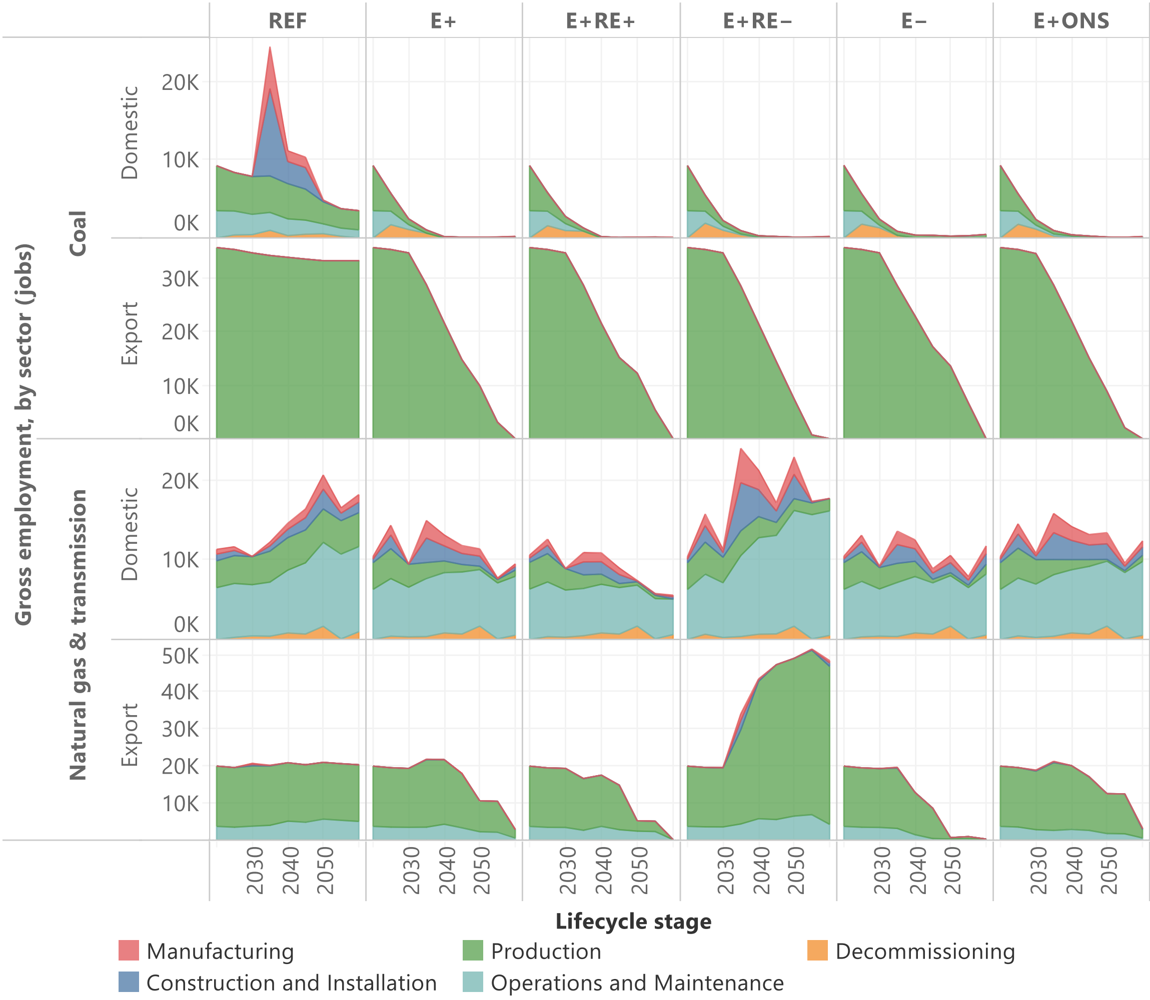
4.3 Labour pathways by resource

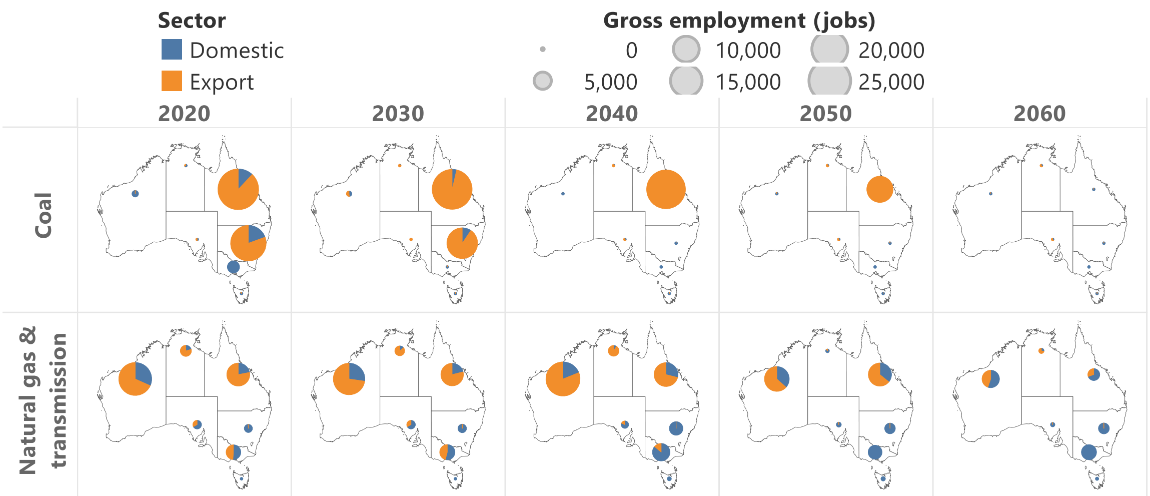
4.3.1 Fossil fuel resource sectors

Figure 22 depicts gross fossil fuels jobs by lifecycle stage, Scenario and sector. Coal jobs decline rapidly across all modelled net-zero Scenarios, from 2020 for the domestic sector, and from 2030 for the export sector, as each begins to decarbonise. Job losses occur linearly to 2060, according to the reduction in coal exports imposed by the export emissions constraint. While domestic sector jobs remain in natural gas and transmission to 2060 across all Scenarios, these generally decline from around 15 thousand to 5-7 thousand job. However, in the E+RE− constrained renewables Scenario, O&M and production jobs remain steady, total employment peaks at 24 thousand in 2035 and again at 23 thousand in 2050 due to additional capacity installations. Export sector jobs have greater variability between Scenarios, with the E+ rapid electrification and E+ONS onshoring Scenarios supporting up to 20 thousand jobs in the 2030s, before declining to 11 thousand in the 2050s and settling between 2-3 thousand jobs in 2060, whereas the E+RE+ full renewables Scenario sees export sector jobs remain steady until declining to 5 thousand in 2050. Finally, the E+RE− constrained renewables Scenario sees a precipitous increase in the number of export jobs in natural gas to meet hydrogen demand through autothermal reforming with CCS, which peaks at 50k in 2060.

The spatial distribution for the E+ rapid electrification Scenario in Figure 22 shows that some domestic natural gas jobs remain in Western Australia, Queensland, NSW and Victoria, with remaining export jobs being concentrated in Western Australia.

Figure 22 | Gross fossil fuel jobs by lifecycle stage and Scenario in full-time equivalent jobs (above), and spatial distribution of fossil fuel jobs by state and sector for each decade to 2060 for the E+ rapid electrification Scenario (below). Note that vertical axis range varies between sectors and technology/resources.





4.3.2 Low-carbon resource sectors

Figure 23 and Figure 24 present the average gross annual low-carbon jobs over two time period of the modelled transition, 2025-2040 and 2045-2060. These are presented for the domestic and export energy sectors, respectively, and by technology/resource and lifecycle stage. These highlight the most prospective technologies and resources playing a role in the net-zero transition, and therefore the areas mostly likely to require workers. The largest areas of employment in the domestic energy sector (Figure 23) relate to the expanded electricity network and construction, installation, operations and maintenance of new renewable energy assets. In the export sector (Figure 24) the majority of employment relates to construction, installation, operations and maintenance of large-scale solar PV and electrolysis installations. While the other Core Scenarios present results that are qualitatively similar to E+, there are nevertheless some interesting variations between scenarios and technologies/resource. These are summarised in below in Table 12.

Figure 23 | Average gross annual low-carbon jobs in the domestic energy sector for the E+ rapid electrification Scenario over the years 2025-2040, and 2045-2060, by technology/resource, and lifecycle stage. Results in full-time equivalent jobs per year.

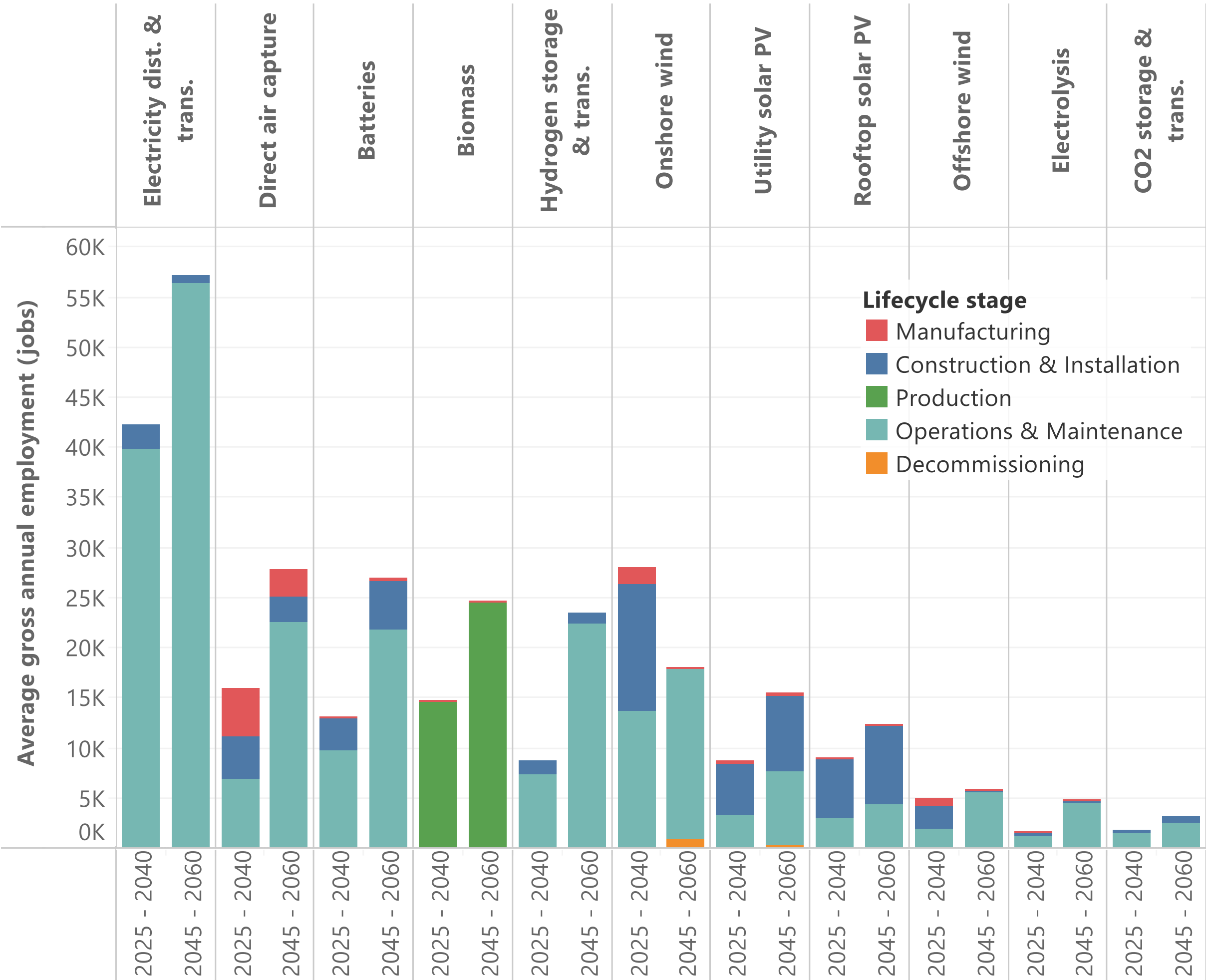


Figure 24 | Average gross annual low-carbon jobs in the export energy sector for the E+ rapid electrification Scenario over the years 2025-2040, and 2045-2060, by technology/resource, and lifecycle stage. Results in full-time equivalent jobs per year.

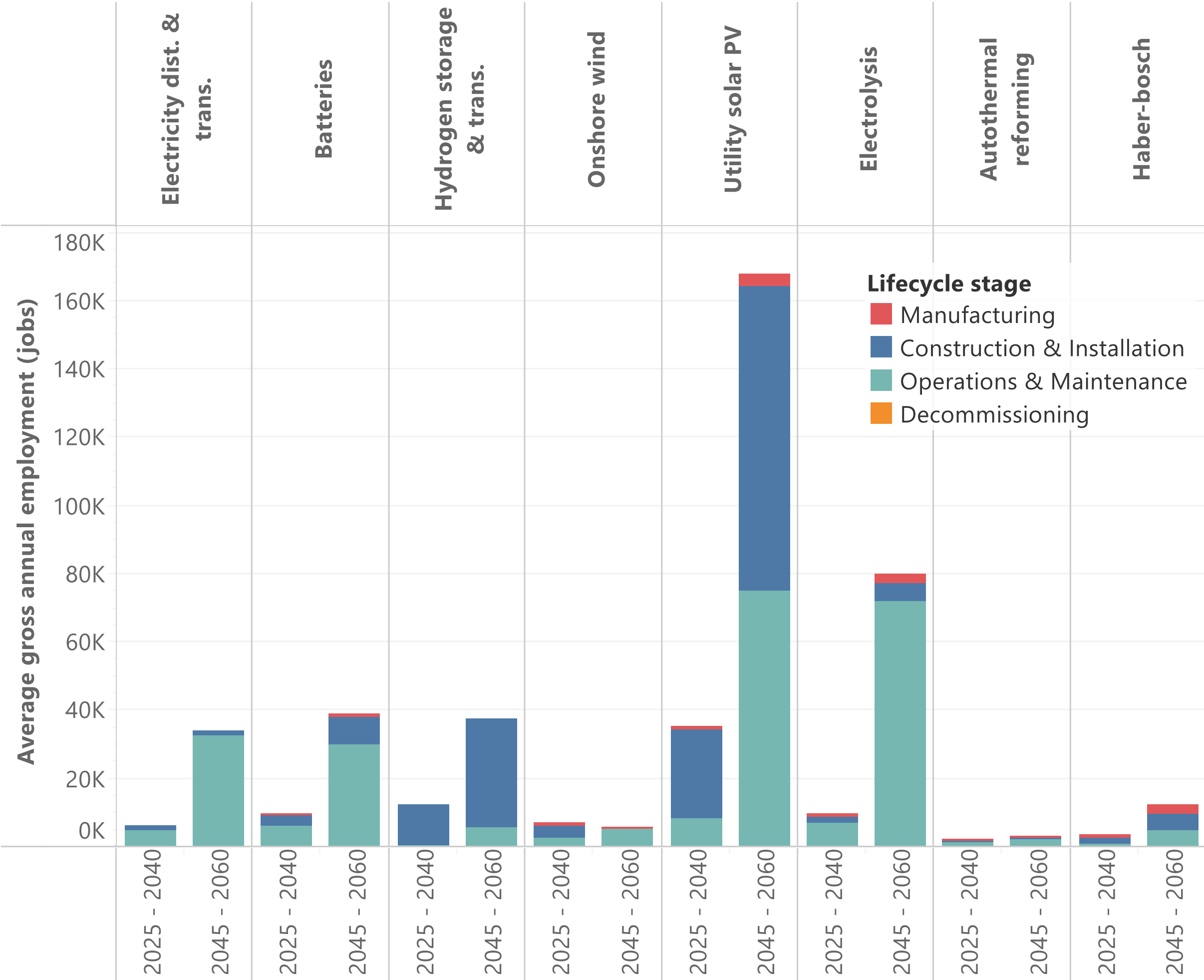


Table 12 | Summary of variation in low-carbon jobs by Scenario.

Technology/resource	Key findings
Autothermal reforming	Majority of employment occurs in E+RE− constrained renewables Scenario as a supplement to electrolysis due to constraint on utility solar deployment. Here, domestic jobs peak at 4k in 2060, and export jobs at 35k in 2060. In the E+ rapid electrification, E− slower electrification and E+ONS onshoring Scenarios, export jobs peak in 2060 at 4k, 1k and 4k respectively.
Batteries	Batteries are a major employer across all Scenarios, with between 17-39k jobs in the domestic sector and 32-59k in the export sector by 2060.
Biomass	Domestic production jobs rapidly increase in all Scenarios apart from E+ONS from 2030-2035, from roughly 2k to 26k. Jobs are sustained at this level in each Scenario, apart from the E+ rapid electrification Scenario where they decline to 18k. There are no export jobs in biomass.
CO_2 storage and transmission	Jobs largely attributed to the domestic sector, although they may enable CO_2 transport from export sector projects. In the E+ rapid electrification, E− slower electrification and E+ONS onshoring Scenarios, domestic jobs peak in 2060 at 5k, 3k and 6k, respectively. CO_2 sequestration is a major source of jobs in the E+RE− constrained renewables Scenario,

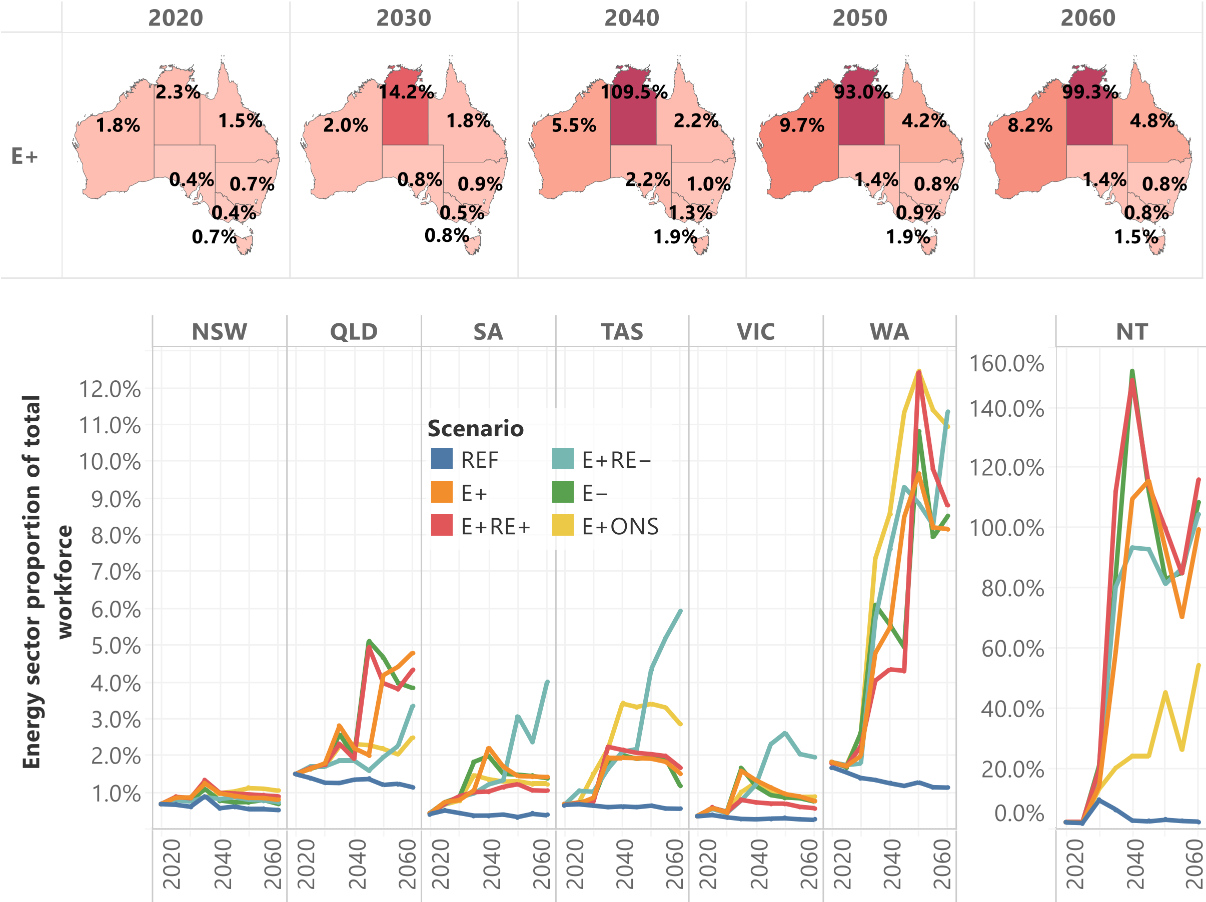
Technology/resource	Key findings
	employing up to 149k in 2060 due to dependence on CCS and direct air capture to sequester and offset emissions from natural gas use.
Direct air capture	Jobs largely attributed to the domestic sector and are present in all Scenarios. Jobs peak between 2035-2050 for all Scenarios, and vary between 22-105k according to the level of residual emissions present in the energy system. The E+RE+ full renewables and E− slower electrification Scenarios have some export jobs, with 12k and 10k respectively.
Electricity transmission and distribution	These jobs are a large employer at present, which continues across all Scenarios with the expansion of the transmission and distribution networks. Domestic jobs peak between 2045-2050, with between 58-104k jobs depending on the Scenario. Export jobs peak in 2060 across all Scenarios, with between 20-44k jobs.
Electrolysis	Electrolysis is a large source of jobs, primarily in the export sector. The domestic sector requires between 4-9k jobs in all Scenarios. In the E+ rapid electrification, E+RE+ full renewables and E− slower electrification Scenarios, export sector jobs are between 110-115k, whereas lower demand for hydrogen electrolysis in the E+RE− constrained renewables and E+ONS onshoring require only 39k and 117k jobs respectively.
Haber-Bosch	Haber-Bosch jobs are concentrated in the export sector, with ammonia the primary energy export medium and being driven by growth in the production of hydrogen through electrolysis and autothermal reforming. Across all Scenarios, jobs vary between 14-17k, with the exception of the E+ONS onshoring Scenario at 4k jobs, as less hydrogen is produced due to export demand being met by onshored aluminium and iron DRI production.
Hydrogen storage and transmission	Jobs are split between the export and domestic sectors. All Scenarios have roughly 26k jobs in the domestic sector, apart from the E− slower electrification Scenario which has 17k. There is greater variability in the export sector, with the E+ rapid electrification, E+RE+ full renewables and E− slower electrification Scenarios having between 41-48k jobs, 21k in the E+RE− constrained renewables Scenario, and 25k in the E+ONS onshoring Scenario.
Offshore wind	Domestic offshore wind jobs peak in 2040 across most Scenarios, at around 7-14k jobs, apart from the E+RE− constrained renewables Scenario which peaks in 2060 with 50k jobs. This is due to the onshore renewables constraint restricting deployment of utility solar. Offshore wind is a small employer in the export sector, with only the E+RE− constrained renewables Scenario employing offshore wind jobs, peaking in 2060 with 23k jobs.
Onshore wind	All Scenarios have a large number of domestic jobs in onshore wind, which peak around 2035 at between 17-54k jobs. In the export sector, jobs peak with construction spikes in 2035 across most Scenarios, creating 10k jobs in the E+ONS onshoring Scenario, 15k in the E+ rapid electrification Scenario, 29k in the E− slower electrification Scenario and 34k in the E+RE+ full renewables Scenario. In the E+RE− constrained renewables Scenario, jobs rise steadily to 21k in 2060.
Rooftop solar PV	Across all Scenarios, domestic rooftop solar jobs follow the same trajectory, peaking at 15k in 2055 due to deployment assumptions detailed in NZAu (2022a). There are no export jobs in rooftop solar.
Utility solar PV	Utility solar is a major employer across most Scenarios and sectors. There are two spikes in employment, in 2025 and a major peak in 2050, which requires between 13-22k jobs. In the E+RE− constrained renewables Scenario, domestic employment peaks in 2035 with 13k jobs. In the export sector, utility solar jobs increase steadily and peak in 2060 in all Scenarios. Total jobs vary between Scenario, with the E+ rapid electrification, E+RE+ full renewables and E− slower electrification Scenarios supporting between 190-214k jobs, whereas the E+ONS onshoring Scenario requires 120k jobs and the E+RE− constrained renewables Scenario creating 78k jobs.

4.4 Workforce projections

As seen in Figure 8, the majority of workforce growth is projected to occur in existing population centres, primarily in Victoria, NSW and Queensland. However, as previously noted and shown Figure 15, the majority of new energy sector jobs are driven by the large clean energy export task and are therefore in more regional and remote areas. Western Australia has the largest projected sectoral workforce, with Queensland and the Northern Territory having comparable sectoral workforces in absolute terms. It should be noted that, while Figure 15 above disaggregates by domestic and export sectors, each would draw on the same workforce, and so the analysis below considers total energy sector employment as a proportion of the project workforce.

Figure 25 shows the relative proportion of the projected workforce by state and territory (see Figure 8) employed by the energy sector, which indicates significant regional variation over time and between Scenarios. Western Australia and the Northern Territory experience the largest increase in proportion of their workforce in energy sector jobs. In Western Australia, the energy sector accounts for up to 12% of all work, whereas in the Northern Territory, the energy sector workforce is projected to exceed the total projected workforce in almost all Scenarios. This result highlights a key limitation of the energy system and employment modelling discussed below.

Figure 25 | Proportion of projected workforce occupied by the energy sector, by state/territory and year, mapped for the E+ rapid electrification Scenario (above), and graphed for all Core Scenarios (below).



4.5 Occupation projections

Figure 26 presents gross and proportional jobs over time by ANZSCO major group. With the decarbonisation of the export sector from 2030, proportional representation of machinery operators and drivers decreases significantly, as jobs for Drillers, Miners and Shot Firers are lost with the reduction of coal mining activity. Unsurprisingly, the growth in C&I employment demonstrated in Figure 11 significantly increases the absolute and proportional jobs for labourers, as well as clerical and administrative workers. There is also a proportionate growth of management roles. 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 aligned with the increase in C&I jobs from 2025.

Minor ANZSCO levels can nonetheless provide valuable insights into occupational groups that will experience substantial growth during decarbonisation. Figure 27 presents gross 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. Unsurprisingly, roles relating to electrification and engineering dominate these jobs, with significant numbers in construction and project administration roles as well.

Figure 26 | Gross (top) and proportional (bottom) jobs in each ANZSCO major group by Scenario and Domestic and Export sector over time. Results in full-time equivalent jobs.

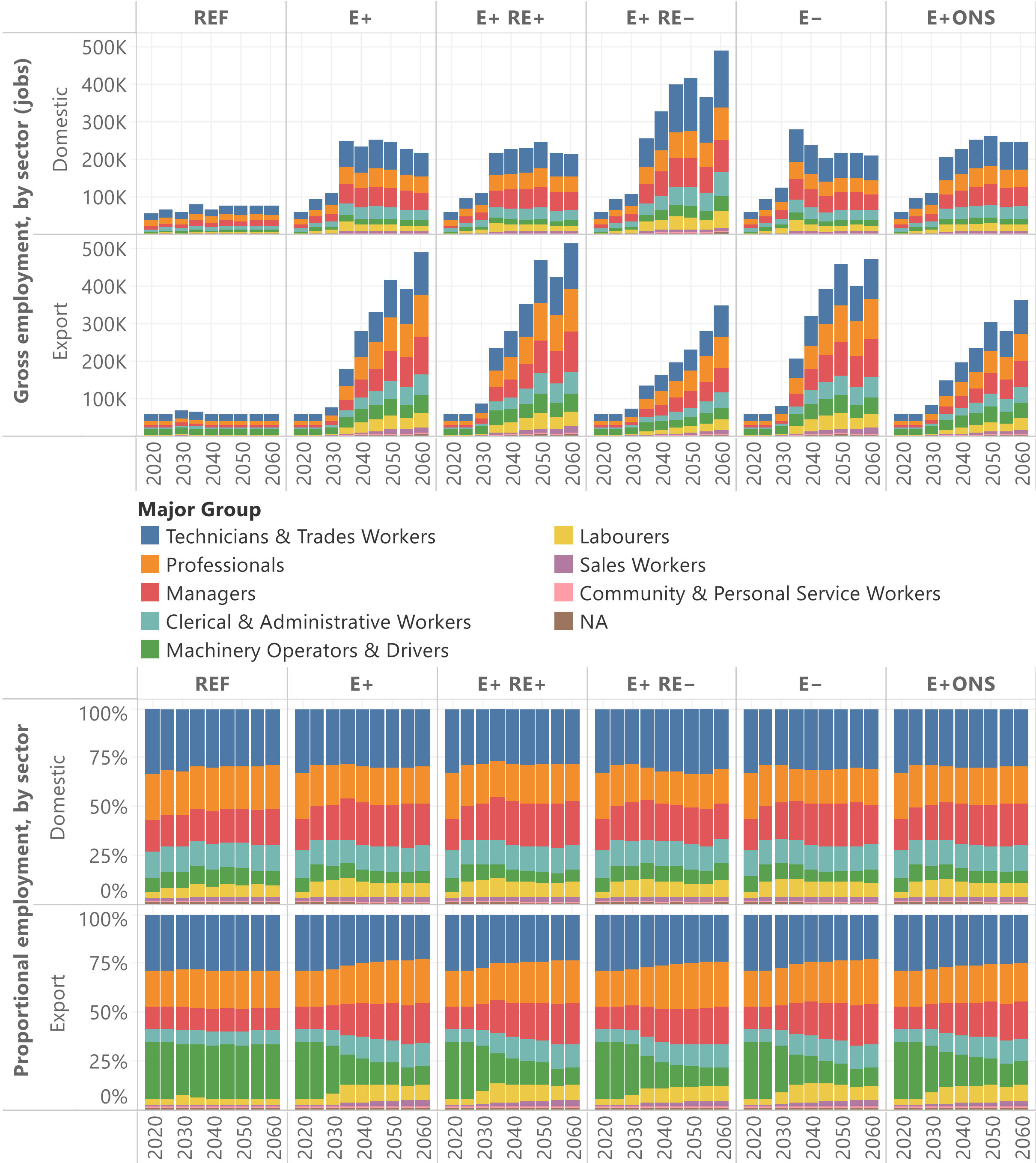
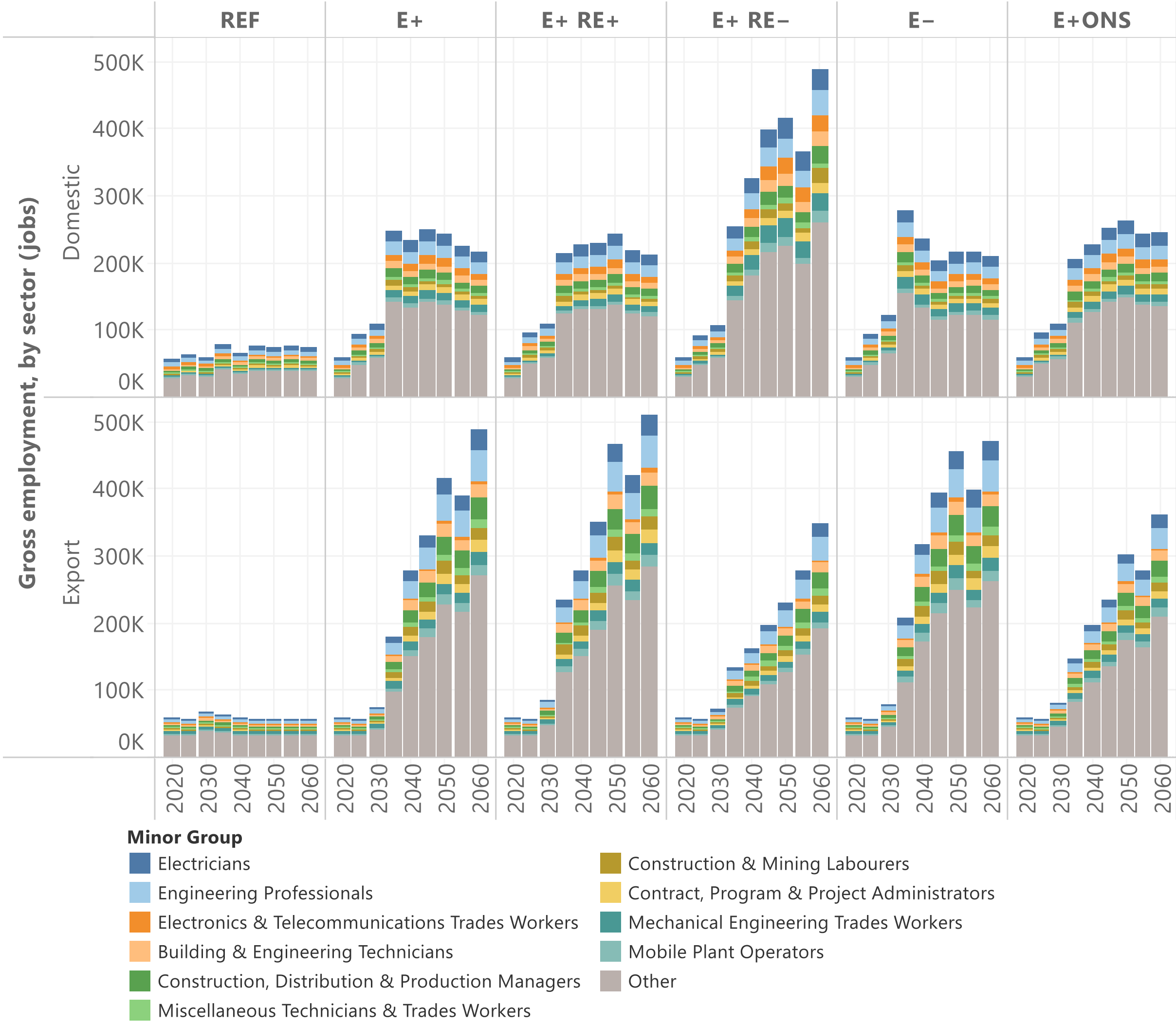


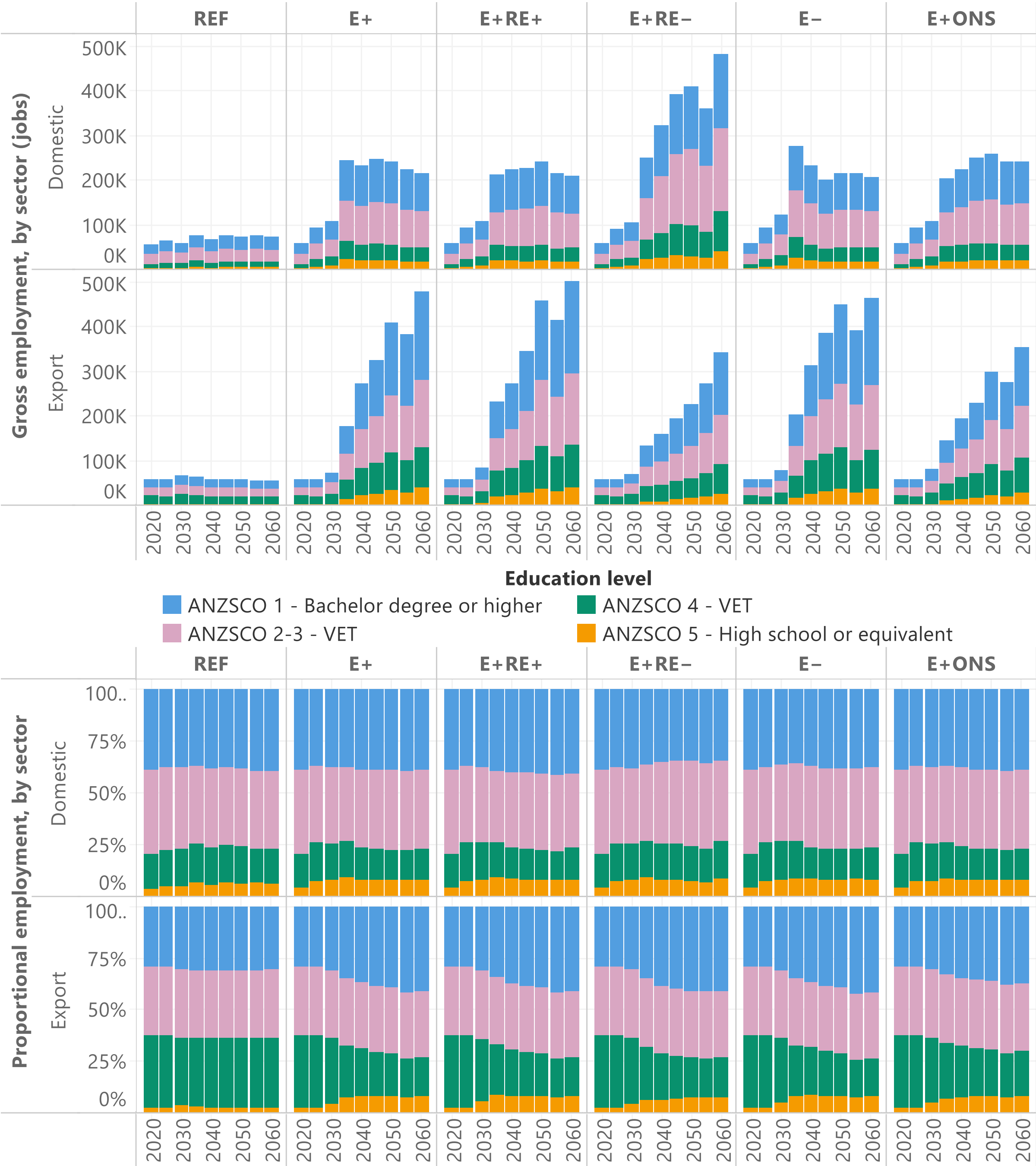
Figure 27 | Gross jobs in the top 10 ANZSCO minor groups (and others) by Scenario and Domestic and Export sector over time. Results in full-time equivalent jobs.



4.6 Skill level projections

Figure 28 provides gross and proportional jobs by education level for each Scenario over time. As with the occupation projections seen in Figure 26, in the domestic sector proportional employment by skill level is generally stable, with most skill levels fluctuating a few percentage points throughout 2020-2060. There is more change in the export sector, as lower-skilled jobs in coal mining, specifically Drillers, Miners and Shot Firers, which currently occupy a large proportion of the export workforce, are replaced by occupations at ANZSCO skill levels 1-3. Of note, most jobs require further education and training, at either vocational education and training (VET) or bachelor levels.

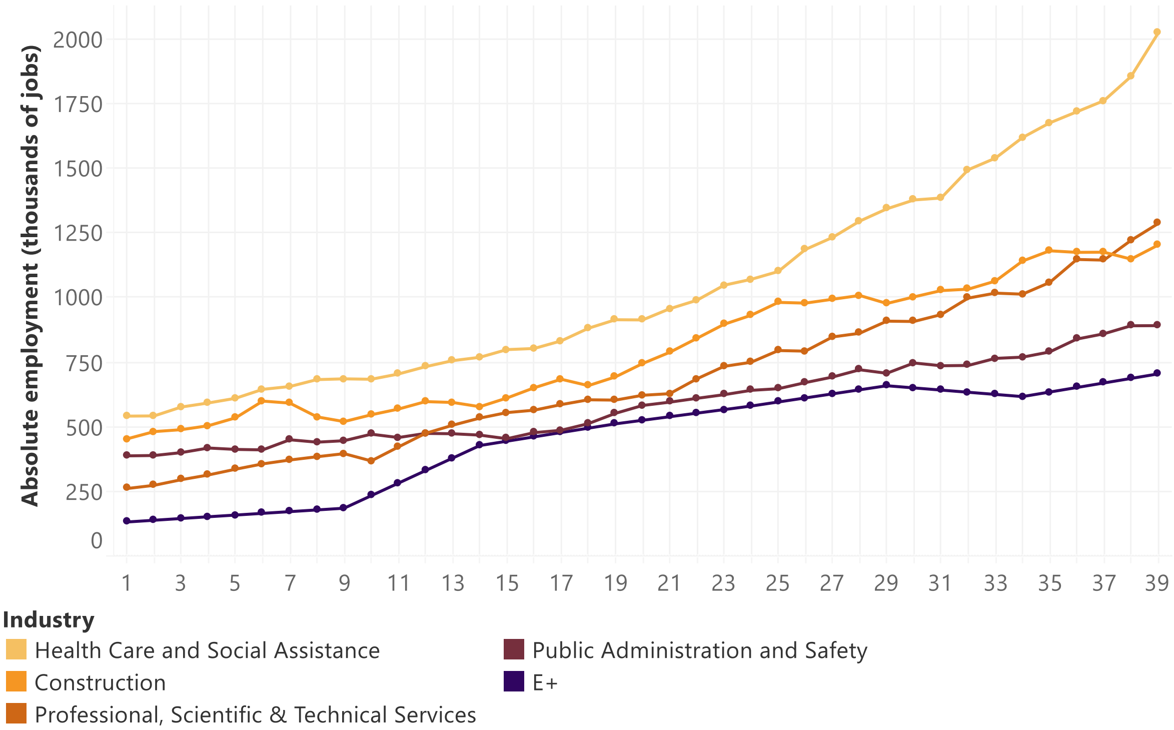
Figure 28 | Gross (top) and proportional (bottom) jobs by education level for each Scenario over time. Results in full-time equivalent jobs.



5 Discussion

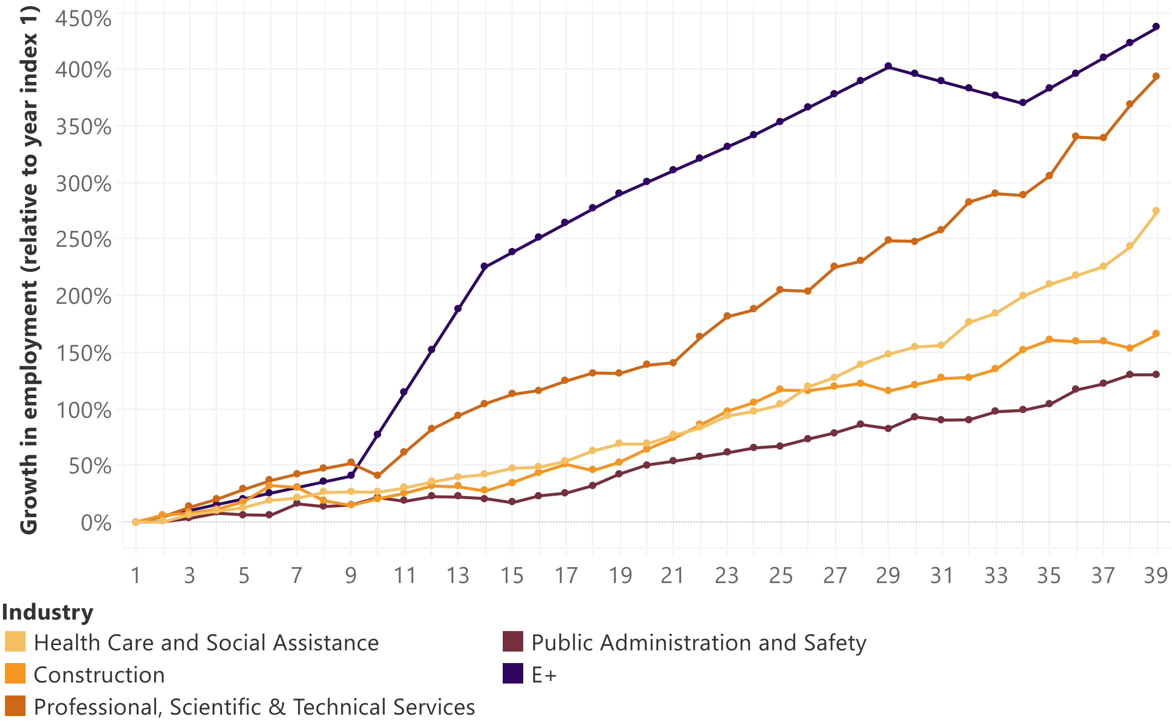
These results provide an understanding of the scale and pace of workforce change required to achieve decarbonisation of both domestic and export emissions in Australia over the next four decades. While historical trends are an imperfect comparison, Figure 29 shows absolute jobs for the Health Care, Construction, Professional Services and Public Administration industries over the last 39 years (ABS, 2022), with projected jobs for the E+ rapid electrification Scenario (2022-2060) added to the time series. The Health Care, Professional Services and Construction industries experienced much higher absolute growth than is projected for the E+ Scenario, each increasing by 1,482 thousand, 1,025 thousand, and 750 thousand jobs, respectively. Public Administration provides the closest comparison at 630k jobs, relative to the E+ rapid electrification Scenario's ~640k jobs. This demonstrates that in absolute terms, this level of growth has been sustained by multiple other industries over a similar period.

Figure 29 | Absolute jobs (thousands) per industry over the last 39 years (1984-2022, year 1 = 1984) for Health Care and Social Assistance, Construction, Professional, Scientific and Technical Services and Public Administration and Safety. Projected jobs for E+ rapid electrification Scenario (2022-2060, year 1 = 2022) interposed over this time series.



However, Figure 30 shows the percentage growth relative to the first year of measurement for the same industries. This demonstrates that the relative growth required by the E+ rapid electrification Scenario exceeds that experienced by any of those industries, due to the lower baseline employment in the energy sector. As previously noted, the majority of jobs in all decarbonisation Scenarios require further education and training beyond secondary school. This infers that the capacity of Australia's higher education system must grow rapidly and significantly in specific areas to accommodate these needs. Indeed, the energy sector is already experiencing delays due to skill shortages in key occupations identified as essential for the transition in Figure 27, including electricians, construction and project managers and engineers (Rutovitz et al., 2020; Clean Energy Council, 2022).

Figure 30 | Growth in employment per industry, relative to the first year of the last 39 years time series (1984-2022, year 1 = 1984) for Health Care and Social Assistance, Construction, Professional, Scientific and Technical Services and Public Administration and Safety. Relative growth of jobs for the E+ rapid electrification Scenario (2022-2060, year 1 = 2022) interposed over this time series.



As seen in Figure 14, gross job growth could occur across all regions for the domestic and export sectors. The locations of these jobs will be split between regions and capital cities depending on the nature of work. Rutovitz et al. (2020) used industry surveys to produce percentage estimates for the number of jobs that will be located rurally for certain prominent technologies, by their lifecycle stage, outlined in Table 13. Interpolating these modifiers as higher and lower modifiers across the whole energy supply chain provides insights into the possible scale of distribution of regional and capital city jobs across domestic and export jobs outlined in Figure 14. This location split is shown for the average 2050-2060 total modelled employment for the Core Scenarios in Figure 31.

This indicates that 59-71% of total employment is potentially located in regional areas. While not shown in Figure 31, domestic energy system jobs vary between 60-72% in regional areas, while export system jobs vary between 59-73% in regional areas. While job creation on this scale presents an important opportunity for revitalisation of regions and towns, substantial population increases will require major investments in infrastructure and the creation of additional indirect and induced jobs necessary to house, feed, transport, educate and ensure the health of the energy sector workforce and their families that move into these regions (Cass et al., 2022). There is a substantial and urgent role for state and territory governments to work closely with landholders, local businesses, town residents, local councils, developers and Indigenous communities on development plans from the beginning of projects (Australian Senate Select Committee, 2019). This will assist with building consensus and community support, provide leadership and momentum for change, and give confidence in the process to all interested parties (Cass et al., 2022).

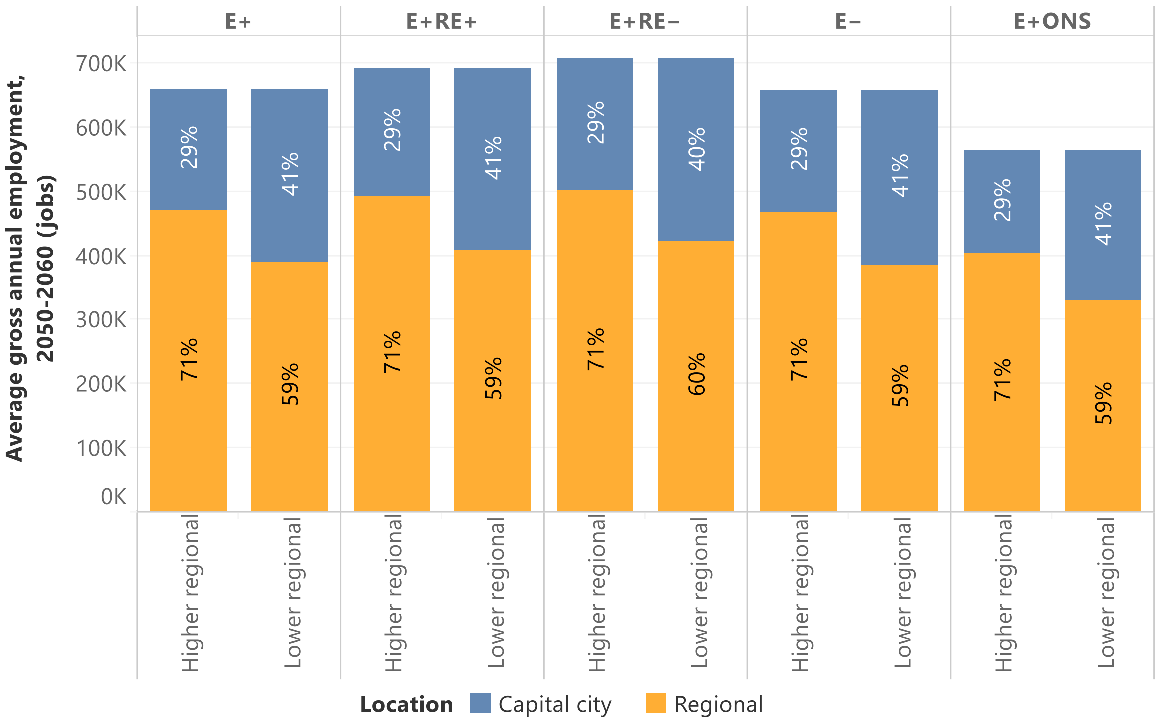
Furthermore, the potential for large-scale renewable projects in regional Australia on lands subject to Native Title and other rights demonstrates the importance of proper engagement with First Nations communities. There is of course potential for Indigenous communities to benefit from regional investment through benefit sharing and royalties from renewable projects, employment, and from associated infrastructure development. Government must ensure that investors and developers work effectively with Indigenous communities in ways that recognise cultural value, respect protocols, and build relationships (Janke 2021).

Table 13 | Regional job modifiers, from Rutovitz et al. (2020).

Lifecycle stage	Wind farms – higher O&M modifiers	Solar farms – lower O&M modifiers
Manufacturing	50%	50%
C&I	67%	69%
Production	73.3%*	54.6%*
O&M	73.3%	54.6%
Decommissioning	67%*	69%*

* Note production regional modifier has been taken from O&M, and decommissioning regional modifier from C&I.

Figure 31 | Comparison of average gross annual jobs from 2050-2060, using higher and lower regional modifers, for the Core net-zero Scenarios.



A further consideration for the labour projections of this report is the role of governments in balancing the imperatives of decarbonisation in both the domestic and export sectors, given each draw on the same workforce (Electrical Trades Union, 2022). Internal competition for workers between domestic and export sectors is very plausible, leading to labour bottlenecks, delayed domestic decarbonisation, and higher energy costs for domestic consumers. Similar conflicts could occur between states and territories, as each works to optimise individual interests by capturing a share of developing export industries and pursuing varied domestic decarbonisation pathways at the expense of economic efficiency and the national interest.

Finally, given the number of jobs required, their regional and often remote location, and the ambitious scale and pace of change required, it is also very plausible that skilled migration may need to rise significantly. The role of skilled migration to meet domestic and export decarbonisation objectives further necessitates the involvement of federal and state governments, working with industry, unions, education providers, local communities, and other interested parties.

6 Limitations

Energy activity and employment modelling

This employment modelling is dependent on energy activity inputs that are subject to many assumptions and limitations that are likely to produce different results when applied to the 'real world'. Our energy activity optimisation adopts a techno-economic efficiency objective (i.e. minimising the total cost of the energy transition) and a linear emissions constraint for each net-zero Scenario (NZAu, 2022a). These assumptions simplify complexities inherent in any large, social transformation that will affect decision-making regarding the timing of construction or the location of infrastructure, from local factors such as community opposition or labour constraints, to global supply chain disruptions such as those resulting from the COVID-19 pandemic or the Russian invasion of Ukraine. Although, such simplifications are a necessary component of any large-scale, long-term modelling, the above results have highlighted two key limitations affecting the reliability of job projections: the absence of regional capital and labour cost modifiers, and modelling in 5-year timesteps.

Perhaps most notably, if energy activity employment in a state began to approach the results for the Northern Territory outlined in Figure 25, projects would likely experience ballooning capital costs due to labour shortages and the remote location, which would require significant upstream investment in infrastructure needed to house, feed, transport, educate and ensure the energy sector workforce and their families (Cass et al., 2022). This would be a significant creator of induced jobs and create further population pressures. Furthermore, modelling in 5-year timesteps involves inherent 'lumpiness', such as the drastic spike in Queensland export jobs in 2060 for the E+ rapid electrification Scenario outlined above. This sort of change is likely to be smoother in the real world and occur over a longer time horizon, as localised large-scale increases in labour demands cannot be immediately met in response to rapid shifts in demand for manufacturing and short-term C&I jobs. There is a need for further sensitivity analysis that incorporates regional cost modifiers on infrastructure and labour availability, as these are likely to exert significant influence in determining the location of export infrastructure.

Furthermore, the attribution of some energy activities and associated jobs between the domestic and export sectors is non-trivial, particularly for multi-step energy processes involving multiple technologies and linkage between certain technologies serving both domestic and export energy demand. For example, while biomass production occurs primarily in domestic regions, the outputs from this activity may ultimately be destined for export via conversion into synthetic fuels through several steps involving plants in different locations.

Employment factors (EFs)

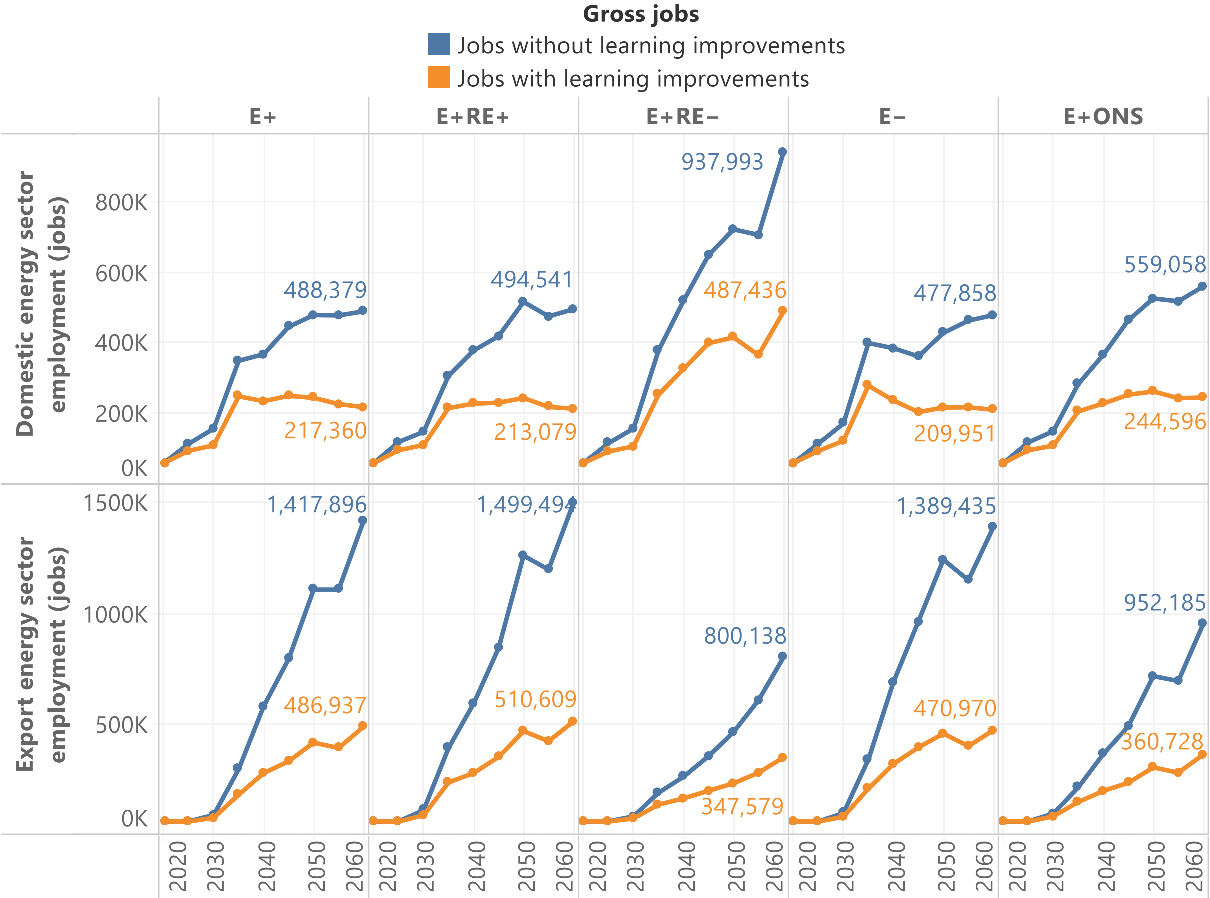
As previously noted, the accuracy of the overall employment projection is dependent on the selection of EFs appropriate to the context of study. While the basis for many of the fossil fuelled, renewable and storage EFs utilised in this study have utilised historical Australian employment validated by industry surveys (Rutovitz et al., 2015; 2020, 2023), the suitability of many others is subject to question. This is particularly the case for emerging and nascent sectors, such as direct air capture and the green hydrogen supply chain, which includes electrolysis and hydrogen storage and transmission. Furthermore, EF availability has restricted the employment model to those technologies and lifecycle stages outlined in Table 4.

Exogenous factors affecting EFs or lifecycle learning factors such as an increased Australian share of manufacturing over time, or increased automation in the C&I of utility solar and batteries have also not been considered in these projections. Efficiencies achieved through the construction and operation of plants at scale have also not been considered (Ouassou, 2021). Finally, O&M learning has not been fixed to the lifetime of a plant, and instead decreases over time. While it is likely that a plant will achieve some operational learning improvement over time, it does not benefit from the broader technological improvements experienced by new builds.

Learning factors

As previously noted, while all technologies will experience learning improvements, the rate of learning for a given technology is inherently uncertain. However, the choice of learning rate strongly influences projections for the total modelled jobs created for a given technology/resource, with emerging technologies modelled to experience profound reductions in labour intensity of up to 65-76%. For technologies and sectors projected to experience rapid deployment, these declines produce significant reductions in total labour demand. Figure 32 presents a comparison of gross jobs with and without learning improvements. Total jobs without learning by Scenario varies between 1.5-2.0 million total jobs, which is a 2.1-2.7-fold increase on the gross jobs with labour learning improvements.

Figure 32 | Comparison of gross jobs for Domestic and Export sector and Scenario, with and without learning rate adjustments, with labels for 2020 and 2060. Note that axis range varies between sectors.



Occupation projections

Occupation projections are based on data from the 2021 Census. As such, they do 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 emergiang technologies such as electrolysis and battery storage. The rapidly evolving nature of energy technology and the workforce that supports it must therefore be kept in mind.

Finally, while this study has projected net positive jobs for each state across both domestic and export sectors over time for each Scenario (Figure 17), it has not analysed the impact on several, very important considerations such as wages, employment security and the complementarity of skills between new and lost jobs in a given region. As noted, jobs for Drillers, Miners and Shot Firers will decline from 2030 as coal mining jobs reduce. These jobs may not be replaced with jobs of a similar skill set, salary and security in a given region. Considerable further research is required to evaluate such impacts further.

Appendices

Appendix A: Summary of changes to modelling inputs and energy activity from preliminary results

The results in this report differ from the interim results published in August 2022 (McCoy et al., 2022) due to changes made to the input assumptions including EFs, learning rates (LR), the removal or addition of lifecycle stages, and the energy activity basis used. A summary of all changes is shown in Table 14, which includes an impact assessment describing the effect on overall jobs by technology/resource.

Note also that previous occupation projections utilised 2016 Census data, whereas this publication uses 2021 Census data.

Table 14 | Summary of all changes to modelling inputs and methodology from the previously published preliminary results.

Technology/resource	EF	LR	Lifecycle stage	Energy activity	Impact assessment
Aluminium production		✓			Minor reduction in jobs due to LR increase
Autothermal reforming	✓	✓	✓		Negligible change in jobs due to increases in EFs, offset by LR increase and the removal of decommissioning lifecycle stage
Batteries	✓		✓		Large reduction in jobs due to reduction in EFs. Further minor reduction in jobs from removal of decommissioning lifecycle stage.
Biofuels	✓	✓	✓		Large reduction in jobs due to selection of EFs that better reflect energy activity (i.e., as fuel conversion rather than generation), LR increase and removal of decommissioning lifecycle stage
Biomass	✓	✓			Moderate increase in jobs due to increase in EFs and LR
CO_2 storage		✓			Minor reduction in jobs due to LR increase
CO_2 transmission		✓			Minor reduction in jobs due to LR increase
Coal	✓	✓			Negligible change in jobs due to changes to EFs and LR decrease
Direct air capture	✓	✓	✓		Large increase in jobs due to increases in EFs, offset to a small extent due to LR increase and removal of decommissioning lifecycle stage
Electricity distribution		✓		✓	Very large reduction in jobs due to change in energy activity basis for calculation, and increase in LR
Electricity export	✓	✓			Moderate decrease in jobs due to reduced EFs and increase in LR
Electricity transmission		✓	✓	✓	Large reduction in jobs due to change in energy activity basis for calculation, and increase in LR, offset slightly by inclusion of C&I lifecycle stage
Electrolysis	✓		✓	✓	Minor increase in jobs due to changes in EFs, by change in energy activity basis using output rather than nameplate capacity, and by removal of decommissioning stage
Fischer-Tropsch	✓	✓	✓		Minor decrease in jobs due to large reduction in EFs, as well as increased LR and removal of decommissioning stage

Technology/resource	EF	LR	Lifecycle stage	Energy activity	Impact assessment
Haber-Bosch	✓	✓	✓		Negligible change overall due to changes in EFs being offset by increase in LR and removal of decommissioning stage
Hydro	✓	✓	✓		Minor increase in jobs due to reduction of LR, increase in manufacturing EF and removal of decommissioning stage
Hydrogen storage	✓	✓		✓	Minor reduction in jobs due to changing energy activity basis of calculation,
Hydrogen transmission		✓			Minor reduction in jobs due to LR increase
Iron DRI		✓			Minor reduction in jobs due to LR increase
LNG	✓	✓	✓		Minor increase in jobs due to EF increases being offset to an extent by increase in LR and removal of decommissioning stage
Methanation	✓	✓	✓		Moderate increase in overall jobs due to EF increases being offset to an extent by increased LR and removal of manufacturing and decommissioning stages
Natural gas	✓	✓			Minor increase in jobs to LR decrease and increase in decommissioning EF, offset by reduction in manufacturing EF
Natural gas transmission		✓			Minor reduction in jobs due to LR increase
Offshore wind	✓	✓			Minor increase in jobs due to LR reduction, offset by reduction in C&I and O&M EFs
Oil refinery	✓	✓	✓		Negligible change in jobs, as increases in EFs offset by increase in LR and removal of decommissioning stage
Onshore wind	✓	✓			Minor increase in jobs due to LR reduction, offset by reduction in C&I EF
PHES		✓	✓		Minor increase in jobs due to reduction of LR and removal of decommissioning stage
Rooftop solar	✓		✓		Minor reduction in jobs due to removal of decommissioning lifecycle stage and decrease in C&I EF
SMR	✓	✓	✓		Negligible change in jobs, as increases in EFs offset by increase in LR and removal of decommissioning stage
Utility solar PV	✓				Minor decrease in jobs due to reduction of manufacturing, C&I and decommissioning EFs

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