The Australian Electricity Workforce for the 2024 Integrated System Plan: Projections to 2050.

Final Report

Final report

RACE for Change

Research Theme CT11: The Australian Electricity Workforce for the 2024 Integrated System Plan: Projections to 2050.

ISBN: 978-1-922746-59-7

September 2024

Citations

Rutovitz, J., Gerrard, E., Lara, H., and Briggs, C. (2024). The Australian Electricity Workforce for the 2024 Integrated System Plan: Projections to 2050. Prepared for RACE for 2030.

Project team

Institute for Sustainable Futures, University of Technology Sydney

- Jay Rutovitz
- Helen Lara
- Dr Elianor Gerrard
- Dr Chris Briggs
- Rusty Langdon
- Farzan Tahir
- Josie Toakley

Australian Energy Market Operator (AEMO)

RACE for 2030

Project partners

Acknowledgements

We would like to extend our thanks to our project partner the Australian Energy Market Operator (AEMO) for both making this work possible and their extensive help and contributions. We would also like to thank our Industry Reference Group: the Clean Energy Council, Department of Energy and Public Works (Queensland), Department of Climate Change, Energy, the Environment and Water (NSW Treasury), the Department of Energy, Environment and Climate Action (Victoria), Renewables, Climate and Future Industries Tasmania, and members of AEMO's ISP 2026 Consumer Panel. Their insights have contributed greatly to the quality of this work. The authors, however, take full responsibility for any errors and omissions.

Acknowledgement of Country

The authors of this report would like to respectfully acknowledge the Traditional Owners of the ancestral lands throughout Australia and their connection to land, sea and community. We recognise their continuing connection to the land, waters, and culture and pay our respects to them, their cultures and to their Elders past, present, and emerging.

What is RACE for 2030?

Reliable, Affordable Clean Energy for 2030 (RACE for 2030) is an innovative cooperative research centre for energy and carbon transition. We were funded with $68.5 million of Commonwealth funds and commitments of $280 million of cash and in-kind contributions from our partners. Our aim is to deliver $3.8 billion of cumulative energy productivity benefits and 20 megatons of cumulative carbon emission savings by 2030. racefor2030.com.au

Disclaimer

Key findings

- A rapid scale up of the energy workforce is needed to implement the optimal development path in the Integrated System Plan (ISP) for all three of its scenarios. Under the Step Change scenario – considered most likely by energy stakeholders and well-aligned with policy commitments by Federal and State Governments - overall electricity sector employment will have to double to 66,300 by 2029. If Australia becomes a major exporter of renewable energy (the Green Energy Exports scenario), almost 63,000 additional electricity sector workers would be needed by 2029, rising to almost 119,000 total workers by 2050.
- Under all scenarios, most employment growth occurs in wind farms, solar farms and distributed batteries, while rooftop solar jobs are constant. In terms of workforce decline, while coal and gas together initially make up 35% of the electricity sector workforce, this drops to 6% in Progressive Change (a scenario with a constrained economy), 4% in Step Change, and 2% in Green Energy Exports by 2050. Jobs in coal reach zero in Step Change by 2038, and in 2034 in Green Energy Exports. In Progressive Change, 800 jobs remain in 2050. This decline is outstripped by the increase in other electricity sector jobs, offering some opportunities for transition employment. However, these jobs may not be in similar occupations or locations, and additional planning and diversification is needed to ensure a smooth and just transition for coal regions and communities.
- Under all scenarios, construction dominates the employment profile through the 2020s as the build-out of renewable energy, transmission and storage accelerates, with the majority of jobs being in operations and maintenance from 2033 onwards. Construction employment in large scale technologies is subject to major upswings and downswings, with increases of 27,000 in just five years to 2029 in Step Change (16,000 in Progressive Change and 50,000 in Green Energy Exports), followed by sharp drop offs: the Step Change peak is followed by losing 24,000 construction jobs over four years, and the Green Energy Exports scenario adds 50,000 and then loses 38,000 construction jobs in the same period. This 'boom/bust' pattern creates significant risks for labour supply, exacerbated by competing demands for infrastructure build in other parts of the economy and the fact that much of the energy infrastructure is in rural areas.
- Those occupations primarily needed in construction are very volatile, with demand for electrical engineers rising three-fold by 2029, then dropping below current levels in the late 2030s. Electricians, mechanical trades, and operations managers, meanwhile, increase over the entire period as they are also required for operations and maintenance. The rapid increase in requirements for energy workers brings a high risk of skill shortages which could impact on the achievement of the ISP's optimal development path. Skill shortages create the risks of delays, increased project costs, and increased cost of capital to reflect increased risk.
- Workforce projections were also developed for the 2022 ISP. The increase in workforce requirements from now until 2030 has become steeper in all three scenarios between the 2022 and 2024 workforce projections. While this is challenging, it is needed to enable Australia's emission targets to be reached, which in turn will require a rapid scaling up of the workforce each year from now until 2030.
- The electricity workforce needed nationally to deliver the energy transformation is far larger and more diverse than outlined in this report. The workforce required for energy efficiency, demand and energy management, and electrification will be significant, with considerable overlap with the occupations already identified in shortage for electricity supply, such as electricians and engineers. There is a dearth of information on the scale of this workforce, with estimates for 2030 varying from 200,000 to 400,000. This information gap needs to be urgently addressed if we are to develop the energy workforce of the future.

Executive Summary

This report provides electricity sector workforce projections for the 2024 Integrated System Plan (ISP) developed by the Australian Energy Market Operator (AEMO). The study was undertaken by the Institute for Sustainable Futures, University of Technology Sydney (ISF) in collaboration with AEMO and was funded by the RACE for 2030 Cooperative Research Centre and AEMO.

The workforce projections cover electricity generation, storage, and transmission construction for the three core ISP scenarios:

- **Step Change** includes a rapid energy transition with strong economic growth. It supports Australia's commitment to keep global temperature rise to below 2°C.
- **Progressive Change** reflects a constrained economic and supply chain environment, meaning less energy is required to meet the needs of a smaller economy. While meeting legislated commitments, cumulative electricity sector emissions to 2050 are 36% higher than under the Step Change.
- **Green Energy Exports** includes an exceptionally fast rate of decarbonisation aimed at Australia making its contribution to keeping global temperatures to below 1.5°C, with a strong emphasis on a green exports economy and electrification. Cumulative electricity sector emissions to 2050 are 46% reduced compared to the Step Change.

Projections do not include electricity retailing or the operation of the transmission and distribution networks.

AEMO assigned likelihoods of 43% for Step Change, 42% for Progressive Change and 15% for Green Energy Exports, informed by consultation with its 'Delphi Panel'.

Jobs are presented as full-time equivalent (FTE) for each year and are the sum of people working on construction projects, operations and maintenance, manufacturing, and fuel supply for coal and gas generation. One FTE could be one person working full time just for that year, two people working full time for six months, or an ongoing full-time job in operations and maintenance. Construction jobs are by nature temporary, although workers may move from one project to another and be in continuous employment.

Electricity sector jobs increase steeply in all scenarios in the run up to 2030

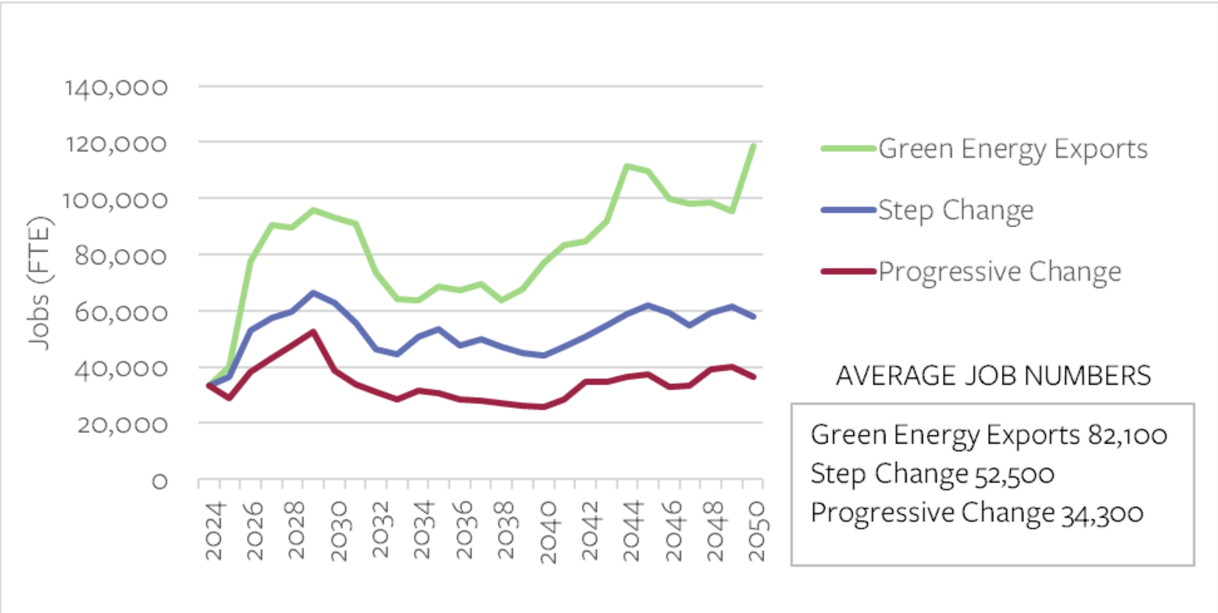

Figure E1 NEM: total job numbers by scenario

All three scenarios have a peak in 2029, followed by a significant drop off, caused by the construction boom to meet the 2030 target (Figure E1).

- **Step Change**: the electricity sector workforce reaches 66,300 in 2029, and averages 52,500 from now to 2050. After the 2029 peak, jobs drop to 44,400 over four years, a reduction of nearly 5,500 per year, and then generally plateau during the 2030s before rising again in the 2040s.
- **Progressive Change**: jobs peak in 2029 at 52,700, and then drop to 28,400 (below present levels) over four years, shedding 6,000 jobs each year. Jobs generally fall during the 2030s, before rising again in the 2040s.
- **Green Energy Exports**: employment averages 82,100, with a peak of 96,000 in 2029. This is a rise of nearly 63,000 in just five years, which would be very hard to achieve. This is followed by dramatic falls (nearly 32,000 in four years). After a brief plateau, jobs rise steeply to reach 111,400 in 2044, and 118,700 by 2050.

While this report includes workforce projections from 2024 to 2050 in line with the ISP, later years should be treated as indicative only as they are 26 years hence. There may be step changes in labour productivity in that time, for example resulting from the introduction of new technologies or from automation, rather than the gradual increase in labour productivity anticipated in these projections.

A very rapid scale-up of the electricity workforce is required

Under all scenarios, a very rapid workforce increase is required. In Step Change, an extra 33,000 workers are needed after just five years (Figure E2), doubling the workforce by 2029. The ramp up for Green Energy Exports is far steeper, with a combined increase of 63,000 needed by 2029, effectively trebling the workforce. Even in Progressive Change, which assumes a significantly constrained economy, an increase of about 19,000 is anticipated by 2029 to meet peaks in infrastructure construction.

These sharp increases in the modelled workforce are followed by sudden drops. Implementing policies to smooth construction profiles could avoid some of these fluctuations and allow for more orderly skills development, easing the challenge of meeting workforce demands and increasing the social benefits of the transition.

Most of the job growth is in renewable energy which doubles by the end of the period in Step Change (Figure E2) and increases fivefold in Green Energy Exports. The proportion of renewable energy jobs is close to 60% in 2024 and between 71% and 83% by 2050 in all scenarios. Storage employment increases from 4% in 2024 to between 14% and 25% in 2050, with a peak of 9,500 in the mid-2030s. Transmission construction (including lines and substations) reaches peaks of between 5,000 and 7,000 in 2028 and 2029.

Fossil fuel employment in power stations for producing gas or coal for Australian electricity generation[1] declines steadily over the period, to just over 2,000 jobs in 2050. This is a drop from 35% of the workforce now to between 2% and 6% in 2050. This decline is outstripped by the increase in other electricity sector jobs, which may offer some opportunities for transition employment. However, these jobs will not necessarily be in similar occupations or locations, so planning and diversification will be needed to ensure a smooth and just transition for coal regions and communities.

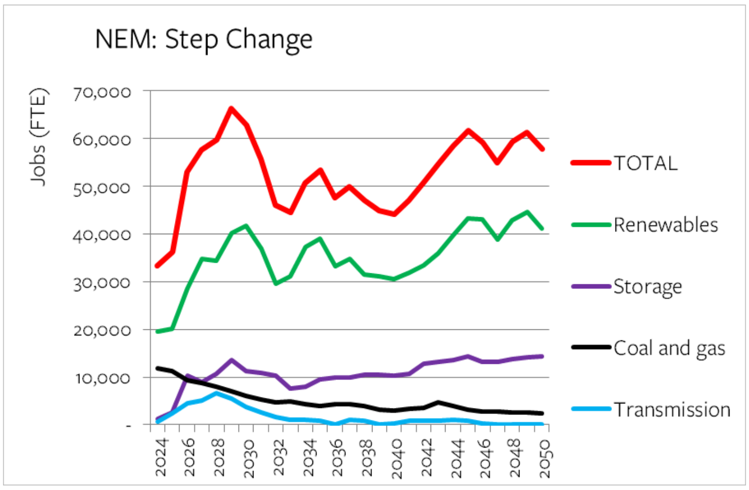

Figure E2 National Electricity Market, jobs by technology group, Step Change

The electricity workforce needed nationally to deliver the energy transformation is considerably larger than outlined here. The workforce required for energy efficiency, demand and energy management, and electrification will be significant, with considerable overlap with the occupations already identified in shortage for electricity supply, such as electricians and engineers. There is a dearth of information on the current and future scale of the demand-side workforce, with estimates for 2030 varying from 200,000 to 400,000[1]. This information gap needs to be urgently addressed if we are to develop the energy workforce of the future.

Lack of good quality data means the occupational shares for batteries and offshore wind, the workforce needed in mining or mineral processing for renewable energy technologies, the ongoing workforce in the electricity networks and retailers, decommissioning, and the off-grid hydrogen production in the eastern states is not included in these projections. The modelling also does not include Western Australia or the Northern Territory, as the ISP only covers the National Electricity Market (NEM).

Wind, solar farms and batteries are the primary drivers of employment growth

Under all scenarios, most employment growth occurs in wind farms, solar farms and distributed batteries. Figure E3 shows the annual employment by technology over the period.

- **Wind** dominates under all scenarios, accounting for an average of 30% of employment in the Step Change, 34% in Progressive Change, and nearly 38% in Green Energy Exports. The wind workforce for Step Change and Progressive Change peaks in the later part of this decade, with between 20,000 - 26,000 jobs, while the Green Energy Exports scenario reaches 46,000 in the 2040s.
- **Distributed solar and distributed batteries:** the combined workforce accounts for between 27% and 43% of jobs. Rooftop solar jobs are remarkably constant in all scenarios, while distributed batteries show strong, maintained growth in Step Change and Green Energy Exports. By 2050 this combined sector will generate 31,900 jobs in Step Change, 10,500 in Progressive Change, and 35,900 in Green Energy Exports.
- **Solar farms** account for between 8% and 16% of jobs. The greatest growth occurs in Green Energy Exports, with jobs peaking at 44,400 in 2050. Average employment is 13,100 in Green Energy Exports, nearly five times the average in Progressive Change and three times the average in Step Change.

[1] It is important to note that these jobs only represent coal and gas for domestic electricity production, not coal and gas for export.

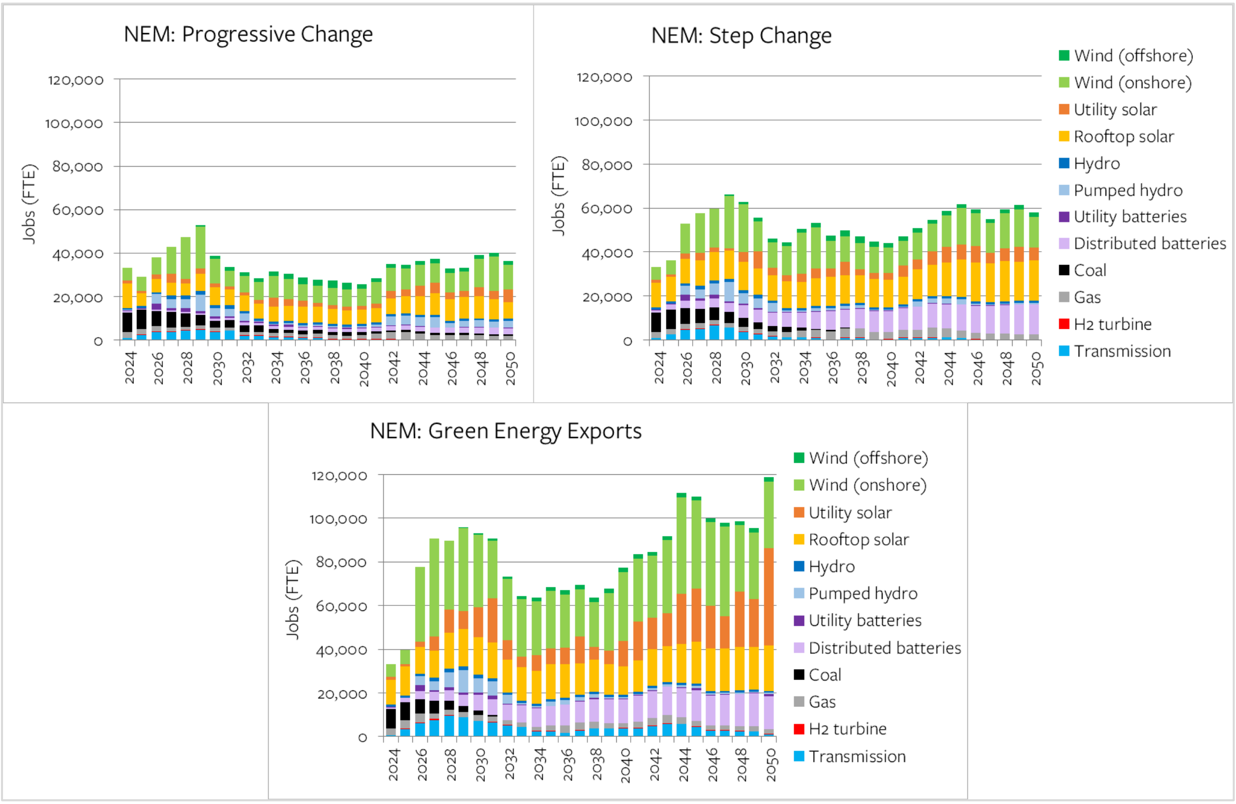

Figure E3 National Electricity Market, annual jobs by technology and scenario

- **Hydro and pumped hydro** make up a small portion of employment in the overall electricity sector workforce (4% - 10%). Conventional hydro employment is stable across all scenarios, while pumped hydro has a major employment peak (9,000 – 10,000) in the mid-to-late 2020s, and a further burst of construction activity in the late 2030s and 2040s.
- **Utility batteries** account for just 1-2% of electricity sector employment in all scenarios, and average 500-600 jobs. There is an installation spike up until 2030 with similar numbers across all scenarios.
- **Coal and gas** together make up 35% of the electricity sector workforce at the start of the period, dropping to 6% in Progressive Change, 4% in Step Change, and 2% in Green Energy Exports by 2050. Jobs in gas decline very slowly in all scenarios, to between 1,600 and 2,300. Jobs in coal reach zero in Step Change by 2038, and in 2034 in Green Energy Exports. In Progressive Change, 800 jobs remain in 2050.
- **Transmission construction** employment is a small portion of overall employment (3% - 5%). However, it is characterised by strong peaks, particularly in the years up to 2030, and then dwindles to near zero by 2050 under both Step Change and Progressive Change. Under Green Energy Exports, however, investment in transmission remains strong over the entire period, with an average of 4,300 jobs.

Most jobs in the electricity sector will be in operations and maintenance by the 2030s

Under all scenarios, construction dominates the employment profile through the 2020s but operations and maintenance (O&M) employment gradually increases as the fleet of renewable energy generation and storage increase. O&M employment exceeds 50% in all scenarios by 2033, and by 2050 makes up more than 65% of the workforce (Figure E4).

Australian governments and other stakeholders are developing policies to increase local manufacturing for renewable energy technologies, including the Future Made in Australia program which identifies clean energy manufacturing as a priority area[2]. These projections include onshore manufacturing based on the findings of a 2020 industry survey[3], and vary from 2% for solar to 23% for onshore wind. We undertook sensitivity analysis on increasing this share to between 10% and 30% of onshore manufacturing for all technologies. This could add 1,200 jobs on average over the period in Step Change (900 in Progressive Change and 1,900 in Green Energy Exports), noting that the achievable increases are very uncertain.

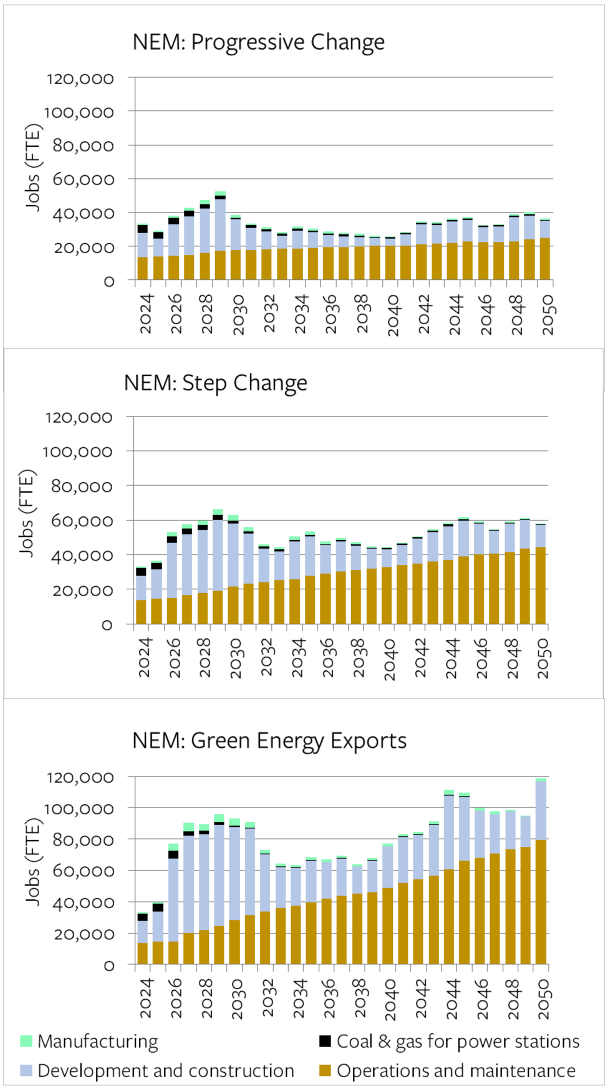

Figure E4 National Electricity Market, jobs by project phase (electricity generation, storage, and transmission construction)

Demand is highest for trades & technicians, with an average of 14,100 needed until 2041

The largest group of occupations is trades and technicians, averaging 14,100 until 2041 under Step Change (Figure E5) [2]. Wind technology creates the most employment on average for trades and technicians, with wind and solar nearly equal for professionals and managers. Solar creates the highest number of labouring jobs, machine operators and drivers, and administration roles. The key trends across occupational groups in Step Change are:

- **Trades and technicians**: demand reaches 16,500 by 2030, and then stays above 13,300.
- **Professionals**: an average of 7,700 until 2041 across a wide range of occupations including engineers, finance, health and safety.
- **Managers** (e.g., construction or operations managers): around 6,500 on average.
- **Labourers**: 5,300 on average, with peak requirements reaching 9,900.
- **Machine operators and drivers** (e.g., truck drivers or crane operators): averaging at 3,200, with peaks of 5,900.
- **Administrative staff**: 2,900 on average.

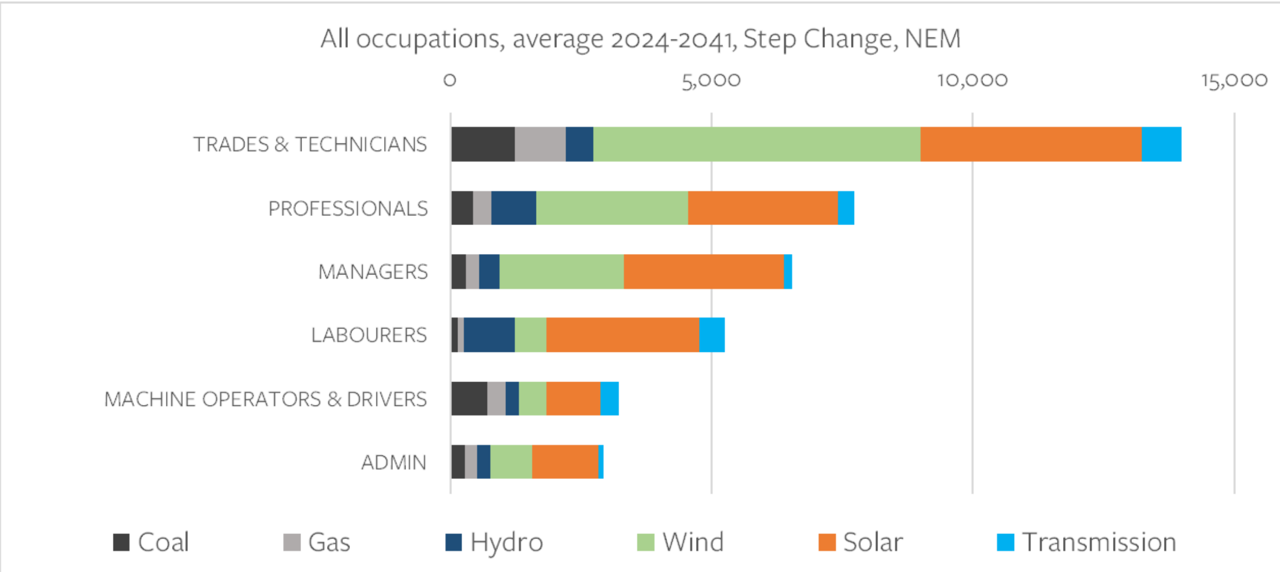

Figure E5 NEM, average occupational structure 2024 – 2041

Average employment projections illustrate the bulk distribution of jobs between technologies but from the perspective of skills, training, and labour supply, the specific occupations and peaks in employment may be the most important variable. Annual requirements for some of the most in-demand occupations under the Step Change are shown in Figure E6[3]. Those occupations primarily needed in construction are very volatile. Electricians, mechanical trades, and operations managers increase over the entire period as they are also required for operations and maintenance.

- Demand for electricians almost doubles by 2030, then fluctuates somewhat around 8,000, with average demand of 7,400 between 2024 and 2041. Most of the demand is in wind and rooftop solar, followed by transmission construction.

[2] Overall numbers include both offshore wind and batteries, but these technologies are not included in the detailed occupational breakdowns, as robust occupational data are not available for these technologies.

[3] Construction labourers and electrical engineers have been included although they are the 7th and 10th most in-demand occupations based on average job numbers as they are important in the peak year.

- Mechanical trades and technicians follow a similar trajectory, increasing three-fold over the next decade to reach 3,100 in 2034, then remaining relatively stable through the rest of the period. Wind is the major source of demand.
- Roles that follow construction are the most variable. Demand for construction labourers and electrical engineers rises three-fold by 2029.
- Demand for administrative staff is also volatile, although not to the same extent, while demand for operations and production mangers generally increases steadily over time as operating projects increase.

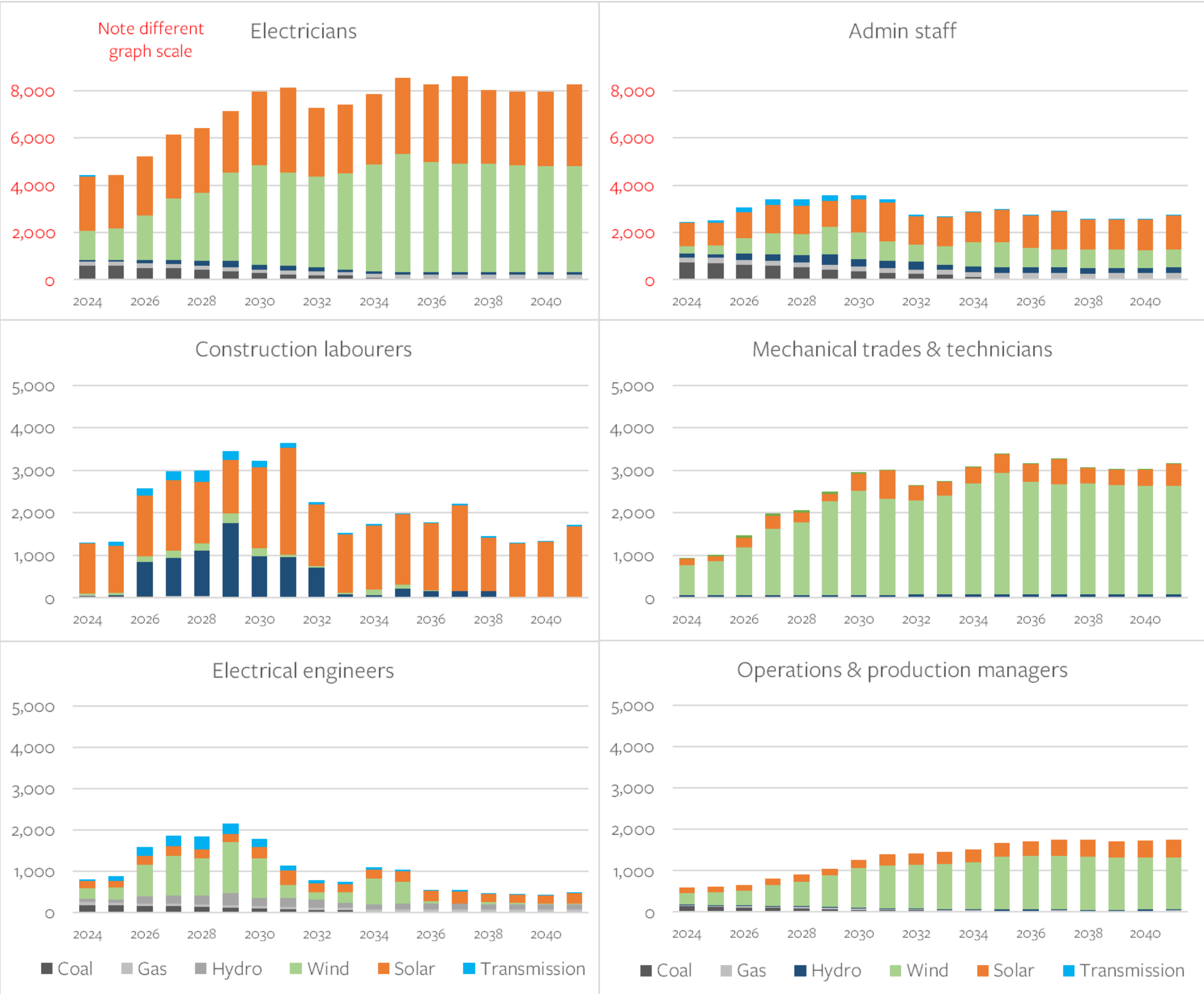

Figure E6 National Electricity Market, in-demand occupations annual employment, Step Change
Note: scale of 0-8,000 for total jobs for the top two occupations, and 0-5,000 for the remainder.

The energy transformation creates significant numbers of jobs across the National Electricity Market, with the highest number in NSW

New South Wales has the highest level of employment, with an average of 18,400 jobs in Step Change, closely followed by Queensland with 15,800 jobs (Figure E7). Victoria is next with 12,200 jobs. Solar and wind account for between 61% and 69% of jobs in all states except Tasmania, where hydro and wind account for 75% of jobs. The distribution of employment between states is similar in Progressive Change. In the Green Energy Exports scenario, the highest number of jobs are created in Queensland (32,300 on average), followed by New South Wales (22,600) and Victoria (15,900). Growth in South Australia and Tasmania is also very strong in Green Energy Exports.

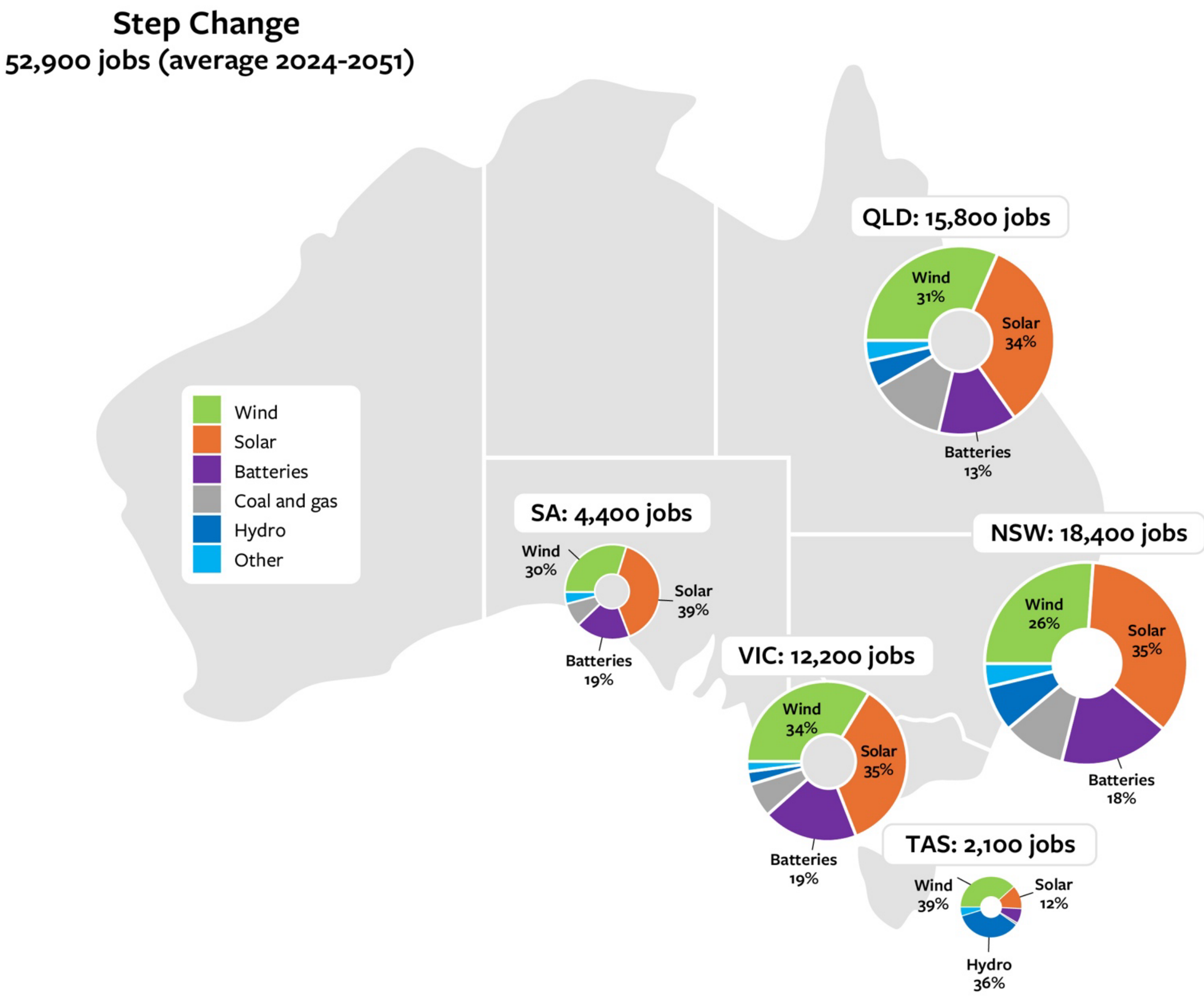

Figure E7 National Electricity Market, average electricity jobs by State, 2023-2050 (Step Change)

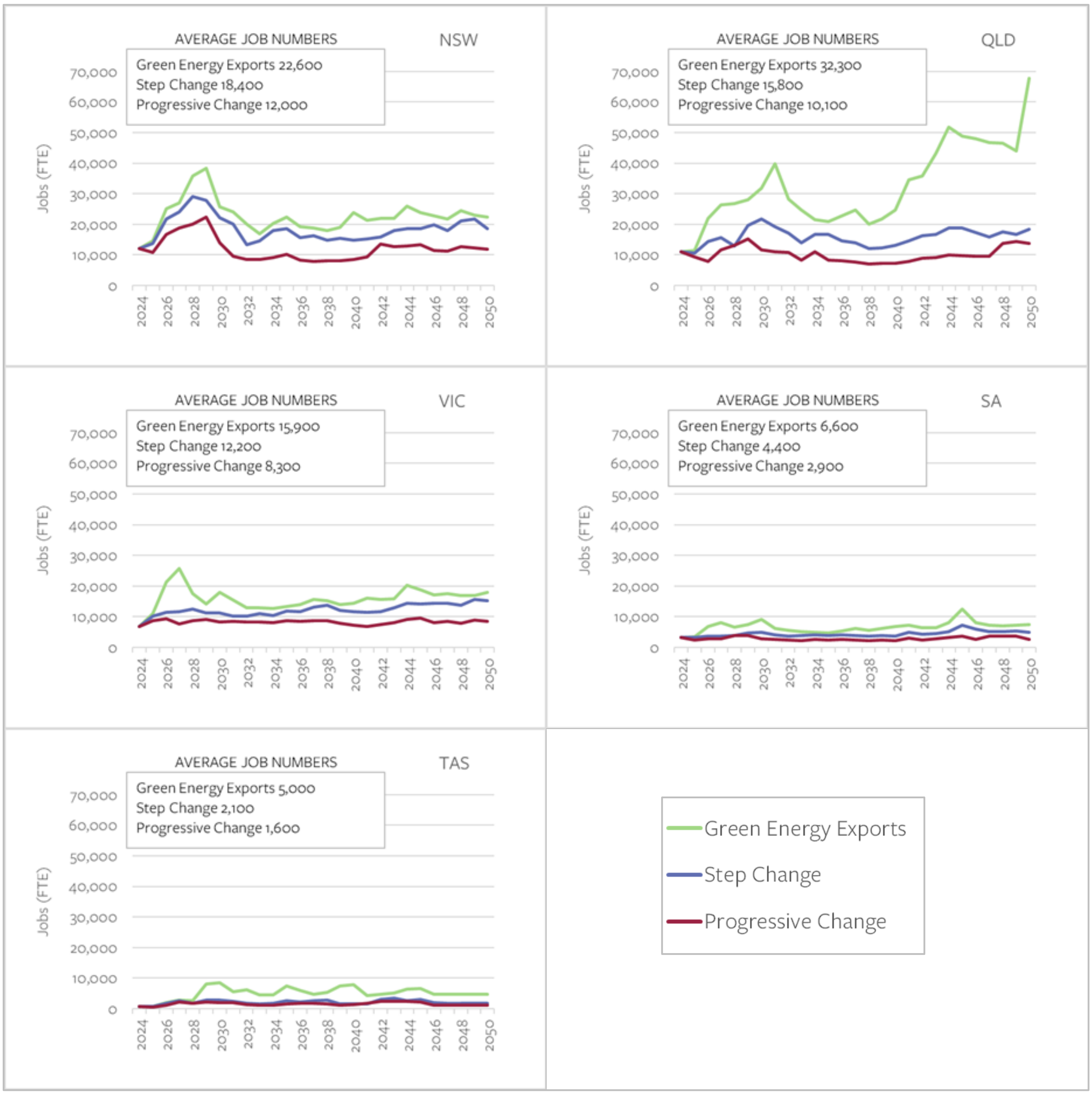

Figure E8 State electricity sector jobs by scenario

There is a major risk of skill shortages which will impact on the timing and cost of the ISP

The rapid increase in requirements for in-demand occupations brings with it a high risk of skill shortages compromising the achievement of the ISP's optimal development path. Skill shortages create the risks of delays, increased project costs (wage inflation, recruitment costs and liquidated damages), and increased cost of capital to reflect increased risk.

The build-out of renewable energy, transmission and storage infrastructure is occurring in the context of tight labour markets with employment at historically high levels. The National Skill Shortage Priority List identifies almost half of professional and trade and technician occupations in national shortage[4], leading to skill shortages in many of the key occupations required for the energy transformation.

The labour market context for renewable energy is particularly challenging due to a number of factors, including the infrastructure pipeline which draws on many of the same occupations, 'thin' regional labour markets for key occupations in major Renewable Energy Zones (REZs), and the difficulty of scaling up the energy workforce training system. The renewable energy sector will be competing for professionals, trades, and technicians against infrastructure projects, in particular 'mega-transport' projects able to offer employment in capital cities instead of remote and regional locations, with generally higher pay.

This is a global problem, as noted by the International Energy Agency: *"Labour and skills shortages are already translating into project delays, raising concerns that clean energy solutions will be unable to keep pace with demand to meet net zero targets"*.[5] This only exacerbates the issue, as bringing expertise in may be increasingly challenging for roles where Australia has developed an increasing reliance on international workers (e.g. wind farm technicians, engineers).

Many workforce initiatives have been implemented or developed by both industry and government since the last ISP, including producing workforce projections alongside the ISP, and there is now more awareness of the task ahead. However, governments are struggling to understand the detailed occupations and skills needed, and how this compares with the likely supply of labour. There also remains a range of structural challenges to increasing the capacity of the training system to scale up the workforce. Powering Skills Organisation, the primary Skills Council for the electricity sector, has identified a range of key issues that need to be addressed:

- Lack of diversity in the workforce: the energy sector has low participation amongst women and First Nations people in particular, which limits capacity to grow rapidly.[6]
- Coordination across sectors: there is competition between sectors for the same groups of workers and a fragmentation of responsibility across Skills Councils. Infrastructure Australia has also advocated for the development of a National Infrastructure Workforce Strategy.[7]
- A shortfall in VET trainers: there is a labour shortage for trainers that also needs to be scaled rapidly.
- Inefficiencies in energy training packages: a package of reforms are proposed to improve the speed in development of training packages and delivery of training.
- Gaps in clean energy skills: training packages in elective skills and post-trade qualifications are required to build the energy workforce with the right skills.

The boom/bust pattern of construction is a key risk factor for labour supply

The requirement for the construction workforce to deliver the energy infrastructure needed for the energy transition is highly variable, with increases of 27,000 in just five years to 2029 in the Step Change (16,000 in Progressive Change and 50,000 in Green Energy Exports). These modelled peaks are followed by sharp drop offs: the Step Change peak is followed by losing 24,000 construction jobs over four years, and the Green Energy Exports scenario loses 38,000 jobs in the same period.

The capacity projection in the ISP is not a detailed delivery plan, it is an indication of the lowest-cost pathway to meeting electricity demand and meeting Australian governments' policies for emissions reduction and renewable energy. From an ISP modelling perspective, this generally results in the model building everything as late as possible, or 'just in time'. The associated workforce projection illustrates the challenge for the supply of skilled labour, and the potential for the boom to be followed by serious contraction in the renewables industry.

There are significant risks for the supply chain if this "lumpiness" is not addressed, exacerbated by the competing demands for infrastructure build in other parts of the economy. The troughs increase the difficulty of putting effective training programmes in place as the pipeline is not steady. These profiles are for all technologies, while specialist skills that are technology specific, and requirements within a state, are likely to be even more volatile.

There is a focus among policy makers on increasing the pipeline of skilled workers, which is certainly welcome. We recommend also exploring the option of smoothing the development pathway to reduce supply chain risks and increase opportunities for workforce development. Bringing projects forward from the late to the early 2030s, rather than deferring projects in the first decade, may allow a smoother workforce profile without compromising emission targets.

Recommendations

The employment projections for the ISP combined with analysis of the labour market and training sector context highlight major risks of skill shortages. There is an urgent need for governments, training providers, and industry to take coordinated action to implement workforce development strategies. This is particularly important in regional areas and the REZs to increase labour supply and create local opportunities. Employment and training should be designed to facilitate a rapid build-out and increase the equity of the energy transition, with training or development initiatives including opportunities for First Nations people and communities most impacted by the transition.

We focus here on recommendations not covered by other major clean energy workforce reports, primarily aimed at managing volatility and the research priorities to address gaps in understanding. Despite the increased focus on workforce issues, governments are still struggling to understand workforce requirements across the energy sector, and the detailed occupations and skills needed.

The first two recommendations are aimed at smoothing workforce profiles and the third at increasing the supply of skilled labour by integrating training into energy sector construction. Recommendations 4 and 5 are aimed at enabling the inclusion of the demand-side workforce in energy sector projections, and recommendation 6 is aimed at improving the coverage and usefulness of workforce projections. We recommend that:

1. The Federal and State Governments consider mechanisms to smooth development and avoid boom-bust cycles without compromising emission targets through the design and implementation of schemes for increasing capacity, such as the Capacity Investment Scheme and Renewable Energy Zones.
2. AEMO consider the cost and emissions implications of smoothing the workforce profile through scenario modelling for the next ISP.
3. The Federal and State Governments, the Clean Energy Finance Corporation and Australian Renewable Energy Agency extend the Australian Skills Guarantee to cover the Capacity Investment Scheme and other publicly funded renewable energy and transmission projects. As of 1 July 2024, this introduced mandatory targets for 10 per cent of labour hours to be completed by apprentices/ trainees, with sub-targets for women, on major construction and information technology projects funded by the Australian government.
4. Research bodies in partnership with industry develop data and methods to include the demand-side workforce in projections, as this workforce is almost entirely uncharacterised despite its crucial role in the energy transition. This requires developing employment indicators for energy efficiency and electrification tasks (in FTE/PJ or GWh) to enable the inclusion of energy efficiency, demand management, energy management, and electrification in workforce projections associated with the ISP.
5. AEMO modify the ISP outputs to support projections for the demand-side workforce, by including outputs in PJ/year or GWh/year for energy efficiency and electrification that affect electrical demand in the ISP; outputs will need to include details of the activities undertaken. While demand scenarios are a key input to any electricity scenario and include energy efficiency and electrification, the associated activities and resulting demand reductions or increases are not currently reported in any detail.
6. Research bodies in partnership with industry develop or revisit employment indicators to improve the coverage, reliability, and usefulness of workforce projections, including:
    - Developing occupational indicators for batteries and offshore wind to support training strategies.
    - Revisiting the employment indicators for major technologies, in particular wind and solar, with reference to the Australian industry to ensure realistic projections.
    - Developing better employment indicators for onshore manufacturing for solar, wind, and batteries.
    - Developing employment indicators where these are not currently available, including hydrogen production, renewable energy and fossil fuel decommissioning, and extraction and processing of critical minerals.

Contents

List of figures

List of tables

List of abbreviations

Acronym	Term
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
CIS	Capacity Investment Scheme
CER	Consumer Energy Resources
FTE	Full Time Equivalent
GW/GWh	Gigawatt / Gigawatt Hours
ISF	Institute for Sustainable Futures
ISP	Integrated System Plan
MW	Megawatt
NEM	National Electricity Market
O&M	Operations & Maintenance
PJ	Petajoules
PV	Solar Photovoltaic
REZ	Renewable Energy Zones
VET	Vocational Education and Training

1 Introduction

This report provides the projected electricity workforce requirements associated with the Australian Energy Market Operator's (AEMO) 2024 Integrated System Plan (ISP)[8]. Projections are segmented to include technology, location and occupation, and cover the generation and storage of electricity and the construction of new transmission lines included in the ISP.

The project was conducted by the Institute for Sustainable Futures, University of Technology Sydney (ISF) in partnership with AEMO and funded by the RACE for 2030 Cooperative Research Centre. An Industry Reference Group made up of representatives from state governments and industry provided valuable insights.

Workforce projections aligned to the ISP were first developed in 2022 under a RACE for 2030 project co-funded by some Australian state governments. The first recommendation in that report was for "AEMO to consult with ISP stakeholders on integrating employment profiles into the ISP". Feedback during stakeholder consultation supported the role of the ISP in emphasising workforce needs, with high level commentary on workforce requirements and workforce projections included in the 2024 ISP. This 2024 workforce projection report was commissioned by AEMO and is referred to as a Supporting Document in the 2024 ISP.

The aim of this report is to provide stakeholders with an in-depth understanding of the workforce implications of different electricity scenarios. Specifically, the report enables state governments, the electricity, and training and education sectors, to develop appropriate and responsive polices, plans and programs. Quality projections of energy sector employment – that cover both location and occupation – are widely recognised as an essential part of delivering an energy transition that is orderly and ensures the full advantages are realised for the Australian economy.

These kinds of projections allow for the development of appropriate training plans and facilities, policy that maximises regional and local economic development opportunities, and the action required to ensure that skills shortages are avoided. [9].

Workforce projections included in this study are for the 2024 Integrated System Plan, covering the three ISP scenarios – Step Change, Progressive Change and Green Energy Exports – and include a manufacturing sensitivity which tests the impact of increasing Australia's share of renewable technology supply chains. Projections include:

- Coal generation (black and brown)
- Gas generation
- Wind (on and offshore)
- Solar (rooftop and utility)
- Batteries (distributed and utility)
- Hydropower
- Pumped Hydro
- Transmission construction

The remainder of the report can be broken down into the following five sections:

- Section 2: provides an overview of the methodology
- Section 3: focuses on the National Electricity Market (NEM) wide reports, including the manufacturing sensitivity and a comparison of the scenarios.
- Section 4: gives NEM-wide workforce projections according to technology.
- Section 5: reports on the workforce projections by state.
- Section 6: discusses the findings and provides recommendations.

For further detail on the workforce projections, there is also a set of "Focus on…" reports for each state, and downloadable workbooks of results available at www.uts.edu.au/isf/explore-research/projects/australian-electricity-workforce-2024-integrated-system-plan-projections-2050

2 Methodology

2.1 Overview

In line with international standard approaches to estimating energy sector employment, this study and the previous 2022 ISP workforce projections[10] utilise an employment factor methodology.

To calculate construction, development, and manufacturing employment in the energy sector, an employment factor (full-time equivalent job-years/megawatt of installed capacity) is applied to the total of constructed capacity (MW) per annum. To estimate employment in operations and management, a factor for jobs per megawatt is applied to the aggregate capacity. Employment factors are lessened over time to capture productivity improvements. Figure 1 below provides a summary of the methodology (see box *Jobs and Job Years*).

Manufacturing employment for year	=	MW installed per year	x	Manufacturing employment factor for that year (job-years/MW)	x	% Onshore manufacturing
Construction employment for year	=	MW installed per year	x	Construction employment factor for that year (job-years/MW)	/	Average construction time
Operation and Maintenance jobs	=	Cumulative capacity	x	O&M employment factor for that year (jobs/MW)		
Fuel employment	=	GWh used per year	x	Fuel employment factor for that year (job-years/GWh)		
Employment factor for year	=	Base year employment factor	x	Technology decline factor for year (equals CAPEX for year / CAPEX for base year)		

Figure 1 Employment calculation: methodological overview

While the calculation is simple, the robustness of results is reliant on the accuracy of both inputs: the capacity projections and employment factors.

JOBS AND JOB-YEARS

Calculating jobs that are project-based and time-limited, such as construction, and those which are ongoing, such as maintenance, require differing approaches. For construction and manufacturing jobs, work is dependent on what is being built and bound to the timeframe allocated to do so. In some cases, construction workers may be able to find continuous employment by moving from one project to another, yet this requires a steady flow of what is being built. We have calculated these jobs in job-years per MW, with one job-year representing one job over the course of the year at full-time capacity. This of course, could also be broken down to represent two people working full-time equivalent over the course of six months or six people working full-time for two months.

In this study, we present maintenance jobs as per MW and as FTE. Since these jobs are assumed to be ongoing, they are calculated in jobs per MW, irrespective of whether it is one person full time or two people part time over a year.

To calculate fuel supply jobs, which are jobs in coal mining or gas production, we look at the total employment to generate one GWh of electricity. Unlike operations and maintenance employment, which is fixed, fuel supply jobs will vary depending on the capacity of each power station.

When we provide a total of jobs for each year, this accounts for the FTE sum of workers working across manufacturing, construction projects, operations and maintenance, and fuel supply in coal and gas generation in that year, irrespective of whether those jobs will continue in the following year.

2.2 The energy transition scenarios and construction

AEMO's Integrated System Plan (ISP) is a roadmap transformation of Australia's National Electricity Market (NEM). It aims to identify the generation, storage, and transmission projects required to ensure a reliable and secure power system through Australia's transition to a net zero economy. This report provides projections of the electricity sector workforce based on the 2024 ISP.

Developing the ISP involves extensive stakeholder engagement and expert input over a two-year process gathering input from governments, investors and developers, consumer and community representatives, energy market authorities, network planners, research and technology institutions and industry bodies. In December 2023 the Draft 2024 ISP was released, followed by a final release on 26 June 2024 after a period of consultation.

The ISP includes three scenarios that reflect various market contexts on the path towards net zero by 2050. These are Step Change, Progressive Change and Green Energy Exports. All three scenarios meet Australia's decarbonisation policy commitments and legislated state government targets, and consider federal and state policies on emissions reduction, energy efficiency, renewable energy, storage, offshore wind, hydrogen, and transmission and Renewable Energy Zones (REZs). This report uses the three scenarios to model Australia's electricity workforce requirements:

- **Step Change** illustrates a rapid pace of energy transition with strong economic growth and with consumer energy resources (CER) playing a strong role. It supports Australia's commitment to keep global temperature rise to below 2°C.
- **Progressive Change** reflects a constrained economic and supply chain environment meaning less uptake of CER and deployment of utility-scale developments, as less energy is required to meet the needs of a smaller economy. While meeting legislated commitments, cumulative electricity sector emissions to 2050 are 36% higher than under the Step Change.

- **Green Energy Exports** indicates an exceptionally fast rate of decarbonisation aimed at Australia making its contribution to keeping global temperatures to below 1.5°C, with a strong emphasis on a green exports economy and electrification. Cumulative electricity sector emissions to 2050 are 46% reduced compared to the Step Change.

Based on extensive consultation, AEMO assigned likelihoods of 43% for Step Change, 42% for Progressive Change and 15% for Green Energy Exports[11], so while the Step Change scenario is the most likely scenario, the margin is small.

AEMO tested a series of different combinations of transmission, generation, and storage, in order to identify an 'optimal development path' that is resilient to all three scenarios. The ISP primarily reports on results for the optimal development path for the Step Change scenario, and the same approach is taken for much of the employment modelling in this report.

AEMO modelled a number of sensitivities to the core scenarios, including a Constrained Supply Chain sensitivity for the Step Change Scenario which applied restrictions to the amount of infrastructure which could be delivered per year and longer lead times for transmission. We discuss the impact of this sensitivity on workforce requirements.

Figure 2 shows the cumulative generation and storage capacity installed in the three scenarios. The installation associated with each explains the workforce differences, as the key determinant of workforce requirements is the scale of project construction. The Green Energy Exports scenario has double the cumulative capacity compared to Step Change by 2050, and three times the capacity than Progressive Change.

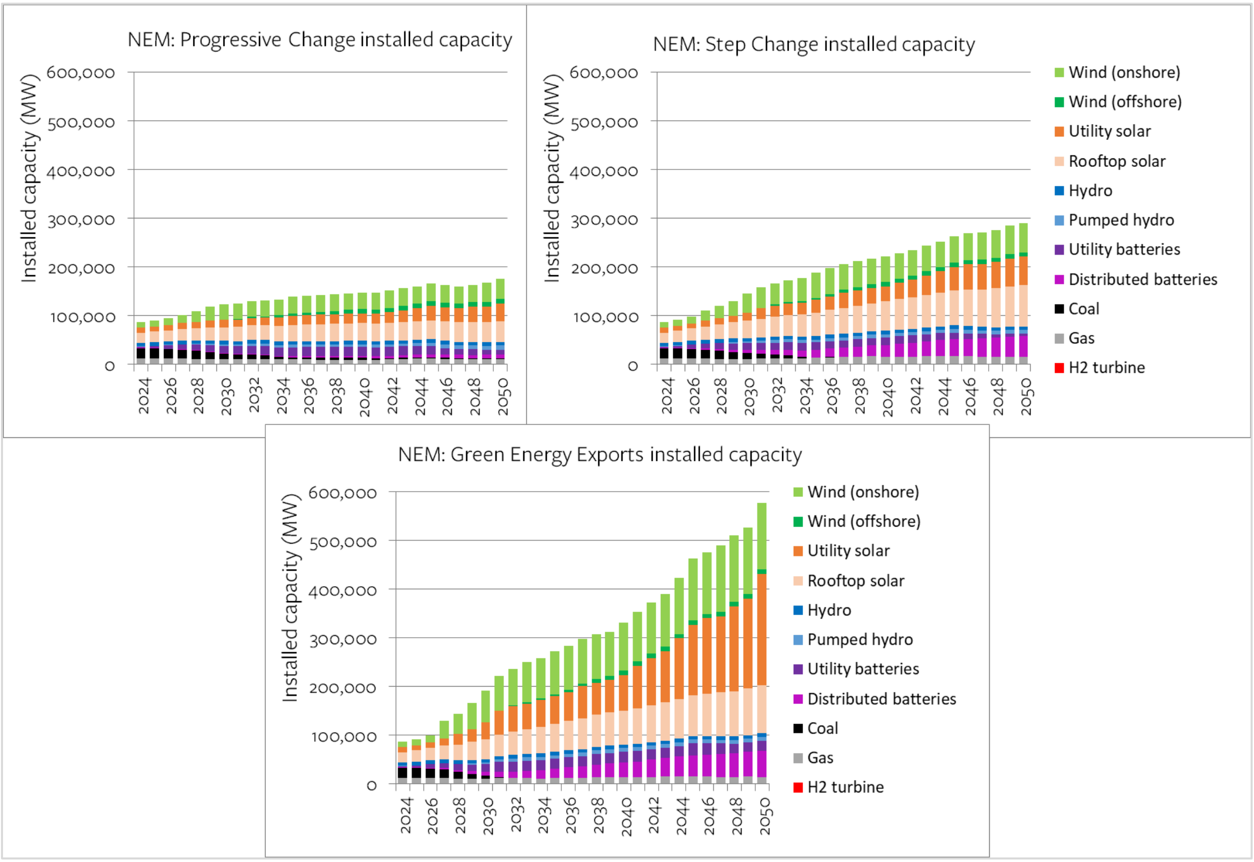

Figure 2 Capacities installed under the ISP core scenarios

2.2.1 Transmission construction

The optimal development path for each scenario includes different transmission project timings for each scenario, and in the latter end of the ISP planning horizon, the inclusion of future ISP projects varies between scenarios. There is considerably higher construction of lines in the Green Energy Exports scenario (25,491 km) over the period compared to the Step Change (8,091 km) and the Progressive Change (6,539 km), reflecting the greater generation capacity in the Green Energy Exports. Many lines are also constructed earlier in the Green Energy Exports scenario, generally by between one and four years.

2.2.2 Data modifications and additions to the ISP

Energy scenario data is sourced from the ISP, with the following additions and modifications.

- **Capacities and generation** for 2024 for all scenarios have been set to the Step Change data supplied by AEMO.
- **Rooftop solar in the Progressive Change scenario**: the ISP projection for Progressive Change is significantly lower than Step Change, with the 2025 capacity at 20.9 GW compared to 22.1 GW, and the 2024 increment forecast as 2.1 GW (Step Change) and 1.7 GW (Progressive Change). We have used the Step Change 2024 capacity, consistent with the approach for other technologies, and noting that distributed installations from July 2023 to June 2024 are 2.3 GW, close to the Step Change. We have modified the 2025-2027 projected capacities as well. Using the ISP forecast data for this scenario would imply there was no additional solar capacity installed anywhere across the NEM during 2025, and no additional rooftop capacity in New South Wales, Queensland, or Tasmania until 2028. We have instead taken a linear extrapolation between the 2024 Step Change capacity and the forecast capacity for rooftop solar in the Progressive Change.
- **Historical capacities for wind and solar** from 2002 were supplied for each state by AEMO for all technologies other than rooftop solar. Rooftop solar capacities by state were supplied from 2015, with NEM data only for 2007-2015. The NEM data was distributed between states using the proportions by state from postcode data downloaded from the Australian PV Institute[12].
- **Distributed batteries:** the capacity for 2024 comes from the AEMO data dashboard[13].

2.3 Employment factors

Employment factors for Australia have been derived over the course of a number of industry surveys in 2020 and 2021[14,15], supplemented by a literature review. The indicators were included in the AEMOs draft input and assumptions report in December 2022[16]. These have been updated using decline factors to reflect that technology costs and employment tend to decline as technologies mature. The final employment factors used in this analysis are detailed in Table 1. The full derivation of these employment factors, other than offshore wind, is detailed in Rutovitz et al 2024[17].

The Victorian Government target for offshore wind has meant there is considerable interest in supporting the development of the offshore wind industry. Offshore wind farms are highly capital intensive, and the greatest share of employment is created in the supply chain rather than directly in construction or operations and management. This has resulted in considerable variation in employment multipliers available from international sources depending on the specific supply chain element included. The 2022 ISP used the employment factors from Sylvest (2020), which appear somewhat low compared to more recent sources. These have been updated using information from the U.S.A. National Renewable Energy Laboratory downloadable input output-model (JEDI), the most recent source benefitting from extensive independent research[218], combined with assumptions on local content. There are high levels of uncertainty about how the industry will evolve in Australia and it has not been possible to undertake industry consultation, therefore the resultant offshore wind employment projections are indicative only. Appendix 1 gives details on how the offshore wind employment factor was revised.

Table 1 Employment factors for the 2024 Integrated System Plan workforce projections

	Construction/ installation Job-years/MW	Manufacturing Job-years/MW	Australian manufacturing Job-years/MW	O&M Jobs/MW	Fuel Job-years/ GWh
Black coal	11.08	5.41	1.62	0.22	0.04
Brown coal	11.08	5.41	1.62	0.22	0.01
Gas	1.27	0.92	0.28	0.14	0.07
Hydro	7.36	3.48	1.04	0.14	
Wind (onshore)	2.65	1.54	0.35	0.21	
Wind (offshore)	1.50	13.68	0.90	0.20	
Utility Solar	1.61	3.08	0.07	0.09	
Rooftop PV	4.19	2.86	0.12	0.13	
Utility batteries	0.53	0.50	0.08	0.03	
Distributed batteries	4.44	0.50	0.08	0.23	
Pumped hydro	7.18	3.48	0.70	0.08	
Transmission line construction					
	Construction/installation (Job-years/km)				
Single circuit	0.70				
Double circuit	3.7				
	Construction/installation (Job-years/$m)				
Transmission (other)	1.90				

2.4 Decline factors

Cost declines for renewable energy technologies are still significant as innovations and efficiencies continue. While possibly not directly correlated to employment generation, there is a strong case that manufacturing, and construction employment does decline alongside overall cost reductions. That is to say, the time taken to construct, install, maintain or manufacture every MW decreases in line with the cost.

In wind technology, for example, the primary influence for declining costs is the turbine size, having shifted over the past twenty years from 0.5MW per turbine to nearer to 3 MW. In turn, there will be an associated decline in the employment created per MW; while there will be additional work associated with installing a larger turbine, this is not going to be comparative to the total MW installed.

Decline factors have a significant impact on the projected workforce requirements (see section 3.2 for a discussion of the role of decline factors in the current workforce projections compared to the 2022 ISP projections).

To establish an understanding of how cost decline can be considered in employment factors, without relying on too many assumptions, we focus on applying the cost decline to the calculated employment factors for manufacturing and construction. This means that the employment factor for a year is equal to the base year factor times the decline factor, explained in the equation below.

$$Decline\ factor\ for\ year\ X = \left(\frac{technology\ cost\ (yr\ X)}{technology\ cost\ (base\ yr)}\right)$$

Following this, we then calculate an employment factor for each year:

$$Employment\ factor\ (yr\ X) = Employment\ factor\ (base\ yr) \text{ x decline factor (year X)}$$

These decline factors are calculated from AEMO cost projections data[19] for all scenarios and all technologies other than rooftop solar. The decline factor is calculated from the generator build costs in the regional build cost summary, using the average of the medium cost for each state for each technology. Rooftop solar is calculated using the costs from the CSIRO, 2023[20]. No decline is applied to coal technologies.

Decline factors have not been applied to operations and maintenance employment, although the 2024 O&M factors were reduced relative to 2022. The O&M factors in use are generally low compared to international standards, and industry consultation in 2020 did not suggest they would reduce further. This may be reconsidered in future work as there are efforts to reduce operational costs via automation.

Decline factors vary by scenario as they are linked to predicted cost reductions, which are related to the number of installations for a particular technology. Table 2 lists the decline factors used here for 2030 and 2050 by scenario. By 2050, the cost of batteries has declined to 36% of the 2023 figure in the Green Energy Exports, compared to 43% in the Step Change, and 50% in the Progressive Change, reflecting the high capacities installed in the Green Energy Exports scenario. Appendix 2 gives the decline factors for all technologies for each scenario.

Table 2 Decline factors by scenario for 2030 and 2050

Technology	2023	2030			2050		
		Step Change	Progressive Change	Green Energy Exports	Step Change	Progressive Change	Green Energy Exports
Hydro	100%	87%	*same in all scenarios*		82%	*same in all scenarios*	
Gas	100%	93%	88%	93%	85%	85%	85%
Batteries	100%	64%	78%	55%	43%	50%	36%
Pumped hydro	100%	87%	*same in all scenarios*		82%	*same in all scenarios*	
Wind (onshore)	100%	74%	76%	75%	68%	73%	62%
Wind (offshore)	100%	72%	77%	48%	61%	74%	36%
Utility-scale PV	100%	71%	69%	71%	38%	43%	33%
Rooftop PV	100%	69%	*same in all scenarios*		34%	*same in all scenarios*	

2.5 Occupational structure

The indicators used to form the basis of the occupational employment projections in this study were derived from two surveys – the 2021 transmission construction survey and the 2020 renewable energy survey[21,22] - and supplemented by information from literature. Full details of the occupational shares are given in Rutovitz et al (2024)[23]. The following technologies have occupational employment factors:

- Utility-scale PV
- Onshore wind
- Pumped hydro (hydro assumed the same)
- Transmission line, sub-station, and associated asset construction
- Rooftop PV
- Coal and gas (inclusive of power station operations and maintenance and fuel supply)

There are two different sets of occupational employment factors for each technology. All the renewable technologies have a set for development and construction, and a set for operations and maintenance. Coal and gas have a set for operations and maintenance and a set for fuel supply; construction is not calculated, as no data is available, however employment will be dominated by operations and maintenance and fuel for these technologies in any case.

To define occupational shares, we drew from the Australian and New Zealand Standard Classification of Occupations (ANZSCO), and present occupations at two levels:

- 1-digit (managers, professionals etc)
- Composite: this may be a 2-digit, 3-digit or 4-digit ANZSCO coded occupation, depending on the size of the workforce requirement and common industry understanding (e.g. electrician)

The occupational shares are applied to the total employment numbers for each technology by phase to calculate the mix for the electricity supply sector (excluding offshore wind and batteries). Total numbers are influenced by the mix of phases over time and particular years. In later years, the operations and maintenance share of employment will have a greater influence, while peak years tend to be dominated by construction.

2.6 Repowering

Repowering a renewable asset, such as solar panels or wind turbines, refers to the process of replacing hardware either due to end of life or because improvements in the technology have significantly enhanced performance, meaning it is more profitable to do so.

We include repowering in the model for utility-scale solar, rooftop PV and onshore wind, with the construction times and employment factors remaining the same as for new infrastructure.

Replacement is assumed to occur after 30 years for utility-scale solar, and after 25 years for onshore wind. The assumption for the replacement cycle is somewhat longer than in the previous ISP workforce projection to bring it in line with AEMO repowering assumptions, which used 20 years for both technologies in previous iterations of the workforce projections for the ISP[24]. As in the previous work, we assume rooftop PV is repowered after 25 years. While there may be some variance in the timescale of repowering, with some happening later than assumed, it is also likely that in some cases this repowering occurs earlier to take advantage of improvements in turbine or panel efficiencies.

Using historic data for utility-scale wind and solar, we assume all existing utility-scale capacity previously installed is repowered. We only include 80% of rooftop solar, assuming that replacement will be more variable.

2.7 Caveats and omissions

The projections developed in this study work solely with the ISP scenarios and are therefore reflective of the inputs and assumptions of the ISP. AEMO's ISP scenarios include all current legislated targets and take account of energy policies. However, anything published after the ISP release is not included.

As the ISP focuses only on the National Electricity Market (NEM), workforce projections for the Northern Territory, Western Australia and the off-grid renewable projects that service mine sites and/or for energy exports have not been included. Given the WA and NT governments have similar net zero targets and the significant anticipated growth in off-grid renewables, the demand for energy sector workers is much broader than captured here.

There are many assumptions that go into these projections, and actual numbers that eventuate could vary significantly, particularly in later years. While declines are applied to account for incremental productivity improvements, these cannot account for step changes that occur in work practices, for example as a result of automation.

Modelling omissions:

- The employment projections in this study do not extend to energy efficiency, electrification of homes and businesses, or energy and demand management. This workforce, however, is likely to be very significant and more research is needed in this space to adequately account for the scale of employment generated by decarbonising the energy system. The ISP does contain energy efficiency and electrification inputs that aid in determining electricity consumption in each scenario, and this is captured as GWh/year electricity savings (energy efficiency) or GWh/year consumption (for electrification) in each scenario. It is recommended that employment indicators are developed in order to include this workforce.
- There is insufficient reliable data available on occupational shares for offshore wind or batteries, so the occupational forecasts do not include these technologies. It is recommended that industry surveys are undertaken so that data for these sectors can be included in future projections.
- Excluded from the employment projections are the adjacent professional services linked to but not directly connected to renewable energy (for example, regulators), jobs in mining and/or mineral processing associated with renewable energy technologies, and the decommissioning and recycling workforce.
- The hydrogen workforce is only partly included in this study, as the employment embedded in the renewable energy generation (wind and solar) for green hydrogen production that is included in the ISP scenarios. As the industry is nascent, robust employment indicators are unavailable, with much of the specifics of the hydrogen sector landscape still unknown. Research and data collection is needed in order to include employment linked to the production and supply chain for hydrogen.

3 Electricity sector workforce projections for the National Electricity Market

3.1 Electricity sector workforce projections by scenario

Electricity sector workforce jobs in the National Electricity Market (NEM) initially increase in all scenarios (Figure 2), with the highest growth occurring in Green Energy Exports and the lowest under Progressive Change.

Across the three scenarios there is an initial jobs peak in 2029, in line with the build out of projects ahead of 2030 decarbonisation targets. Jobs then fall in all scenarios until about 2033, and then broadly increase until the end of the period.

While the scenarios follow a similar profile, there is a huge disparity in the scale of workforce requirements and volatility. Step Change requires an additional 33,000 people by 2029, a challenging increase in just five years, and then sheds over 20,000 jobs over three years. The Progressive Change growth is more modest, with an extra 19,400 people needed by 2029; then the decline parallels the Step Change, with more than 20,000 jobs lost by 2032. The Green Energy Exports growth profile is extreme, with 62,700 additional people required by 2029, followed by again shedding more than 20,000 jobs in three years.

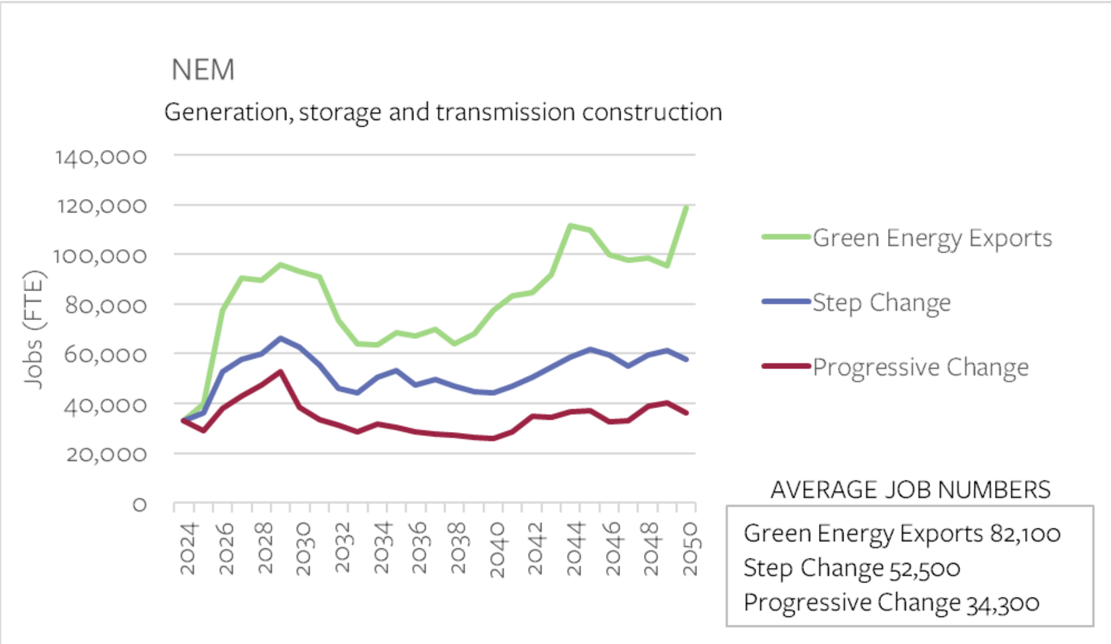

Figure 3 National Electricity Market, electricity sector jobs by scenario

- **Step Change** (the most likely scenario by a small margin): with an average of 52,500 jobs annually. Workforce requirements increase steadily to peak at 66,300 in 2029, and then fall to 46,100 in 2032. Jobs then plateau until 2040, when jobs rise again to reach nearly 59,000 at the end of the decade.
- **Progressive Change**: shows the most limited job creation, with an average of 34,300 jobs. Jobs peak in 2029, with 52,700 jobs, and then decline sharply to 31,200 in 2032. Jobs continue dropping slowly to a low of 25,800 in 2040, and then increase slowly from 2045-2050.
- **Green Energy Exports**: average job numbers are 82,100, almost 50,000 more than the Progressive Change scenario. Green Energy Exports sees dramatic peaks in both 2027 and 2029, with a total of 90,200 jobs in 2027 and 95,800 jobs in 2029. This is a tripling of the workforce in five years. Exponential growth is seen again in the early 2040s, when energy jobs spike to 111,400 in 2044, a near doubling of the workforce in the decade from 2034.

In line with the ISP scenarios, this report creates workforce projections from 2024 through to 2050, although the later years are highly uncertain. For example, while these projections include the assumption of gradual increases in labour productivity which reduce the employment for the same capacity, there could be step changes to productivity (e.g. construction automation). While there is rigour to the methodology, the final decade's projections should be read as indicative only.

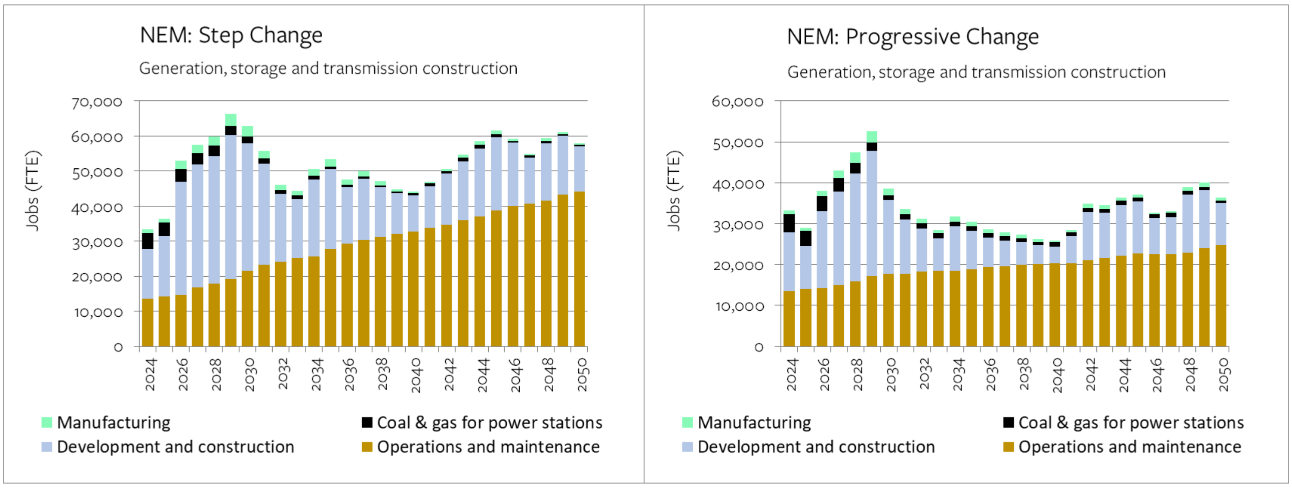

Figure 4 National Electricity Market, jobs by phase (Step Change & Progressive Change)

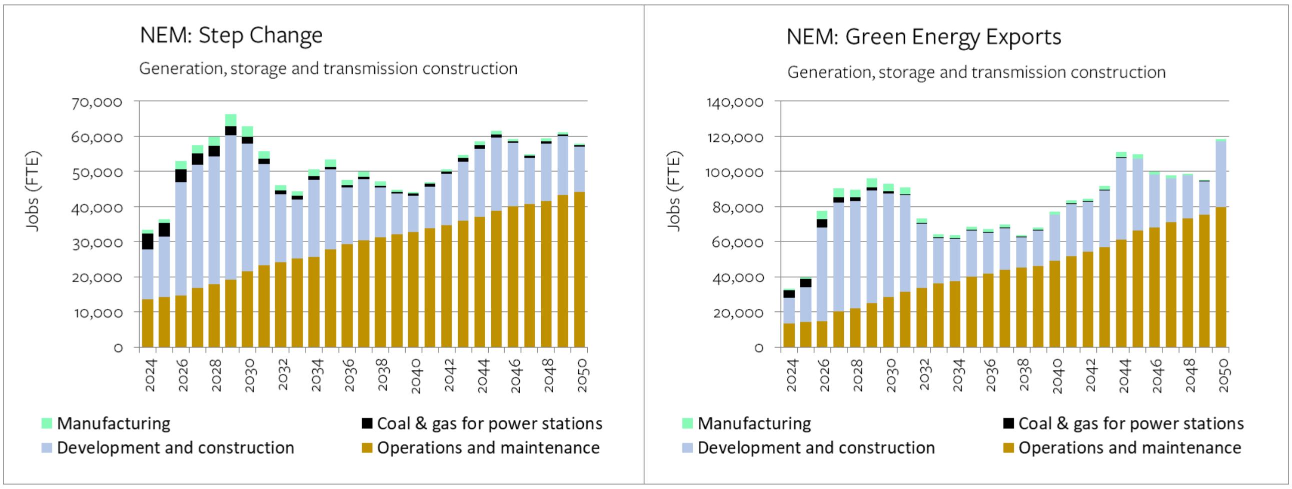

Figure 5 National Electricity Market, jobs by phase (Step Change & Green Energy Exports)

Note the scale for employment is 70,000 on Figure 4, and 140,000 on Figure 5

Figure 4 and Figure 5 show the three scenarios by project phase.

- The development and construction workforce booms in the early period, peaking in all scenarios in 2029. While there is some variation year on year, it remains a strong part of the employment profile. In the Green Energy Exports scenario, there is another marked peak in 2044-2045.
- Operations and maintenance jobs demonstrate consistent growth as a proportion of the workforce in all scenarios. As more projects come online, operations and management jobs become the largest element, accounting for more than 70% of the workforce in all scenarios by 2050 (up from 41% in 2024).
- Manufacturing accounts for a very small proportion of the workforce in all scenarios. The employment factors informing these estimates predate the Future Made in Australia policies, which could somewhat increase these numbers (Section 3.2).

- Fuel employment (extraction of coal and gas for domestic electricity production) is at 4,600 in 2024 but falls to less than 1,000 by 2050 in all scenarios. It is important to note that these jobs only represent coal and gas for domestic electricity production, not coal and gas for export.

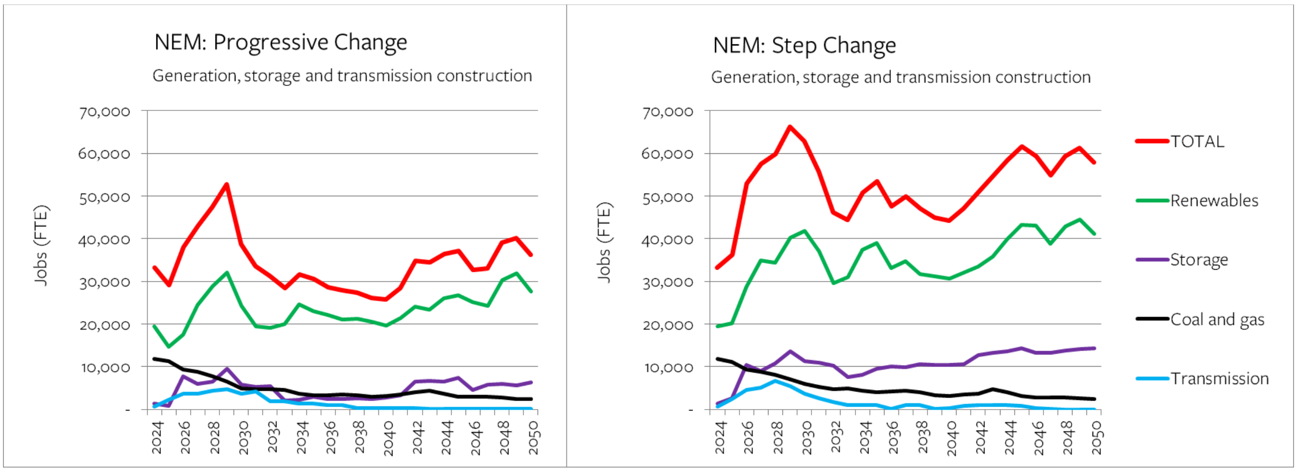

Figure 6 National Electricity Market, jobs by technology group (Step Change & Progressive Change)

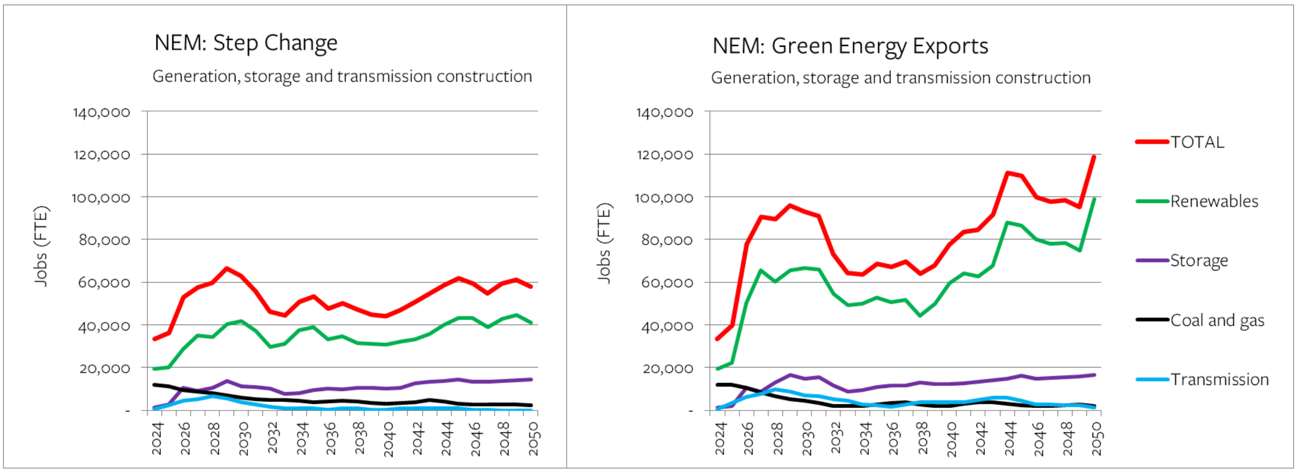

Figure 7 National Electricity Market, jobs by technology group (Step Change and Green Energy Exports)

Note the jobs (FTE) scale reaches 140,000 in Figure 7, and only 70,000 in Figure 6

Figure 6 and Figure 7 show the total number of jobs over the period according to the broad technology group. These are, renewables (inclusive of utility and rooftop solar, on and offshore wind, and hydro), storage (covering both utility-scale and domestic), transmission line construction, and coal and gas. This is in order to capture the peaks in employment indicative of growth in the Green Energy Exports scenarios.

The key differences between the technology groups include:

- Renewables provide the highest amount of jobs under all scenarios, with an average share of 68% of the workforce in Step Change and 74% in both Green Energy Exports and Progressive Change.
- From a very low base, storage jobs increase to 25% of the workforce in Step Change by 2050 and 20% in Green Energy Exports. Under the Progressive Change scenario, the storage workforce represents an average of 7% of the total workforce.
- Transmission employment reaches a maximum of 11% in the Step Change scenario in 2028 and will be at the highest employment in decades, reflecting the urgency of building out the transmission system. Transmission jobs peak over the next five years in all scenarios, in 2028 under Step Change and Green Energy Exports (at 6,700 and 9,700 respectively), and in 2029 in Progressive Change (at 4,700).

- Coal and gas employment declines under all scenarios. While current employment in coal and gas power production sits at about 35% of the total energy workforce, by 2050 this will be 4% in Step Change, 2% in Green Energy Exports and 6% in Progressive Change.

3.2 Workforce projections for the 2022 and 2024 ISP compared

The workforce and capacity projections for the Step Change scenario in the 2022 and 2024 ISPs are shown in Figure 8. Comparing the capacity projections, the ambition for 2030 has increased with a total capacity of just over 145 GW reached in the current ISP compared to approximately 123 GW in the 2022 ISP. This is reflected in the workforce profile, with a very steep rise required from 2026 to 2029. The pattern is similar in the Progressive Change workforce projections for the two ISPs (Figure 9), with a steep capacity increase, and a corresponding workforce increase, required in the run up to the 2030 target.

The increase in workforce requirements from now until 2030 has become steeper in all three scenarios. While this is challenging, it is needed to enable Australia's emission targets to be reached, noting that the Constrained Supply Chain sensitivity which AEMO tested in this ISP did not meet emission targets (section 6.2.1).

It is hard to see how emission targets will be reached without rapidly scaling up the workforce each year from now until 2030. Following the immediate development push for 2030, bringing projects forward from the latter half of the 2030s could avoid the boom-bust cycles which have plagued the renewables industry, and avoid some of the extreme volatility in the workforce profiles.

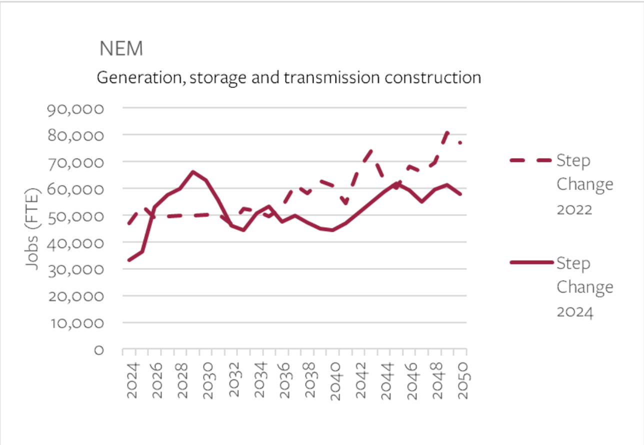

Figure 8 Workforce projections for the 2022 and 2024 ISP – Step Change

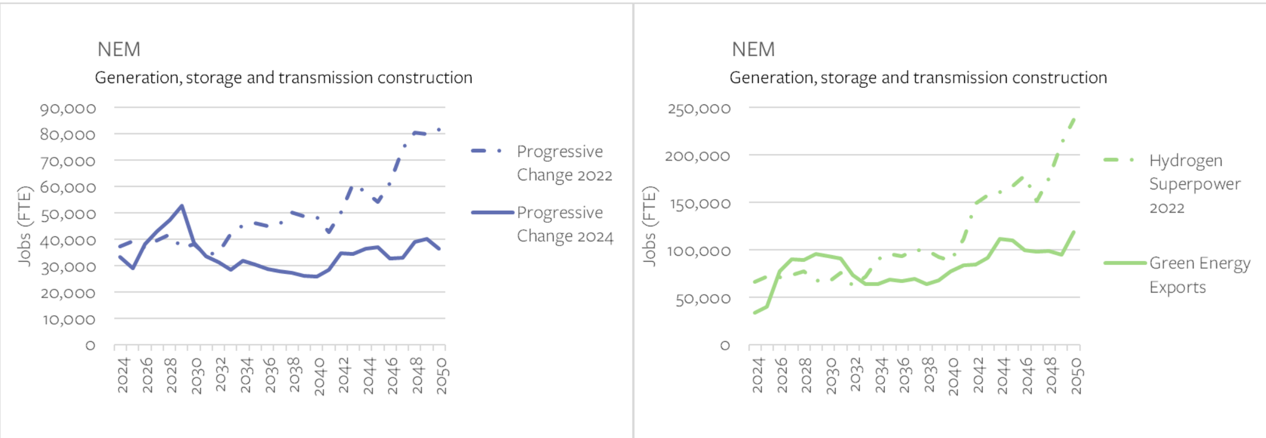

Figure 9 Workforce projections for the 2022 and 2024 ISP – Progressive Change and Green Energy Exports
Note: the different scales on the jobs FTE for Progressive Change (90,000) and Green Energy Exports (250,000).

Average workforce requirements are somewhat lower in the Step Change for the 2024 ISP compared to the 2022 ISP Step Change (52,000 compared to 57,000). The cumulative capacity change is very similar in the two scenarios, with total capacity at 2050 290 GW, 203 GW higher than 2024 (287 GW cumulative and 202 GW addition in the 2022 ISP).

The absolute change in the projected workforce requirements is a result of the decline factors which are applied. These are calculated from the costs used in the modelling, assuming that there is a gradual productivity increase corresponding to the projected cost decline. The impact of these declines is shown in Table 3 for the four major technologies.

The change in construction employment of 17% is almost entirely accounted for by the assumed productivity increase, as a similar total capacity is constructed over the period. For O&M, the change in average jobs is 5%, considerably less than could be expected from the change in the employment creation for each technology. This is explained by the fact that construction is brought forward to meet the 2030 target, so O&M jobs start earlier.

Table 3 Impact of decline factors on employment change between the 2022 and 2024 ISP (Step Change)

Data for Step Change	Employment factors 2022 ISP		Employment factors 2024 ISP		Percentage change	
	2024	2050	2024	2050	2024	2050 (cumulative)
Development and construction						
Wind (onshore)	2.6	2.2	2.7	1.8	-0.4%	18%
Utility-scale PV	1.6	0.9	1.5	0.6	4%	20%
Rooftop PV	4.2	2.0	4.0	1.4	5%	19%
Distributed batteries	4.4	1.6	4.4	1.9	0%	3%
Average development and construction jobs 2024-2050	24,800	20,500				17%
Operations and management						
Wind (onshore)	0.22	as 2022	0.21	as 2024	1%	1%
Utility-scale PV	0.11	as 2022	0.09	as 2024	22%	22%
Rooftop PV	0.16	as 2022	0.13	as 2024	20%	20%
Distributed batteries	0.27	as 2022	0.23	as 2024	16%	16%
Average O&M jobs 2024-2050	30,700	29,300				5%

The workforce projections for Progressive Change, Green Energy Exports, and the Hydrogen Superpower scenario are shown in Figure 9 (the 2022 Hydrogen Superpower is the closest to the 2024 Green Energy Exports).

In the Progressive Change, the steep rise to 2029 is followed by a steep drop off. The 2022 ISP workforce projections are considerably higher overall, with an average of 49,700 jobs from now to 2050, compared to 34,300 in the 2024 ISP. This reflects the lower capacities projected in the 2024 ISP in Progressive Change, with a total of 175 GW installed in 2050 compared to 255 GW in 2050 in the 2022 Progressive Change.

The Green Energy Exports increase in workforce requirements of nearly 10,000 per year shown in the 2024 scenario is hard to imagine achieving and is even steeper than the increase projected for the Hydrogen Superpower in the 2022 ISP. It is likely workforce shortages would become a significant obstacle in this scenario. While Hydrogen Superpower shows far greater numbers in 2050 compared to the Green Energy Exports, this is almost certainly because it was assumed all hydrogen production would be grid-connected in the 2022 projection. Assuming that off-grid and grid-connected production will be of similar volume, an additional 59,000 workers are likely to be required by 2050 (see Section 4.7), so the real difference between the 2022 and 2024 projections at 2050 is much smaller than shown in Figure 9. This demonstrates the risks inherent in looking at workforce projections for the ISP in isolation of all energy-related jobs requirements.

3.3 Manufacturing sensitivity

Australia's share of manufacturing for the electricity sector is currently low. The base case proportion of manufacturing occurring onshore for most technologies was estimated after surveys carried out in 2020, and the proportion is kept constant until 2050 (see Table 4).

However, a number of global and regional factors are leading Australian governments to re-evaluate our role in the clean energy sector including risks associated with geopolitical factors and global trade dynamics and global supply chain shocks and emerging areas of competitive advantage associated, for example with critical mineral resources as well as traditional areas of competitive advantage such as research & development.

Australian Governments are developing policies to increase local manufacturing for renewable energy technologies. In the 2024-25 Federal Budget, five priority areas were identified as part of the $22 billion Future Made in Australia program:

- critical minerals processing
- green metals
- clean energy manufacturing, including battery and solar panel supply-chains
- renewable hydrogen
- low carbon fuels.[25]

Some of the areas which have been identified where local renewable energy manufacturing could grow, include the battery supply-chain, wind tower manufacturing and various parts of solar manufacturing (e.g. ingots, frames).[26]

Consequently, we examine an enhanced manufacturing sensitivity, where an increased proportion of manufacturing employment occurs onshore. It is assumed the manufacturing proportion increases linearly to reach the enhanced level shown in Table 4 by 2034, and then stays at that level until 2050. The percentages of local content which could be reached are highly uncertain, particularly for new industries such as batteries and offshore wind.

Table 4 Proportion of onshore manufacturing (base case and enhance manufacturing scenario)

	BASE	ENHANCED MANUFACTURING	
	2024-2050	2024	2034-2050
Coal	30%	30%	30%
Gas	30%	30%	30%
Hydro	30%	30%	30%
Wind (onshore)	23%	23%	30%
Wind (offshore)	6.6%	6.6%	19%
Utility Solar	2.3%	2.3%	10%
Rooftop PV	4.3%	4.3%	10%
Batteries	15%	15%	30%
Pumped hydro	20%	20%	30%

Figure 10 shows the increase in overall employment in the Step Change scenario with increased onshore manufacturing, while Figure 11 shows the same increase, highlighting what happens in the manufacturing phase alone. While the increase is modest compared to overall electricity sector workforce requirements, the average manufacturing employment nearly doubles, to reach 2,600, and reaches a peak of just over 5,000.

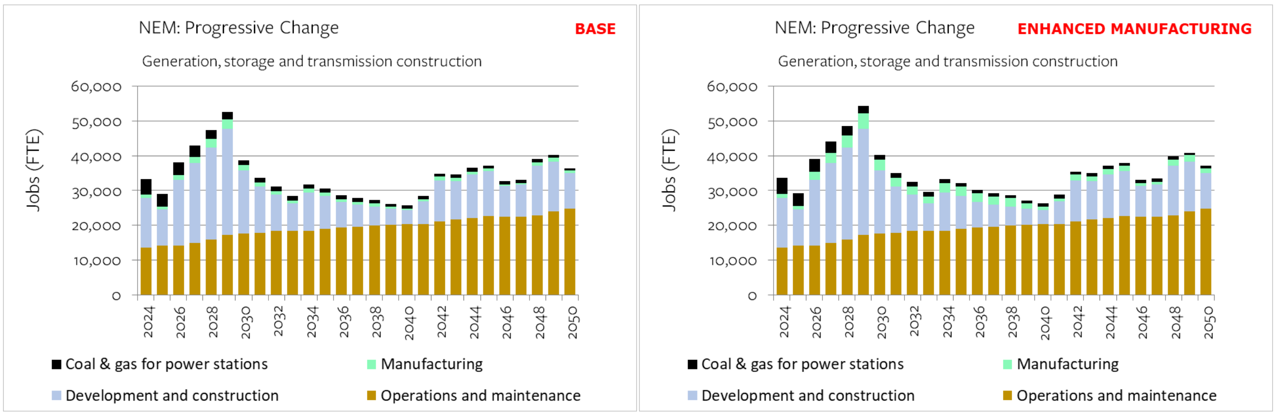

Figure 10 Change in overall employment with active policies to increase onshore manufacturing

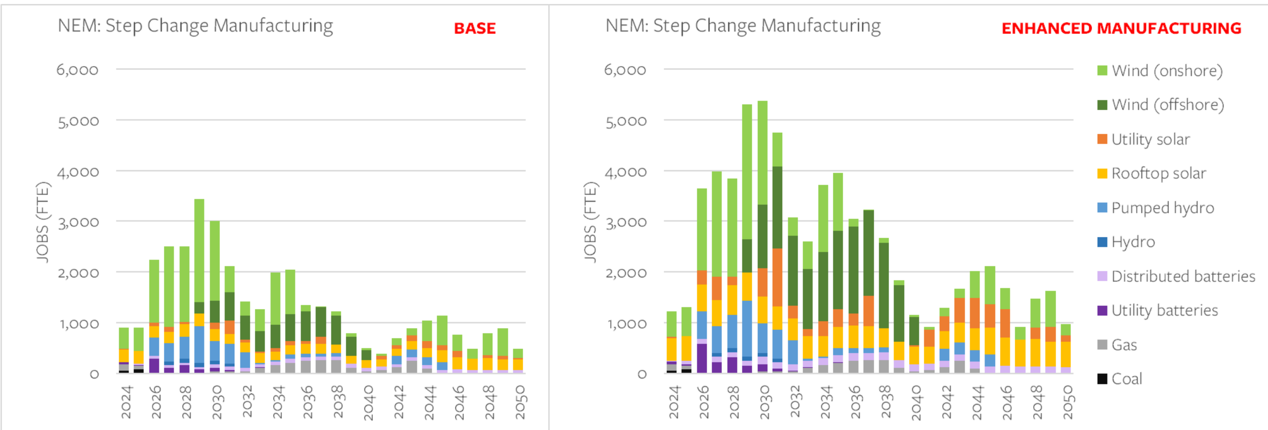

Figure 11 Change in manufacturing employment with active policies

3.4 Employment by occupation in the National Electricity Market

For the energy transition to be manageable and deliver maximum benefit for communities, a clear grasp on overall occupational employment trends is needed. Governments, the training and education sectors, industry and the community need to understand the kinds of jobs created through the energy transition.

Figure 12 shows the average occupational structure from 2024-2041 under the Step Change scenario[4]. Trades and technicians dominate, followed by professionals, managers, labourers, machine operators and drivers, and lastly admin staff. Wind technology creates the most employment for the first three categories and administration staff, while pumped hydro creates the highest number of labourer jobs and coal the highest number of machine operators and drivers.

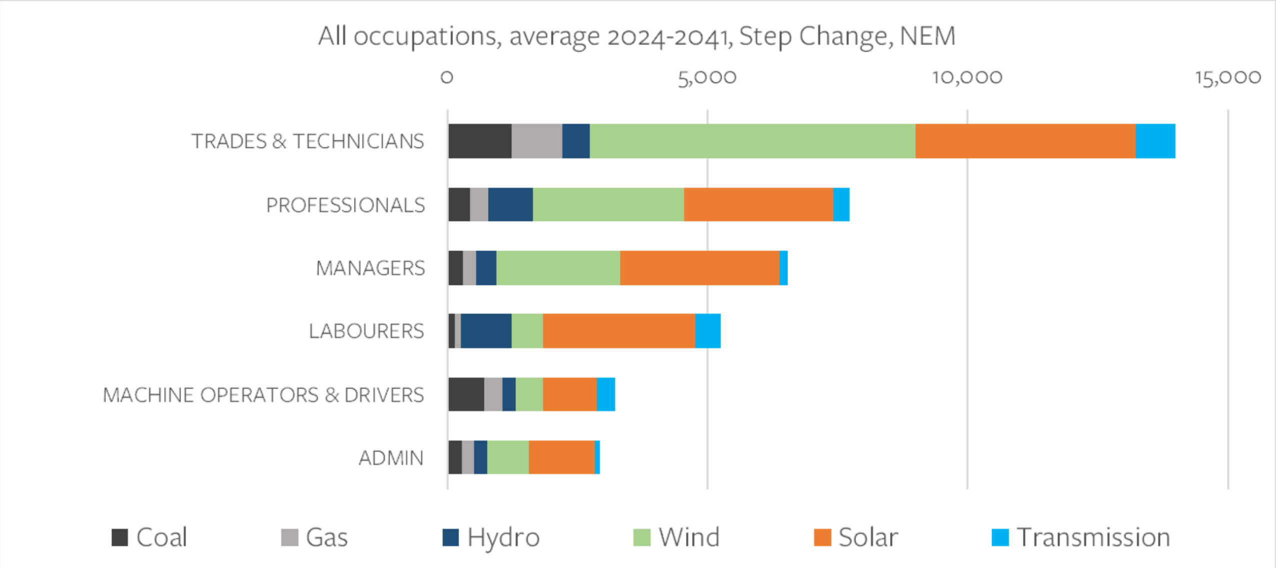

Figure 12 National Electricity Market, average occupational structure 2024-2041 (Step Change)

Under all three scenarios, 2029 is a peak year, as it has the highest overall workforce requirements for the Step Change and Progressive Change and is the early peak year for the Green Energy Exports scenario. Electricians are the most in-demand occupation by a large margin (Figure 14), with of about 7,600 across the NEM[5]. This is critical because a four-year apprenticeship is required to become a licenced electrician.

The NEM is only one source of demand for electricians. Modelling commissioned by Jobs and Skills Australia and Powering Skills Organisation has estimated the supply-demand balance across industry sectors for electricians. Demand projections under their Central Scenario estimated 32,000 more electricians were required up to 2030.[27] Using this data, analysis by Powering Skills Organisation estimated a 'critical shortage' of 17,400 electricians by 2030. Powering Skills Organisation notes this is likely to be an under-estimate as it doesn't include demand in energy efficiency and demand management or upside growth in other adjacent sectors like critical minerals, clean hydrogen or green steel. They estimate 20,500 apprentices are required to commence each year from 2024 to close the existing shortage projection.[28] A range of challenges were identified including a shortfall in trainers, students failing to complete apprenticeships and a lack of diversity in students and workers.

[4] Occupational projections are made for a shorter timeframe as the associated uncertainty is even greater.

[5] Demand for electricians keeps rising after the overall workforce peak, reaching 8,300 in 2030.

There is a second tier of occupations with peak demand between 2,000 and 2,600 - administrative staff, mechanical trades, construction labourers, finance/business/legal/policy professionals, and concreters. Wind dominates employment demand in the peak year for four of the six most in-demand occupations, with the exception of construction labourers, where hydro creates the highest demand (Figure 14). Average demand for the most in-demand occupations highlights a similar group of occupations, although mechanical trades and technicians, operations and production managers and other trades and technicians with more even demand profiles are more prominent and construction workers falls out of the list reflecting the very peaky demand profile (Figure 13).

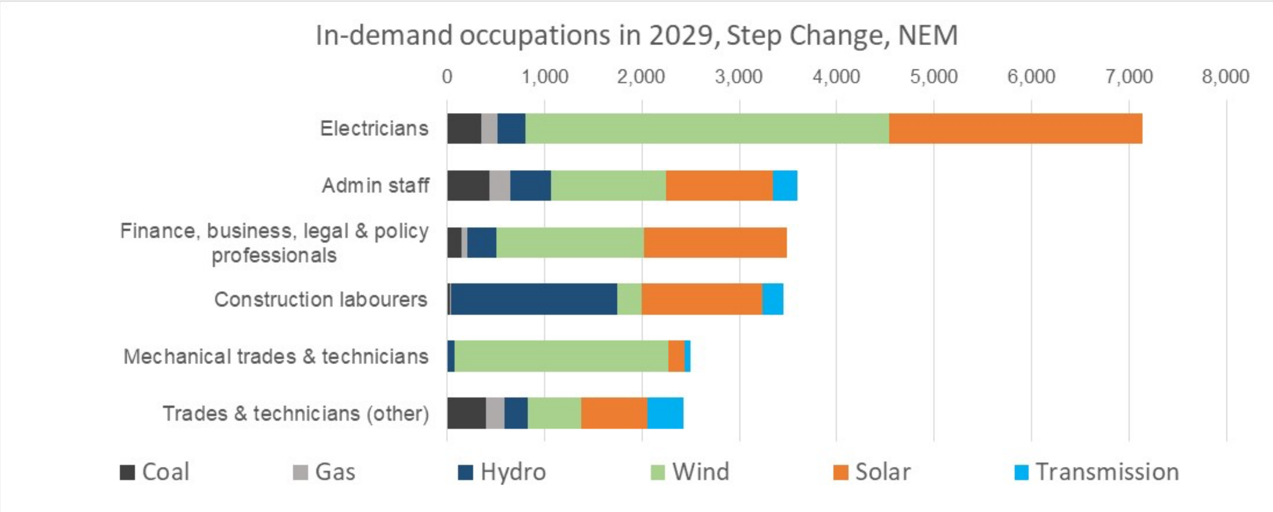

Figure 13 National Electricity Market, in-demand occupations (Step Change)

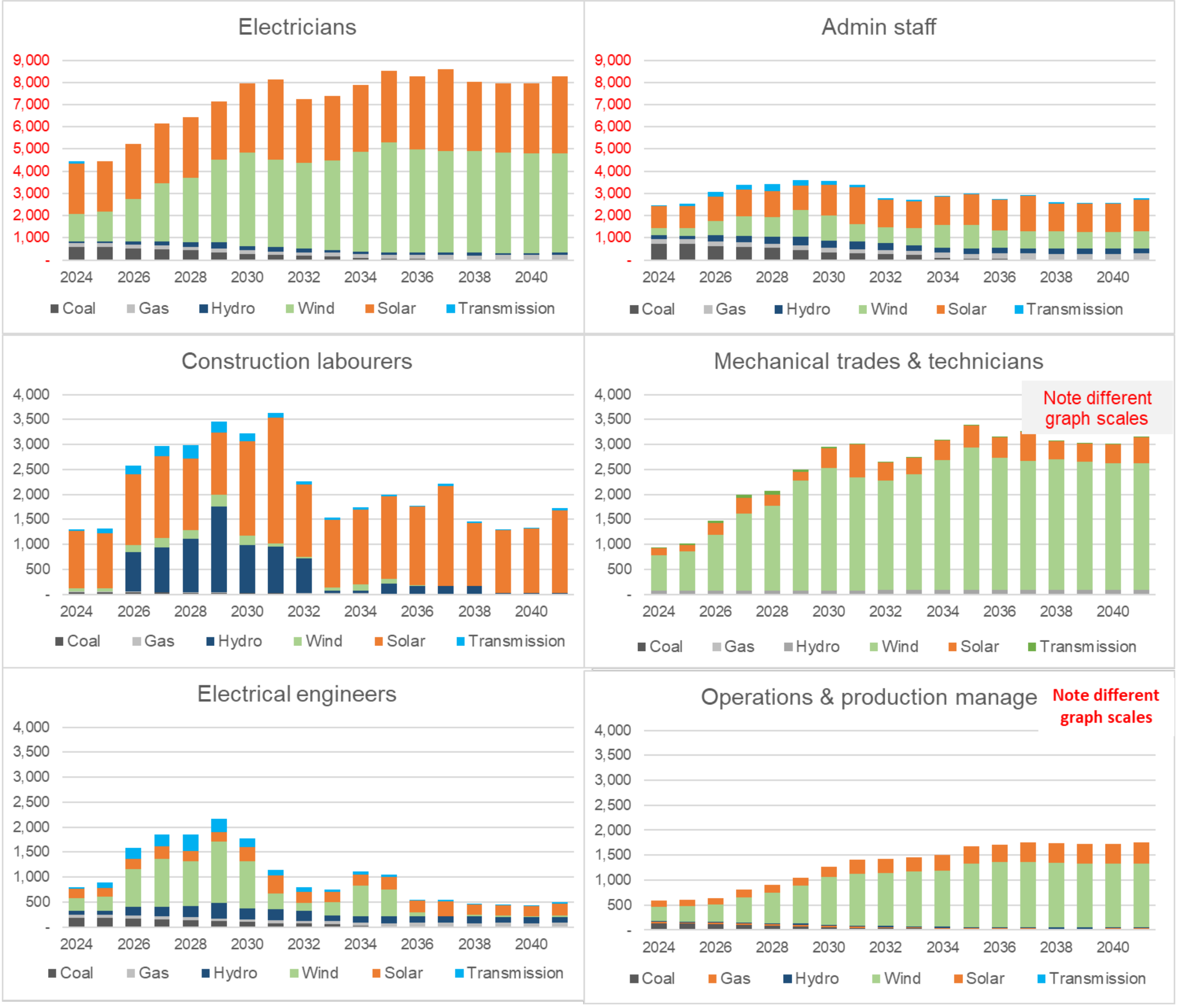

Figure 14 National Electricity Market, in-demand occupations annual requirements (Step Change)
Note: Electricians and admin staff have a scale reaching 9,000 jobs, whereas other occupations have a scale maximum of 4,000 jobs.

There are important variations in the profile of the in-demand occupations (Figure 14). In general, electricians, professionals, and operations managers increase over the entire period, while those occupations linked more directly to construction are far more volatile.

- Demand for electricians almost doubles by 2030, then fluctuates somewhat around 8,000, with average demand of 7,400 between 2024 and 2041. Most of the demand is in wind and rooftop solar, followed by transmission construction.
- Mechanical trades and technicians follow a similar trajectory, increasing three-fold over the next decade to reach 3,100 in 2034, then remaining relatively stable through the rest of the period. Wind is the major source of demand.
- Roles that follow construction are the most variable. Demand for construction labourers and electrical engineers rises three-fold by 2029.
- Demand for finance, business and legal professionals and for operations and production mangers generally increases steadily over time as operating projects increase.

4 Workforce projections by technology for the National Electricity Market

Wind farms and rooftop solar are the primary sources of employment for the NEM across all scenarios, accounting for well over half of average employment (Figure 15). Most battery storage employment is in distributed installations alongside rooftop solar, and the combined rooftop solar and batteries workforce provides up to 43% of employment. Battery storage and utility solar are more variable between scenarios: battery storage employment is almost triple under Step Change relative to Progressive Change, whereas utility solar doubles under the Green Energy Export scenario.

Transmission and pumped hydro both account for a smaller volume of employment. Coal and gas employment share is directly related to the pace of transition with the highest share under the Progressive Change scenario (still around 1-in- workers) but falling to just 1-in-20 under the Green Energy Exports scenario.

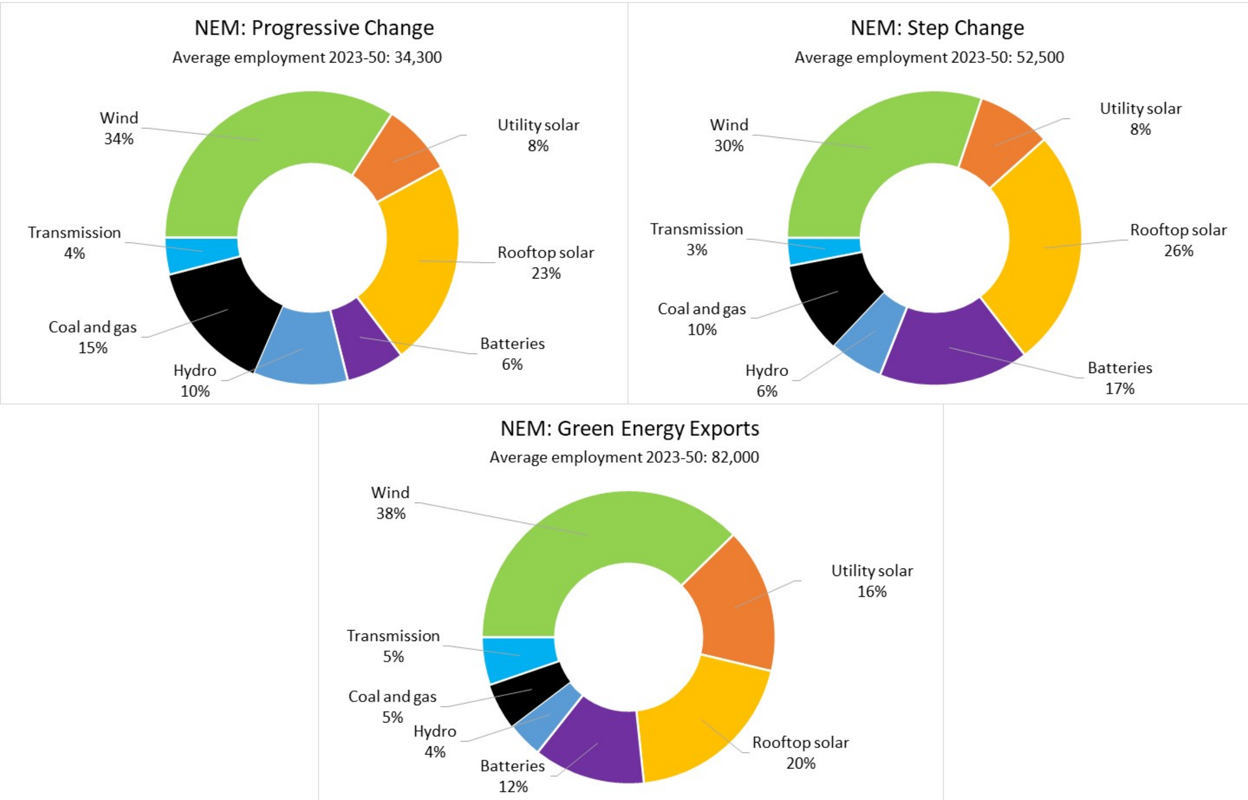

Figure 15 National Electricity Market, average electricity sector jobs by technology and scenario

Figure 16 highlights the annual jobs created by each technology across the NEM and shows the split between onshore and offshore wind and utility-scale and distributed batteries.

Wind: Under all scenarios, wind dominates, making it the technology that creates the largest proportion of jobs. Under Step Change, onshore wind accounts for an average of 13,800 jobs each year, while offshore accounts for a much smaller workforce, with 1,600 jobs each year on average. The Victorian government target[6] for offshore wind is included in all scenarios; the only additional offshore wind delivered is 148 MW in Queensland under the Green Energy Exports. In all scenarios, the wind workforce peaks in the later part of this decade, with 24,600 jobs in 2029

[6] Victoria has a legislated target for offshore wind of 2 GW by 2032, 4 GW by 2035 and 9 GW by 2040.

under Step Change, 38,400 under Green Energy Exports and 19,700 under Progressive Change. After the initial construction peak in the later part of this decade, the wind workforce fluctuates between 10,000 and 20,000 in the Step Change, between 20,000 and 30,000 in Green Energy Exports, and hovers close to 10,000 in Progressive Change.

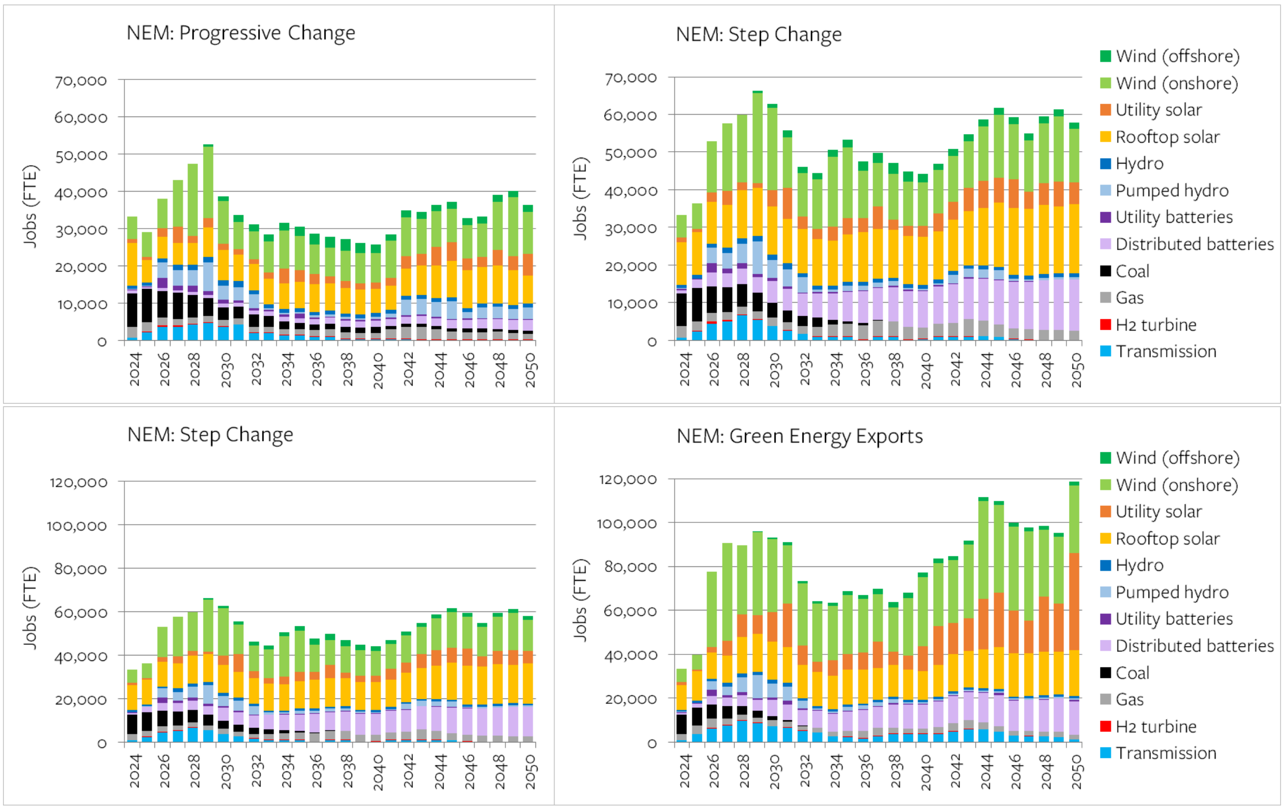

Figure 16 NEM, annual jobs by technology (all scenarios)

Note: the scale on the bottom two graphs shows 120,000 FTE compared to 70,000 in the top two graphs.

Distributed solar and distributed batteries: Unlike other technologies with a fluctuating workforce profile reflecting intensive periods of construction in the lead up to 2030 and 2050 targets, the workforce for rooftop solar is relatively steady under all scenarios. It is important to note that the same workforce will be installing distributed batteries; these experience strong, maintained growth in both the Step Change and Green Energy Exports, with much lower growth in the Progressive Change. By 2050 this combined sector will generate 31,900 jobs in the Step Change (10,500 in Progressive Change and 35,900 in Green Energy Exports). The continuing increase in employment for these technologies is despite the projected decline in employment for each MW installed. By 2050 we calculate employment for rooftop solar and batteries at just 34% and 43% respectively compared to the employment per MW in 2024 (see Section 2.4 and Appendix 2).

Utility-scale solar: This sees the greatest growth under the Green Energy Exports scenario, specifically in the 2040s, with jobs peaking at 44,400 in 2050. Average employment is 13,100 in Green Energy Exports, nearly five times the average in Progressive Change (2,700), and three times the average in Step Change (4,300).

Hydro: Under all scenarios, hydro makes up a small portion of employment in the electricity sector workforce. For hydro power, employment remains the same across all scenarios, reflecting stable investment in this large-scale infrastructure. Pumped hydro, however, utilised as a storage and firming technology, has a more variable profile according to the scenario. Under Step Change and Green Energy Exports, the workforce profile for pumped hydro is very similar, with the workforce profile dominated by intense construction between 2026 and 2032. The Step Change workforce peaks at 8,600 in 2029 (10,400 in the Green Energy Exports), with an average of about 2,000 jobs over the projected period in both scenarios. Under Progressive Change the workforce averages 2,500, with a maximum of 7,600, and there is a second intense period of construction in the 2040s.

Utility batteries: Jobs in utility batteries are likely to be delivered by a different workforce than distributed batteries. There is an installation boom up until 2030 with similar numbers across all scenarios, reflecting similar installed capacities. From 2030 onwards, installations in the Step Change increase very slowly. In Progressive Change there is a steadier increase, reflecting the higher proportion of storage provision by utility compared to distributed batteries. Progressive Change and Green Energy Exports both average 600 jobs during the period, although the profile is more volatile in Green Energy Exports.

Coal and gas: These together make up 36% of the electricity sector workforce at the start of the project period, dropping to 7% in Progressive Change, 4% in Step Change, and 2% in Green Energy Exports by 2050. Jobs in gas decline very slowly over the period, by about half in Progressive Change, one fifth in Step Change, and one third in Green Energy Exports. Jobs in coal decline to zero in the Step Change by 2038, and in Green Energy Exports by 2034, while in Progressive Change, 800 jobs remain by 2050.

Transmission: Under each scenario, transmission employment is a small portion of overall employment, representing 2% under Step Change, 5% under Green Energy Exports and 4% under Progressive Change. It is defined by strong peaks in employment, particularly in the years up to 2030, and then a near dwindling of the workforce by 2050 under both Step and Progressive Change scenarios. Under Green Energy Exports, however, investment in transmission remains strong over the entire period, with an average of 4,300 jobs.

4.1 Wind

Figure 17 shows wind power jobs for all scenarios, including onshore wind, offshore wind and repowering. Repowering involves replacing turbines on existing wind farms so that they can continue to produce power, usually at end of life, although this sometimes occurs earlier because of efficiency improvements in the technology. Repowering starts to appear in 2029, as it has been modelled with a 25-year lifetime (Section 2.6).

In all three scenarios, employment grows steeply up to 2030, peaking in 2029 under Step Change and Progressive Change. Jobs reach 19,700 in Progressive Change, 24,600 in the Step Change and 46,100 in Green Energy Exports, which peaks in 2027 then again in 2044. The initial peak in 2027 represents an increase of nearly 40,000 in just three years; it is difficult to imagine how this would be achieved.

After the initial peak, jobs in Progressive Change drop sharply, and then hover around 10,000 for most of the rest of the period, only climbing again in the late 2040s. Average wind employment throughout the period is 11,700.

In Step Change, the situation is more volatile. Jobs fall by about 10,000 and then have smaller peaks around 2034-2035, 2045, and 2049. Average wind employment is 15,900.

Under the Green Energy Exports scenario wind jobs average 30,900 over the period, and never fall below 22,800 after the initial peak.

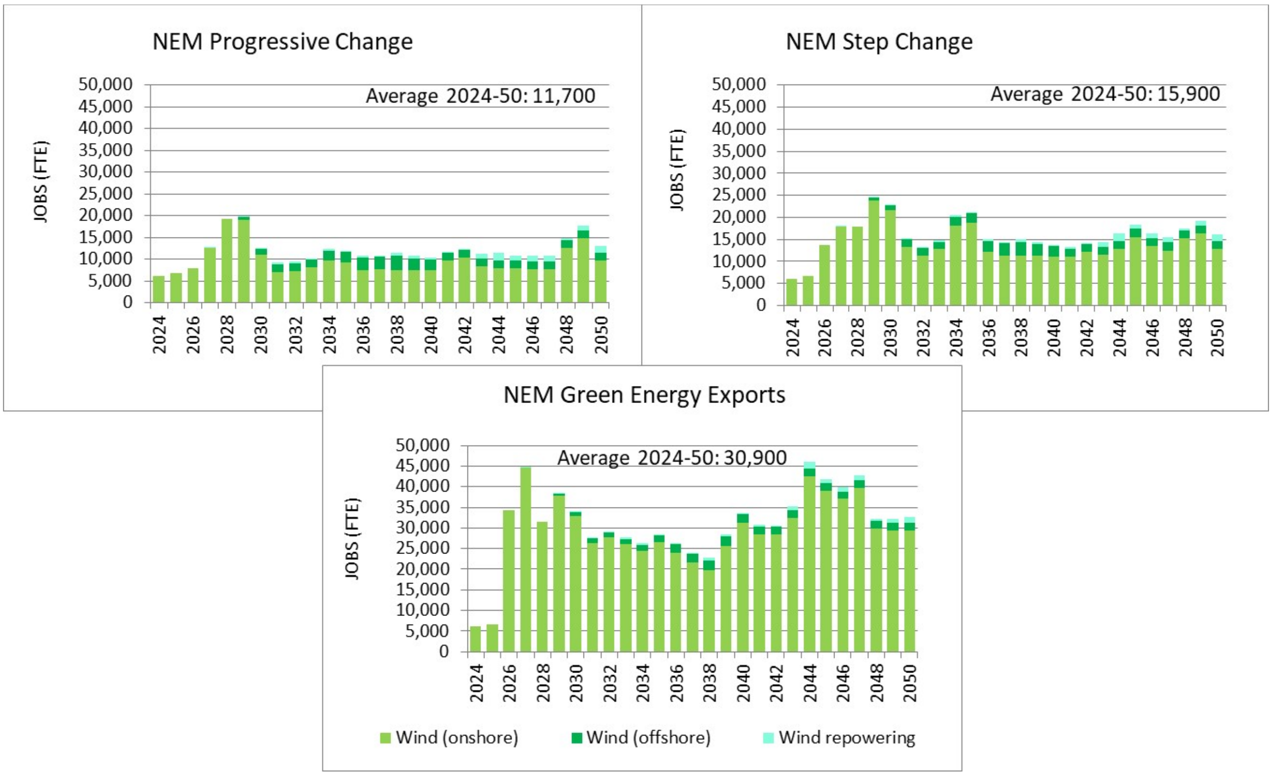

Figure 17 National Electricity Market, jobs in wind (all scenarios)

4.2 Utility-scale solar

Utility-scale solar jobs are shown in Figure 18 for all scenarios. Repowering is included, although it is very minimal as there was little utility solar installed before 2017, and the replacement window is 30 years (Section 2.6).

The jobs profile in Progressive Change and Step Change is very similar until 2030. During the following decade more utility solar is installed in the Step Change, with employment hovering around 5,000. Average employment over the period is 4,300 in Step Change, compared to 2,700 in Progressive Change.

The picture in Green Energy Exports is substantially different. Employment is highly volatile, peaking at 20,000 in 2031, up from just 1,100 in 2024, followed by shedding over 15,000 jobs in the two years to 2033. Over the entire period, jobs average 13,100 in Green Energy Exports, three times the employment in Step Change and nearly five times the employment in Progressive Change.

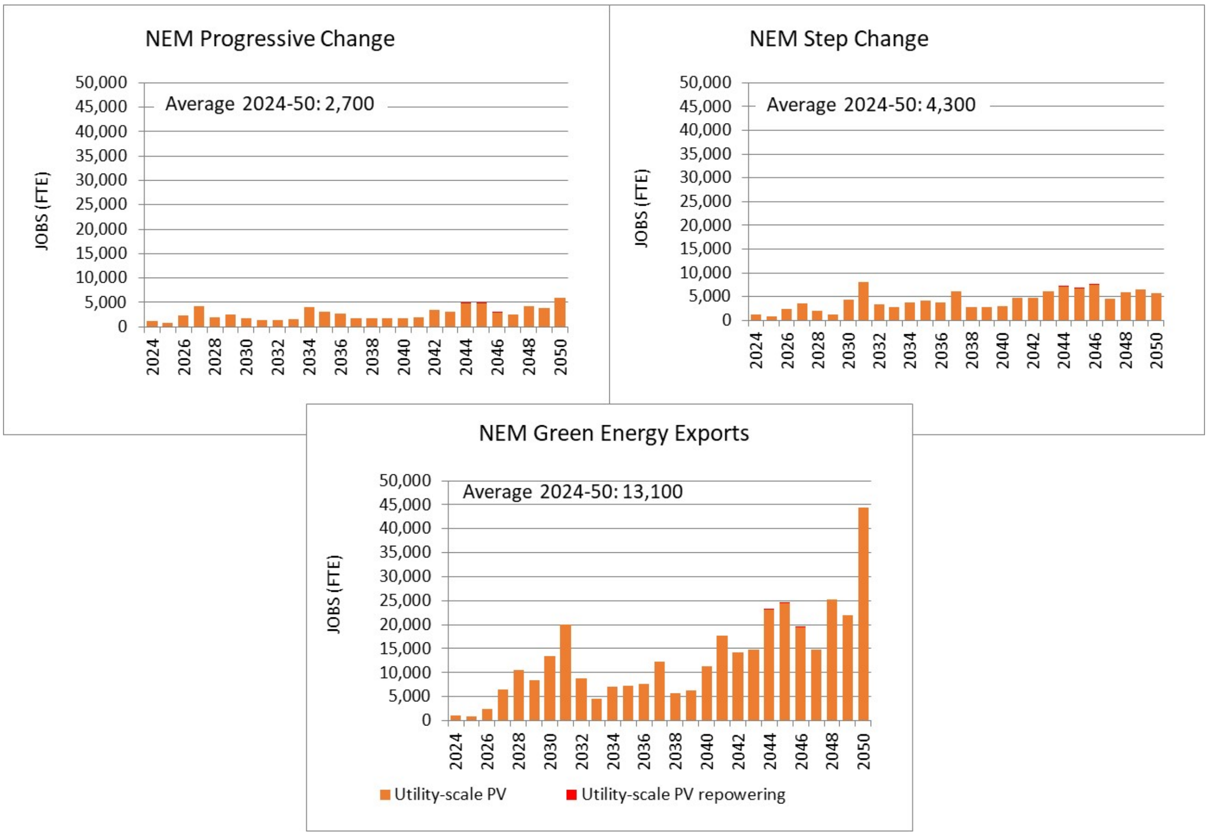

Figure 18 National Electricity Market, jobs in utility-scale PV (all scenarios)

4.3 Rooftop solar and distributed batteries

Rooftop solar and distributed battery employment, inclusive of repowering, grows steadily for the projected period under both Step Change and Green Energy Exports scenarios with a combined annual average of 22,000 and 25,600 jobs respectively (Figure 19). Jobs under the Green Energy Exports are only slightly higher than Step Change. Under both scenarios, employment in rooftop solar is remarkably steady, while distributed batteries grow steadily from a small base through the projected period.

Under Progressive change the combined average is roughly half of that in the other two scenarios. Rooftop PV capacities are projected as much lower in this scenario, driving the lower employment. We note that although the model shows a sudden drop from 2024, this is likely due to adjusting the scenario data to start at the same level in 2024 (Section 2.2.2), and the real trajectory may be more gradual. After the initial drop, the rooftop solar workforce is also remarkably constant in the Progressive Change scenario, albeit at a lower level.

Repowering begins to appear in 2034 and reaches a maximum of 4,200 by 2050 in all scenarios (see Section 2.6 for details of how repowering is calculated); the 25-year time horizon means that variations would only start to appear between scenarios in the 2050s.

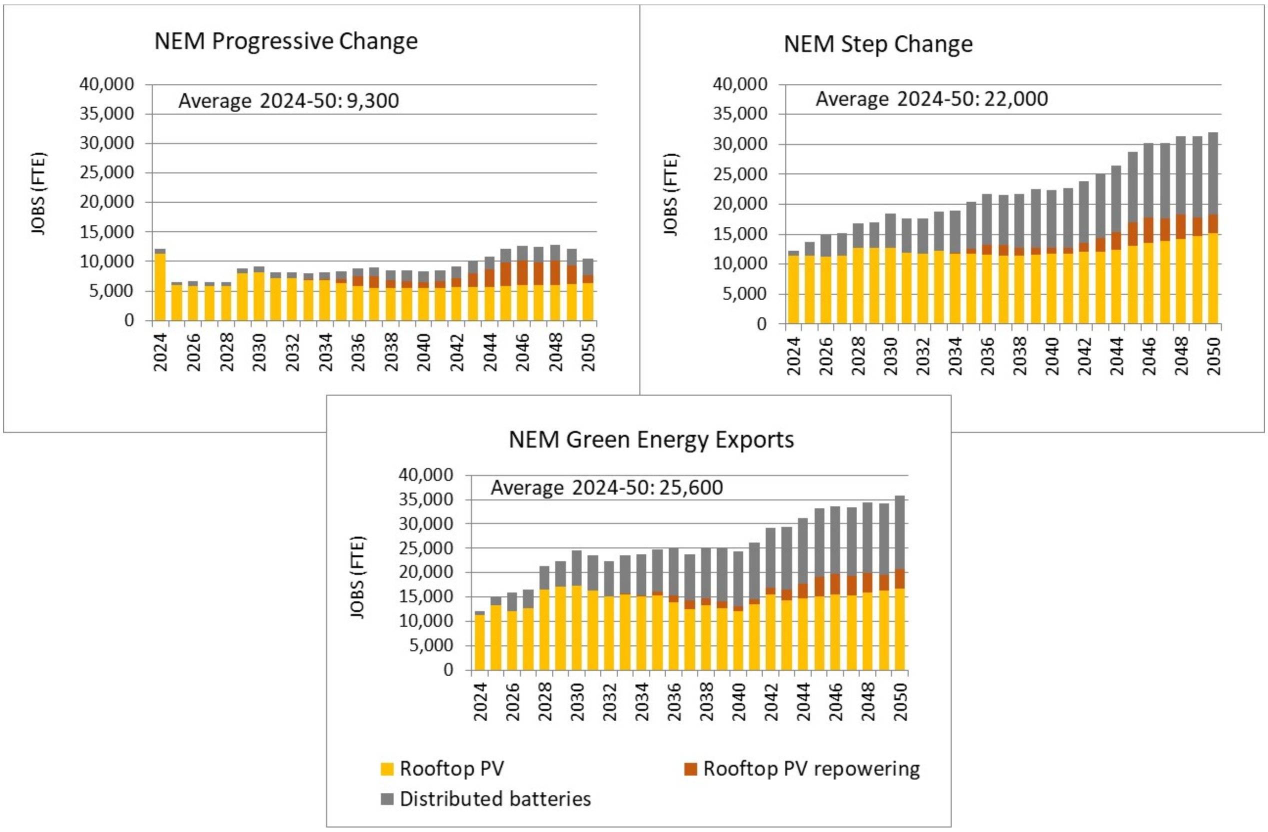

Figure 19 National Electricity Market, jobs in rooftop solar and distributed batteries (all scenarios)

4.4 Large scale storage

Jobs in large scale storage cover both hydro technologies (Figure 20) and utility-scale batteries (Figure 21). Note that the scale for hydro jobs goes up to 14,000, while the utility-scale batteries scale only goes up to 3,000.

There are major employment peaks in pumped hydro under all scenarios in the mid-to-late 2020s, with between 9,000 and 12,000 workers required. There is a further burst of construction activity in the mid-2030s and 2040s (Figure 20).

Employment is highest in Progressive Change, with average employment of 3,600 (3,200 in Step Change, and 3,300 in Green Energy Exports). The higher jobs reflect the greater capacity of pumped hydro in Progressive Change (9.1 GW compared to 7.5 GW or 7.8 GW in Step Change and Green Energy Exports); distributed batteries by contrast are much lower in this scenario, with between 1/5 and 1/6 of the capacity in the other two scenarios. The second period of activity in the 2040s is more maintained, and

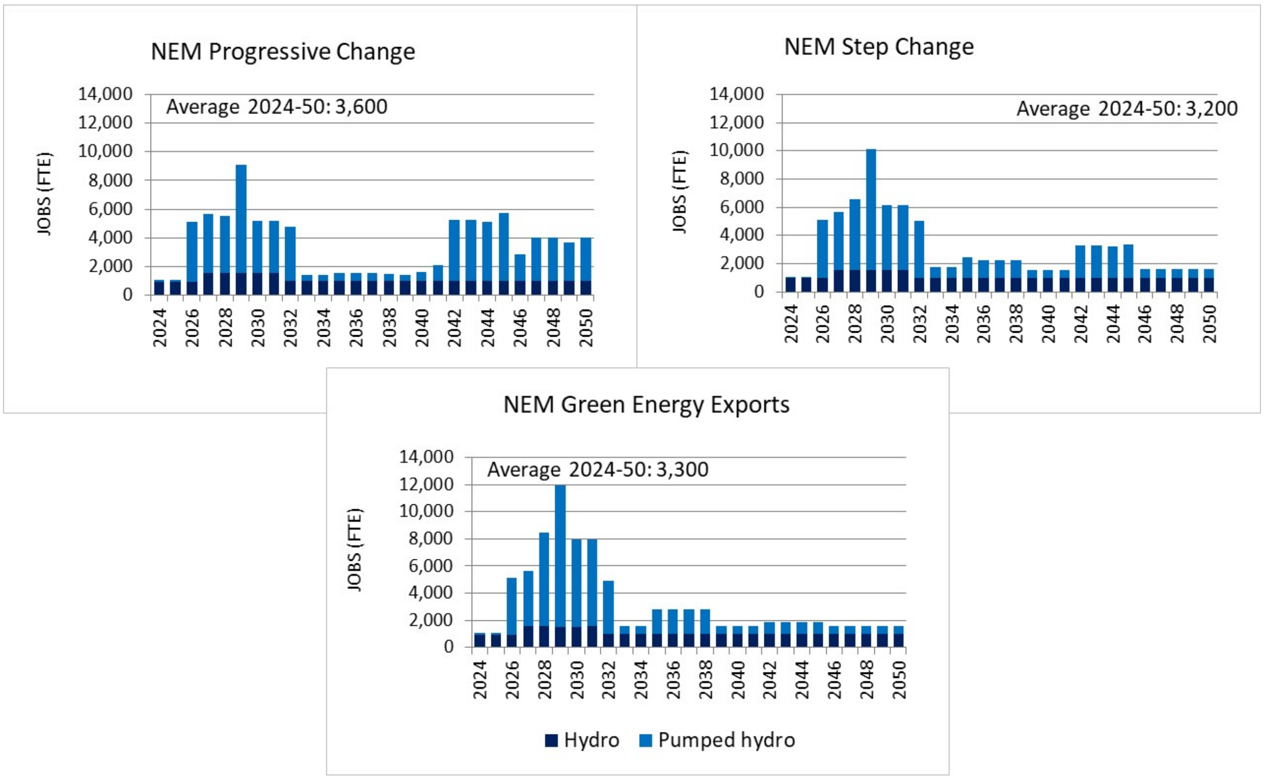

Figure 20 National Electricity Market, jobs in pumped hydro (all scenarios)

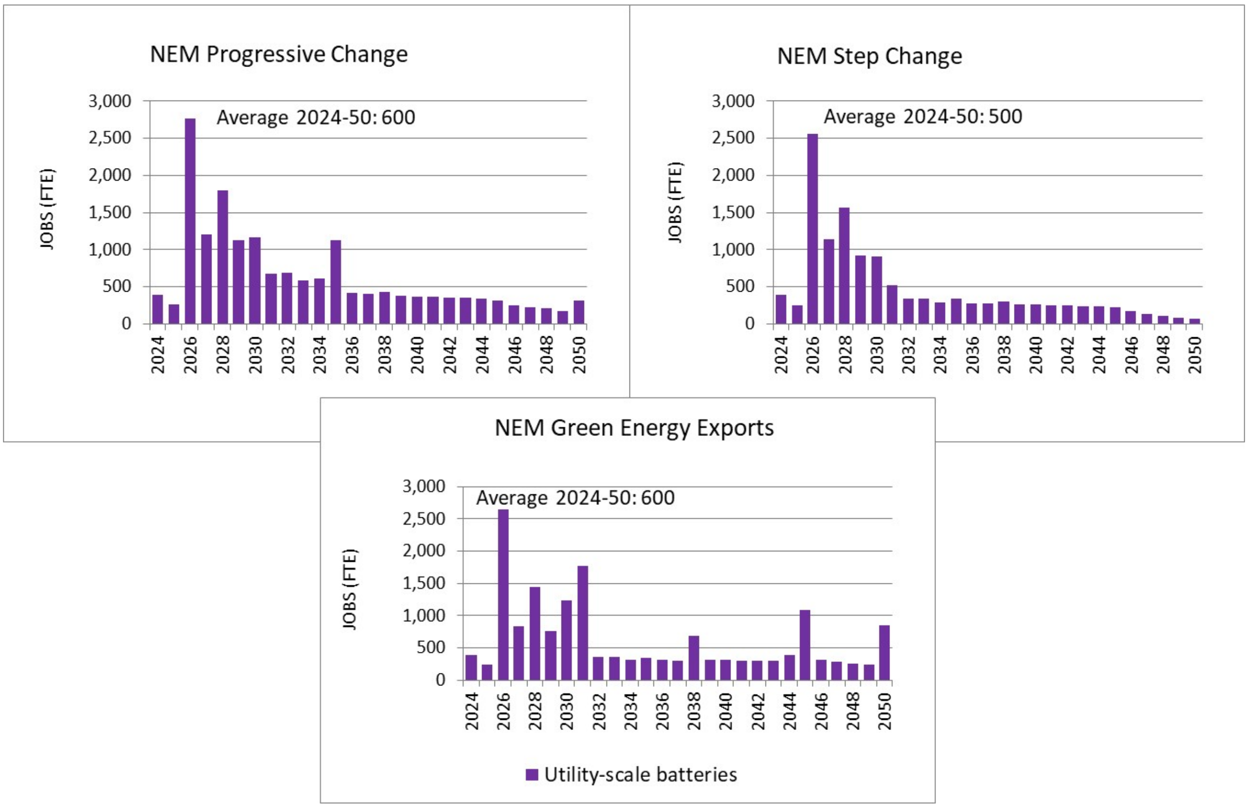

Figure 21 National Electricity Market, jobs in utility batteries (all scenarios)

For utility-scale battery storage (Figure 21), there is an early peak in employment under all scenarios. The employment profile is quite similar between Progressive Change and Step Change, with further bursts of construction activity under the Green Energy Export scenario to meet higher demand. Under the Step Change scenario, jobs drop to 500 in 2031 and stay around this number for the next decade. Under Green Energy Exports there is more volatility up until 2031, but jobs also drop off for the remainder of the period, save for a spike in 2045 to 1,100 jobs.

4.5 Transmission construction

In Figure 22, employment in transmission construction is compared for all scenarios. The employment shown includes both transmission line construction and the associated substations, noting that these may require different skillsets.

Under all scenarios, jobs peak from 2025 through to 2029. For the Step Change scenario, transmission employment averages 1,600 jobs; after peaking at 6,700 in 2028, jobs drop to 1,000 by 2033. Progressive Change (average 1,400) has the least volatile workforce profile. After peaking at 4,700 in 2029, it takes until 2036 to drop to below 1,000.

The Green Energy Exports scenario has much higher employment overall, reflecting the greater transmission build: total construction is nearly 25,500 km in this scenario compared to a little over 8,100 km in Step Change and 6,500 km in Progressive Change. Average jobs are 4,300 in Green Energy Exports, and after peaking at nearly 10,000 jobs in 2028, jobs fluctuate around 4,000 until 2050.

Actual employment, it should be noted, is likely to be more changeable than shown here, as these calculations assume that employment is spread evenly across the construction period for each project.

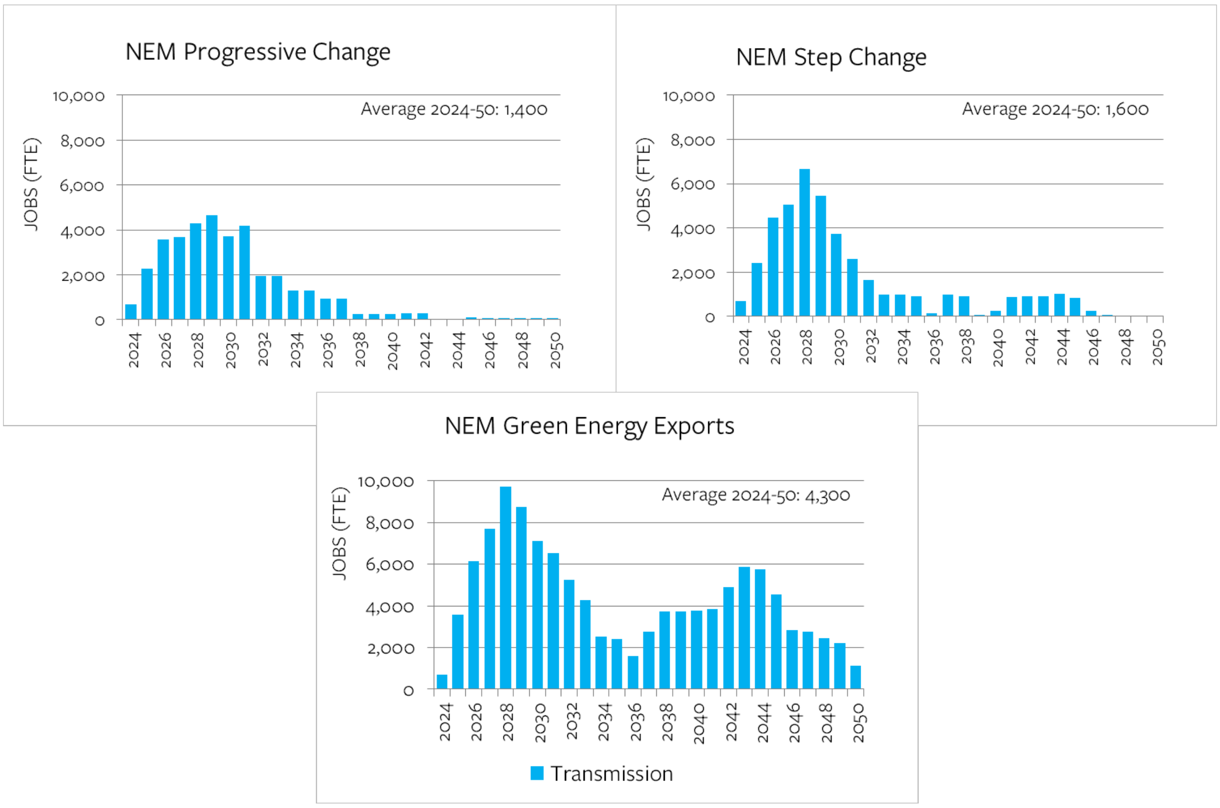

Figure 22 National Electricity Market, jobs in transmission construction (all scenarios)

4.6 Coal and gas

Figure 23 shows the employment in coal and gas for all three scenarios.

From current levels of coal employment of 8,800 in 2024, jobs are only maintained throughout the period in Progressive Change, and even in this scenario fall to 800 by the end of the period. Step Change and Green Energy Exports see a steady decline to zero by 2038.

Gas employment in Progressive Change and Step Change increases somewhat in the early 2040s, and then falls again, to reach about 80% of current levels in 2050 in the Step Change (50% in the Progressive Change). In Green Energy Exports, gas employment follows the same profile but falls to 70% of current levels by 2050.

The combined average employment in coal and gas is similar in all three scenarios (4,800 in Progressive Change, 5,000 in Step Change, and 4,200 in Green Energy Exports).

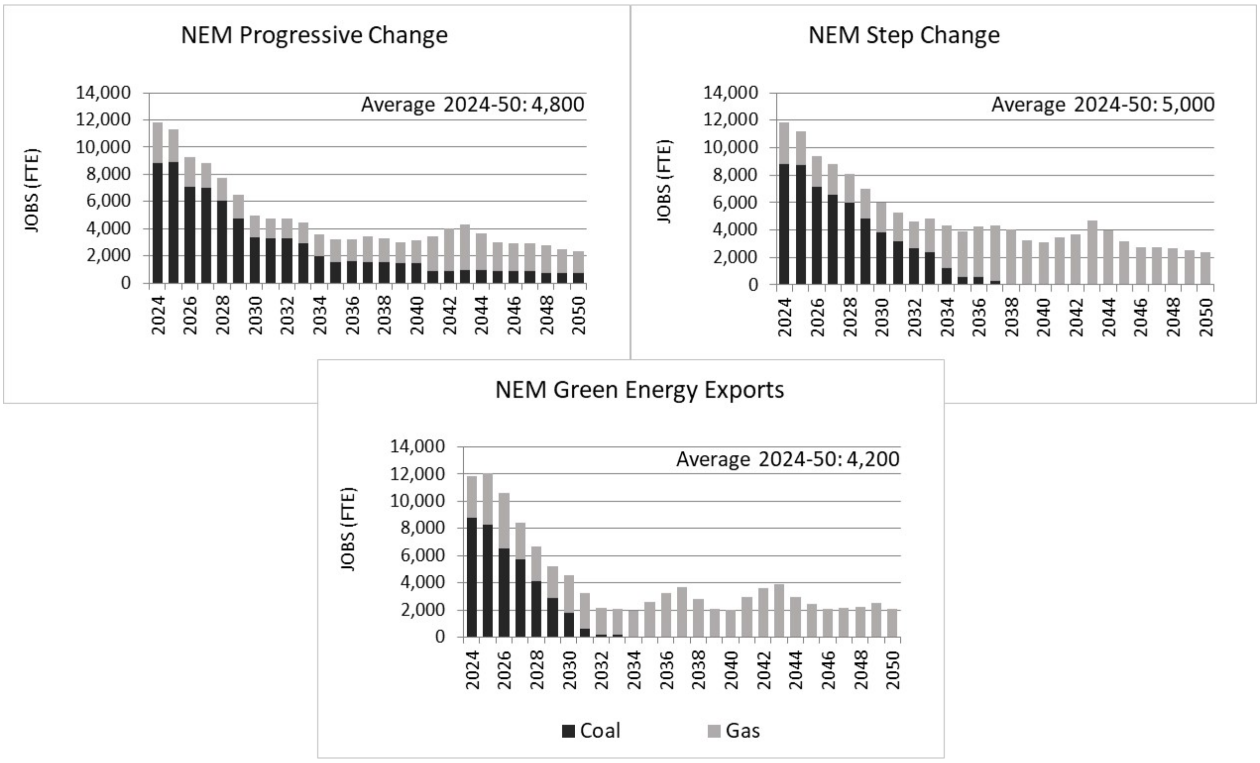

Figure 23 National Electricity Market, jobs in coal and gas (all scenarios)

4.7 Off-grid hydrogen workforce – a brief analysis

In the event that an extensive green energy export industry develops in Australia, it is likely that there will be significant development of off-grid hydrogen production, with associated renewable generation capacity. This is not quantified in this modelling, as the ISP only considers grid connected infrastructure. However, off-grid hydrogen production is likely to be significant in this scenario, and the workforce to deliver the associated renewable energy infrastructure will be drawing from the same pool of labour as the grid connected infrastructure.

Assuming that the off-grid hydrogen production capacity is similar to grid connected, identifying the workforce to deliver the assumed grid connected hydrogen production gives an approximation of the additional workforce needed.

This would amount to an additional 22,000 jobs on average from 2024 until 2050, reaching a maximum of 59,000 additional jobs by 2050. Assuming the same distribution as for grid connected hydrogen, these would be spread across wind (64%) and utility solar (35%), with some in gas and utility-scale batteries.

5 Electricity sector workforce projections by state

Figure 24 summarises the average electricity sector jobs by state from 2024 to 2050 in the Step Change scenario. New South Wales is the leading state, with an average of 18,400 jobs, closely followed by Queensland with 15,800 jobs. Victoria is some way behind with 12,200 jobs on average. Solar and wind account for between 61% and 69% of jobs in all states except Tasmania, where hydro and wind account for 75% of jobs.

In the Green Energy Exports scenario, the highest number of jobs are created in Queensland (32,300 on average), followed by New South Wales (22,600) and Victoria (15,900).

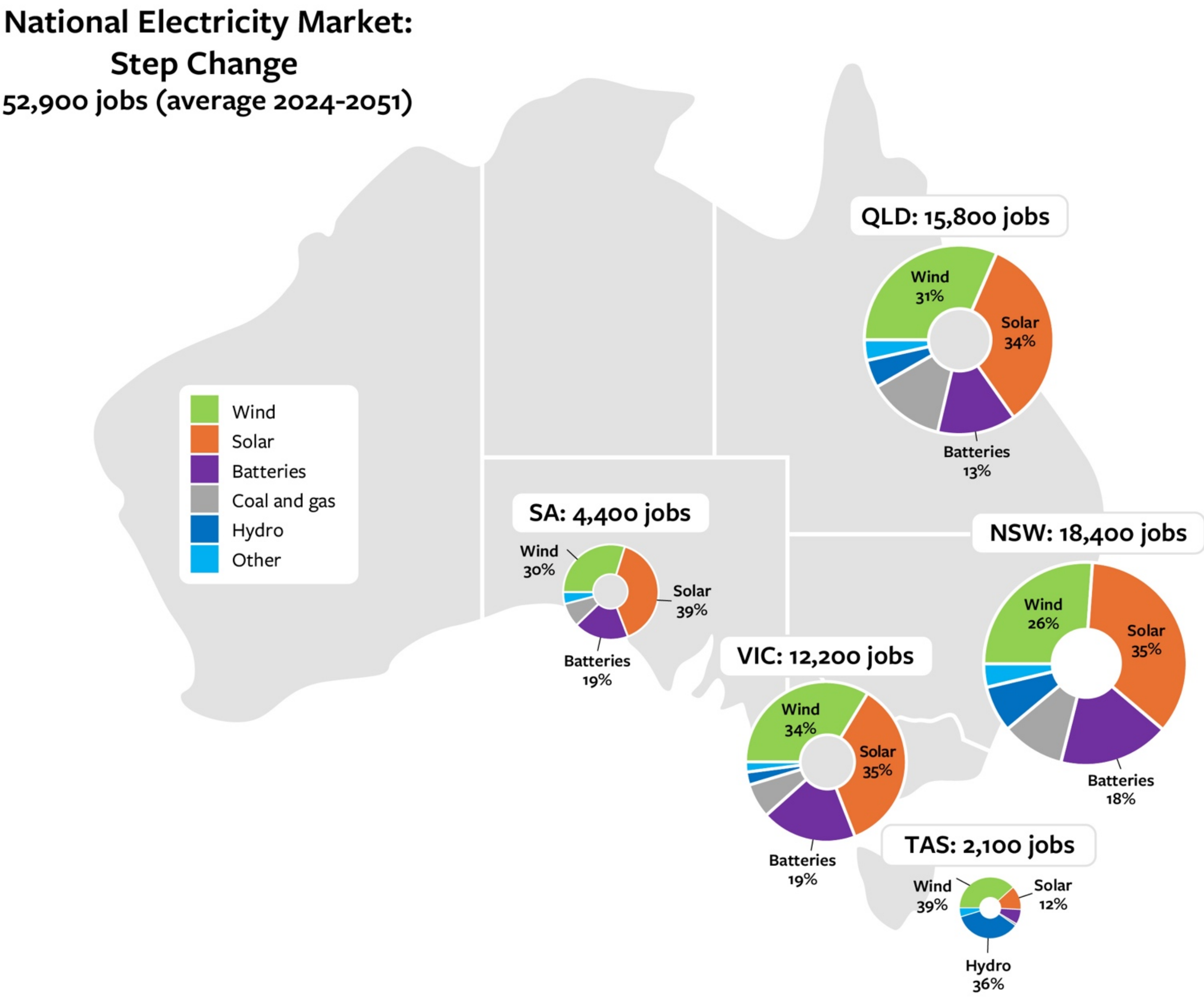

Figure 24 National Electricity Market average electricity jobs by State, 2023-2050 (Step Change)

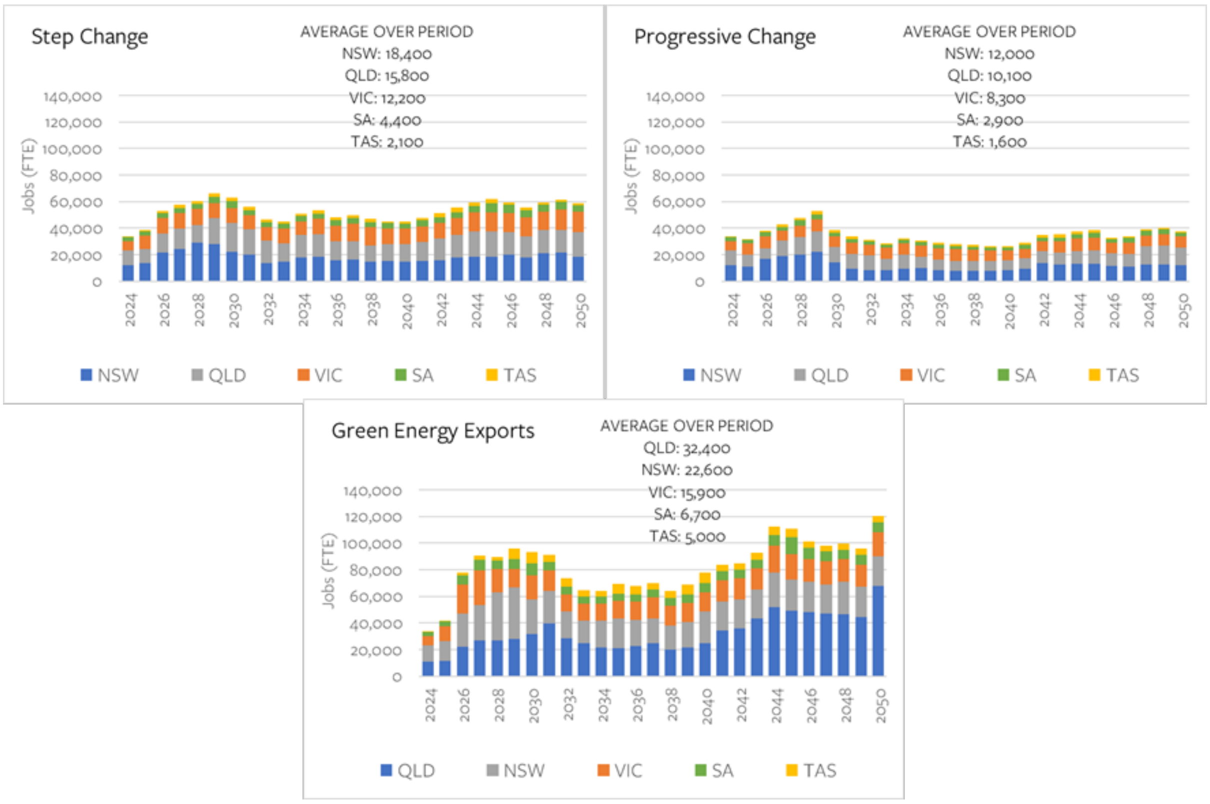

Figure 25 State comparison summary, jobs to 2050

Figure 25 and Figure 26 show the workforce requirements for each scenario by state. While the Green Energy Exports scenario has higher workforce requirements in all states, the impact in Queensland and Tasmania is far greater than the rest of the NEM. In both Queensland and Tasmania, Green Energy Exports requires more than double the average workforce compared to the Step Change, and more than three times the workforce compared to the Progressive Change scenario. In New South Wales, Victoria and South Australia, the difference between Green Energy Exports and the Step Change is less marked, with between one fifth and one half more workers needed on average. The Green Energy Exports scenario still requires close to double the workforce compared to the Progressive Change in these three states.

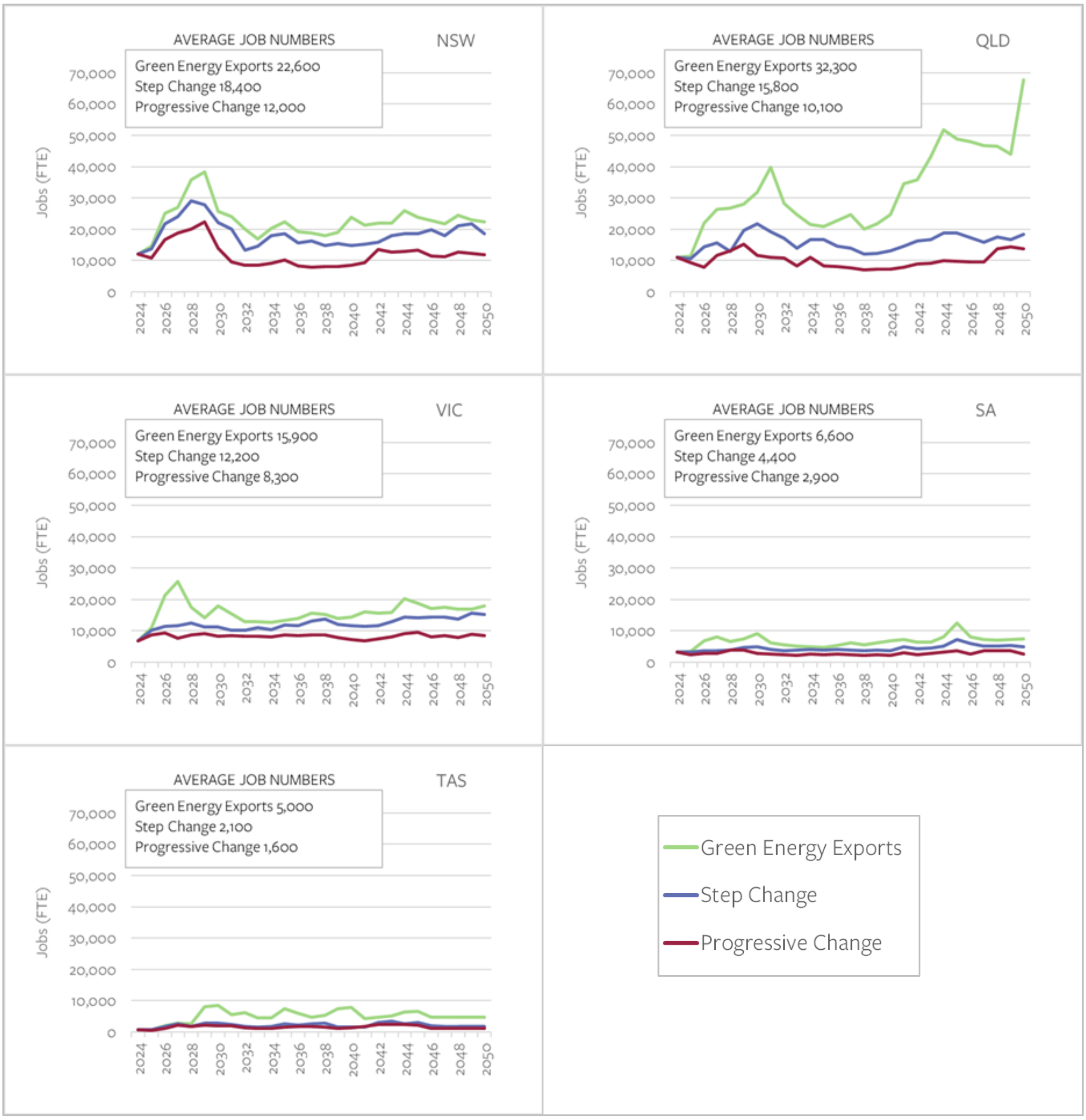

Figure 26 State comparison by scenario, jobs to 2050 (all scenarios)

See the "Focus on.." reports for New South Wales, Queensland, South Australia, Tasmania, and Victoria. These provide detailed results for each state, including occupational and technology employment breakdowns. There are also downloadable workbooks of results available at uts.edu.au/isf/explore-research/projects/australian-electricity-workforce-2024-integrated-system-plan-projections-2050

6 Discussion and recommendations

6.1 Skill shortage risks

The rapid increase in requirements for in-demand occupations brings with it a high risk of skill shortages which could impact the achievement of the optimal development pathways under the ISP. Skills shortages create the risks of delays, increased project costs (wage inflation, recruitment costs and liquidated damages), and increase the cost of capital for future projects to reflect increased risk.

This is a global problem, as noted by the International Energy Agency:

> *"Labour and skills shortages are already translating into project delays, raising concerns that clean energy solutions will be unable to keep pace with demand to meet net zero targets".*[29]

This only exacerbates the issue in Australia, as bringing in expertise from elsewhere may be increasingly challenging in areas where Australia has developed an increasing reliance (e.g. wind farm technicians, engineers). The timetable for the delivery of renewable energy generation, transmission, and storage to maintain energy security as coal-fired power stations retire is tight. The 2024 ISP states:

> *"Although the ISP cannot forecast exactly where and how the generation, storage and transmission of the future will emerge, the [optimal development path] is clear that urgent investment and delivery across the sector is needed to ensure secure, reliable, affordable, low-emission electricity through the NEM. ... However, planned projects are not progressing as expected, due to the time needed for approval processes, investment decision uncertainty, cost pressures, social licence issues, supply chain issues and workforce shortages."*[30]

In the context of tight labour markets with unemployment very low even in the context of historically high employment participation rates, the National Skill Shortage Priority List identifies one-third of all occupations in national shortage – almost double the number in 2021. Almost half of professional and trade and technician occupations are in shortage.[31] Consequently, there are skill shortages in many of the key occupations within renewable energy, a selection of which can be found in Table 5.

Table 5 Recruitment difficulty and skill shortages, selected occupations

Occupation	National Skills Priority List, 2023 Rating	Future Recruitment Demand compared with Economy Average
Construction manager	Shortage (all states)	At economy average
Engineering manager	Shortage (all states)	At economy average
Mechanical technician	Shortage (all states)	At economy average
Electrical engineer	Shortage (all states)	At economy average
Civil engineer	Shortage (all states)	At economy average
Electricians	Shortage (all states)	Below economy average
Electrical lineworker	Shortage (all states)	At economy average
Rigger	Shortage (all states)	At economy average
Crane operators	Shortage (all states)	At economy average
Concreters	No shortages	At economy average
Earthmoving plant operators	Shortages (all states excluding Victoria)	At economy average
Truck Driver	Shortage (all states)	At economy average

Source: Jobs and Skills Australia (2023) Skills Priority List.

The infrastructure pipeline

Whilst the labour market has eased somewhat throughout 2024, overall conditions remain tight. The labour market context for the development of renewable energy is also challenging due to a number of factors, including the infrastructure pipeline which draws upon many of the same occupations, regional labour markets, and the capacity of the training system to scale up the energy workforce.

Infrastructure Australia has observed that governments have taken steps to smooth what it previously described as an unprecedented infrastructure pipeline, but it is still projecting 'extraordinary growth' in regions across New South Wales, Queensland and the Northern Territory. Infrastructure Australia's survey of the construction industry found labour and skill shortages were rated as the primary risk to market capacity. Across public infrastructure which incorporates building and transport as well as energy, there is a large supply shortage and the deficit for trades and labourers is yet to peak.[32]

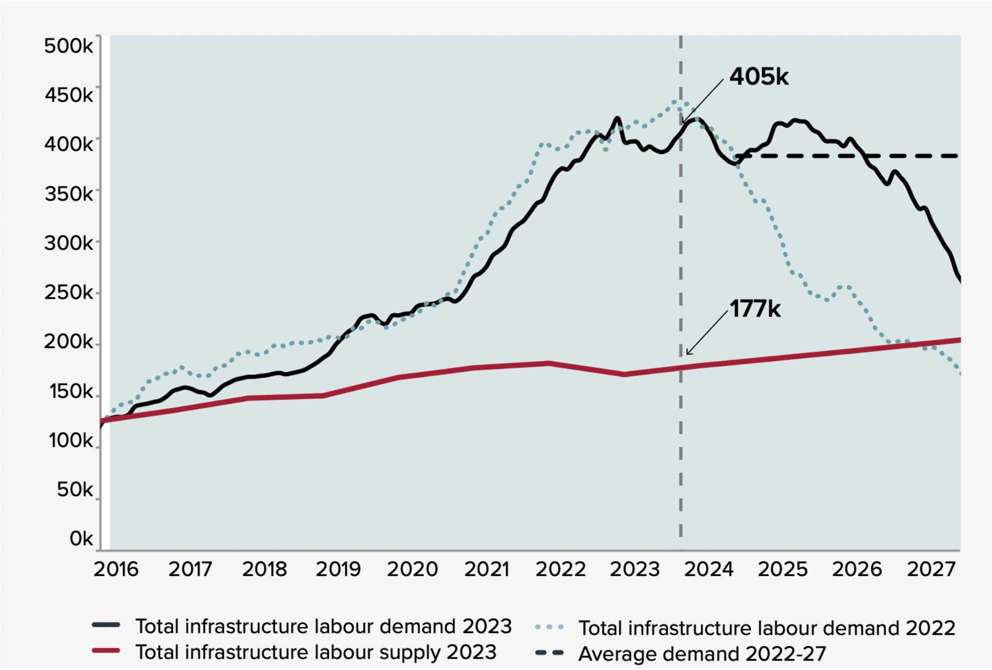

Figure 27 National supply and demand for public infrastructure workers

Source: Infrastructure Australia 2023, Market Capacity Report 2023 p.64[33]*. Public infrastructure pipeline demand includes major and non-major public infrastructure projects, road maintenance projects and privately funded infrastructure for public use.*

Consequently, the renewable energy sector will be competing for professionals, trades, and technicians against infrastructure projects, in particular 'mega-transport' projects able to offer employment in capital cities instead of remote and regional locations, and generally higher pay.

Structural challenges to growing the electricity workforce: training capacity and diversity

Powering Skills Organisation, the primary Skills Council for the electricity sector, has identified a range of key challenges to expand the capacity of the training system to increase the energy workforce:

- Lack of diversity in the workforce: the energy sector has low participation amongst women and First Nations people in particular, which limits its capacity to grow rapidly.[34]
- Coordination across sectors: there is competition between sectors for the same groups of workers and a fragmentation of responsibility across Skills Councils. Infrastructure Australia has also advocated for the development of a National Infrastructure Workforce Strategy.

- A shortfall in VET trainers: there is a labour shortage for trainers that also needs to be scaled rapidly.
- Inefficiencies in energy training packages: a package of reforms are proposed to improve the speed in development of training packages and delivery of training.
- Gaps in clean energy skills and options in training packages: there are gaps in elective skills and post-trade qualifications required to build the energy workforce with the right skills.

Jobs and Skills Australia has also identified a range of reforms to increase capacity such as establishing TAFE Centres of Excellence.[35]

New government policies are being implemented or under development but need to be accelerated. There are a range of structural challenges that need to be addressed to increase the capacity of the training system to scale up the workforce.

6.2 Boom and bust cycles

The expected trajectory of the construction workforce requirements to deliver the energy infrastructure needed for the energy transition is shown in Figure 28. The profile is highly variable, with increases of nearly 27,000 in just the five years to 2029 in the Step Change (50,000 in the Green Energy Exports). These peaks are followed by sharp drop offs: the Step Change peak is followed by losing 24,000 construction jobs over four years, and the Green Energy Exports scenario loses 38,000 jobs in the same period.

The capacity projection in the ISP is not a plan, of course, it is an indication of the least cost pathway to meeting electricity demand and meeting Australia's emission targets. This generally requires building everything as late as possible. The associated workforce projection illustrates the challenge for the supply of skilled labour, and the potential for the boom to be followed by serious contraction in the renewables industry.

There are significant risks for the supply chain if this "lumpiness" is not addressed, as evidenced at present with the difficulty to find the personnel to deliver projects. Risks are exacerbated by the competing demands for infrastructure build in other parts of the economy, and by the fact that much of the infrastructure is in rural areas with restricted labour supply. The troughs increase the difficulty of putting effective training programmes in place as the pipeline is not steady. These profiles are for all technologies, while specialist skills that are technology specific, and requirements within a state, are likely to be even more volatile.

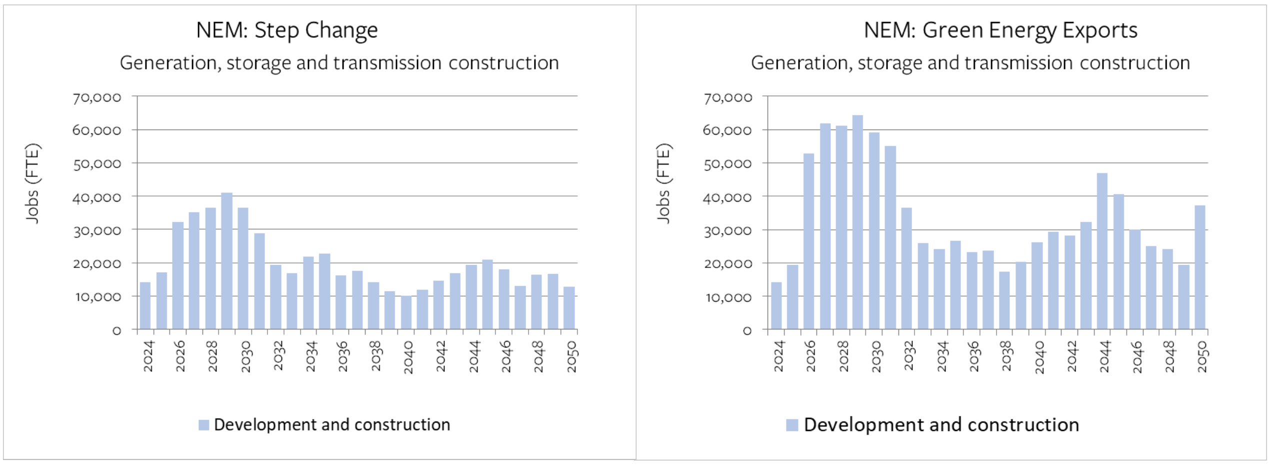

Figure 28 National Electricity Market, development and construction workforce

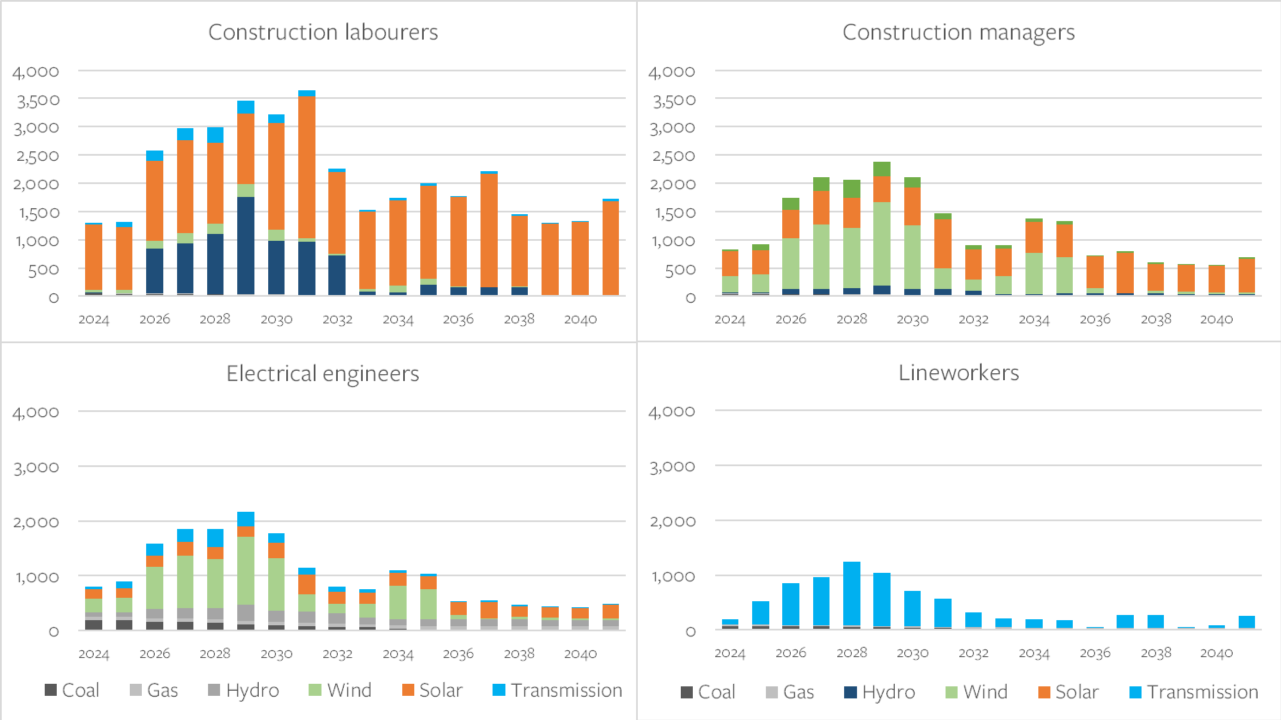

Figure 29 National Electricity Market, in-demand construction occupations, Step Change

Figure 29 shows how this profile plays out for some occupations that are needed in high numbers for construction but not required so much for operations and maintenance[7]. These include construction labourers and managers, electrical engineers, and lineworkers. Only construction labourers are not listed as occupations already in shortage across all states (Table 5). The sharp surges in demand are reflected in these occupations. There is a focus among policy makers on increasing the pipeline of skilled workers, which is certainly necessary. We recommend exploring the option of smoothing the development pathway to reduce supply chain risks and increase opportunities for workforce development. Bringing projects forward from the late to the early 2030s, rather than deferring projects in the first decade, may allow a smoother workforce profile without compromising emission targets.

6.2.1 Constrained supply chain sensitivity

The 2022 Workforce Projections for the ISP report recommended AEMO "consult with ISP stakeholders on including a sensitivity for capacity development that results in smoothed employment profiles". Following stakeholder consultation, AEMO undertook a constrained supply chain sensitivity analysis intended to model the impact of combined delivery risks. While this sensitivity did not specifically refer to employment, it did have the suggested impact of reducing the 'lumpy' build profile. This scenario made specific assumptions on temporary delays in transmission build and generation and storage project construction, as well as additional cost imposts, with the effect of pushing back project development.

While the employment profile was somewhat smoothed, as would be expected, this sensitivity did not meet Australia's legislated emission targets as insufficient renewable generation came online by 2030. The sensitivity was not designed with the intent of reducing the volatility of project development and the associated employment, which would require bringing projects forward as well as pushing them back, so is not a test of whether it is possible to meet emission targets without a highly volatile workforce profile.

[7] The demand profile for electricians, for example, is much smoother, as electricians are also required in high numbers for operations and maintenance.

6.3 Recommendations

The employment projections for the ISP combined with analyses of the labour market context and the capacity and performance of the training sector highlight major risks of skill shortages. There is an urgent need for governments, training providers, and industry to take coordinated action to develop and implement skills, training, and workforce development strategies. This is particularly important in regional areas and the REZs to increase labour supply and create local employment and training opportunities. Employment and training should be designed to facilitate a rapid build-out and increase the equity of the energy transition, with training or development initiatives including opportunities for First Nations people and communities most impacted by the energy transition.

A series of reports have been released in the past year. Jobs and Skills Australia undertook a comprehensive review with recommendations on growing the clean energy workforce[36]. Powering Skills Organisation, a skills council for the Australian energy sector, has developed a strategy for changes to the training system to increase the supply of electricity sector workers[37]. A jobs strategy to increase First Nations employment in the energy sector was released by the First Nations Clean Energy Network[38].. The Queensland Government has released a renewable energy jobs plan and the New South Wales and Victorian governments are currently developing workforce plans. It is urgent that governments, training authorities and industry act on the range of recommendations in these reports and implement measures to scale up the electricity workforce.

Our recommendations focus on two important areas not addressed in these reports: workforce volatility and the information and research priorities to address gaps in understanding. Despite the welcome attention on workforce and skills, governments are still struggling to understand workforce and the detailed occupations and skills needed across the energy sector, particularly for the demand-side workforce.

There is widespread agreement that the projected volatility in workforce requirements raises serious challenges for labour supply, increases the risks and costs of the energy transition, reduces the opportunities for local employment, and increases the socio-economic burden (e.g. provision of housing for temporary workers). Much of the construction activity will occur through tenders under the Capacity Investment Scheme (CIS) or associated state tenders such as the Long-Term Energy Supply Agreements in New South Wales, which provides some leverage to influence the pace of development by, for example, narrowing the minimum and maximum capacity tendered annually or through the sequencing of tenders.

As of 1 July 2024, the Australian Skills Guarantee introduced mandatory targets for 10 per cent of labour hours to be completed by apprentices or trainees, with sub-targets for women, on major construction and information technology projects funded by the Commonwealth government and valued over $10 million. Procurement through the CIS and associated state tenders provide a lever to increase industry-wide investment in training and workforce development.

Jobs and Skills Australia observed that employer intakes of learning workers need to increase in clean energy and recommended the Australian Skills Guarantee be expanded to include generation and transmission projects as 'one means of stimulating a training culture'.[39] In addition to embedding employment and training targets within the CIS, these targets could be included in procurement by the Clean Energy Finance Corporation (CEFC) or the Australian Renewable Energy Agency (ARENA) which do not currently incorporate employment or training requirements.. Alongside government programs and investment in training capacity, embedding training requirements in procurement can increase employer participation.

Our first two recommendations are aimed at smoothing workforce profiles and the third at increasing the supply of skilled labour by integrating training into energy sector construction. Recommendations 4 and 5 are aimed at enabling the inclusion of the demand-side workforce in energy sector projections, and recommendation 6 is aimed at improving the coverage and usefulness of workforce projections.

We recommend that:

1. The Federal and State Governments consider mechanisms to smooth development and avoid boom-bust cycles without compromising emission targets through the design and implementation of schemes for increasing capacity, such as the Capacity Investment Scheme and Renewable Energy Zones.
2. AEMO consider the cost and emissions implications of smoothing the workforce profile through scenario modelling for the next ISP.
3. The Federal and State Governments, the Clean Energy Finance Corporation and Australian Renewable Energy Agency extend the Australian Skills Guarantee to cover the Capacity Investment Scheme and other publicly funded renewable energy and transmission projects.
4. Research bodies in partnership with industry develop data and methods to include the demand-side workforce in projections, as this workforce is almost entirely uncharacterised despite its crucial role in the energy transition. This requires developing employment indicators for energy efficiency and electrification tasks (in FTE/PJ or GWh) to enable the inclusion of energy efficiency, demand management, energy management, and electrification in workforce projections associated with the ISP.
5. AEMO modify the ISP outputs to support projections for the demand-side workforce, by including outputs in PJ/year or GWh/year for energy efficiency and electrification that affect electrical demand in the ISP; outputs will need to include details of the activities undertaken. While demand scenarios are a key input to any electricity scenario and include energy efficiency and electrification, the associated activities and resulting demand reductions or increases are not currently reported in any detail.
6. Research bodies in partnership with industry develop or revisit employment indicators to improve the coverage, reliability, and usefulness of workforce projections, including:
   - Developing occupational indicators for batteries and offshore wind to support training strategies.
   - Revisiting the employment indicators for major technologies, in particular wind and solar, with reference to the Australian industry to ensure realistic projections.
   - Developing better employment indicators for onshore manufacturing for solar, wind, and batteries.
   - Developing employment indicators where these are not currently available, including hydrogen production, renewable energy and fossil fuel decommissioning, and extraction and processing of critical minerals.

Appendix 1 – Offshore wind employment factors

Offshore wind farms are highly capital intensive, and the greatest share of employment is created in the supply chain rather than directly in construction or operations and management. This has resulted in considerable variation in employment multipliers from international sources, depending on the specific supply chains element included.

The 2022 ISP used the employment factors from Sylvest (2020)[40], which appear somewhat low compared to other sources. International employment factors are shown in Table 6, with supply chain elements for operations and maintenance separated as far as is possible. The U.S.A. National Renewable Energy Laboratory downloadable input output model (JEDI) is the most recent source benefitting from extensive independent research[241].

The employment multipliers for the 2024 ISP have been revised using the NREL JEDI model. Using the model requires assumptions on local content, and we recognise that much of the supply chain employment will occur overseas. The specific assumptions on local content used in the JEDI model to derive the current and potential employment factors are shown in Table 9 and Table 10. While these may be low compared to onshore wind, the technology is highly capital intensive, and less of the value chain will appear in employment.

High levels of uncertainty about how the industry will evolve and the appropriate local content assumptions should be stressed, especially as it has not been possible to undertake industry consultation. These employment factors, and the resultant employment projections, are therefore highly uncertain and should be taken as indicative only.

The revised Australian employment figures are shown in Table 7, with local percentages as shown, alongside the 2022 employment factor for comparison. A possible increase in supply chain which could occur with government and industry support is also shown in Table 7.

Table 8 illustrates the employment factor used for operations and maintenance. A significant proportion of O&M employment is indirect (supply chain) employment, and the elements included in each assessment vary. Five of the sources in Table 8 are for the employees directly related to the project. Two sources gave both supply chain and direct operational employment, with the supply chain accounting for 91% of employment in the case of the Hornsea 3 project, and 72% in the NREL JEDI model. We assume that most of the supply chain employment would occur overseas and include only 13% in the calculation for Australian operations and maintenance employment (this constitutes 10% of the employment associated with vessels).

Table 6 Total employment in offshore wind by project phase (multiple sources)

		IRENA (2018)	JEDI (2022)	Sylvest (2020)
Manufacturing	job -years/MW	11	14	5
Development and construction	job -years/MW	2.28	1.94	1.36
O&M direct	Jobs/MW	0.21	0.14	0.08
O&M (supply chain)	Jobs/MW	n/a	0.47	n/a
Sources		[1]	[2]	[3]

Table 7 Australian employment in offshore wind by project phase

		Current		% of total		Potential employment	
		JEDI / UTS	2022 ISP	JEDI / UTS	2022 ISP	JEDI / UTS	
Supply chain	job -years/MW	0.90	0.38	6.6%	6.9%	2.63	19%
Development and construction	job -years/MW	1.50	1.36	77%	100%	1.34	69%
O&M direct	Jobs/MW	0.14	0.08	100%	100%	0.14	100%
O&M (supply chain)	Jobs/MW	0.06	-	13%	-	0.16	35%
Sources		From [2]	[3 & 4]			From [2]	

Table 8 O&M employment in offshore wind (multiple sources)

Project/ Source		**Arklow Bank**	**Beatrice**	**Rampion**	**Star of the South**	**Dogger Bank**	**Hornsea 3**	**JEDI model**
Year		2018	2019	2018	2022	2023	2018 (2026)	2022
Capacity	MW	800	588	440	2200	3600	2900	1000
O&M direct	FTE	80	90	60	200	200	120	141
O&M supply chain	FTE						1170	470
Total	FTE	n/a	n/a	n/a	n/a	n/a	1290	611
O&M direct	Jobs/MW	**0.1**	**0.15**	**0.14**	**0.09**	**0.06**	**0.04**	**0.14**
O&M supply chain	Jobs/MW						0.40	0.47
Total	Jobs/MW						0.45	0.61
% direct							9%	23%
% supply chain							91%	77%
		[5]	[6]	[7]	[8]	[9]	[10]	[2]
Sources		[5]	[6]	[7]	[8]	[9]	[10]	[2]

Offshore wind employment sources

[1] International Renewable Energy Agency. (2018) [42]
[2] NREL (2022) [43]
[3] Sylvest, T. (2020). [44]
[4] Rutovitz, J., et al (2023) [45]
[5] https://www.sserenewables.com/offshore-wind/projects/arklow-bank-wind-park/
[6] https://www.beatricewind.com/about
[7] https://www.rampionoffshore.com/wind-farm/questions-and-answers/
[8] Star of the South (2022) Project overview. Available starofthesouth.com.au
[9] https://www.sserenewables.com/offshore-wind/projects/dogger-bank/
[10] Ørsted (2018) Hornsea Project (expected commissioning is 2026, although the report is 2018)[46]

Table 9 Local content for CAPEX (inputs to JEDI model) – offshore wind

	International	Existing capacity	Potential capacity
Turbine Component Costs			
Nacelle/Drivetrain *Materials & Labour*	100%	0%	0%
Blades *Materials & Labour*	100%	0%	10%
Towers *Materials & Labour*	100%	0%	90%
Other/Miscellaneous	100%	100%	100%
Balance of System Costs			
Substructure and Foundation			
Monopile	100%	20%	50%
Scour Protection	100%	20%	50%
Spar	100%	20%	50%
Semisubmersible	100%	0%	0%
Mooring System	100%	20%	50%
Electrical Infrastructure Components			
Array Cable System	100%	0%	0%
Export Cable System	100%	0%	0%
Offshore Substation	100%	0%	15%
Assembly and Installation			
Foundation *Vessel*	100%	40%	40%
Foundation *Labor*	100%	100%	100%
Mooring System *Vessel*	100%	40%	40%
Mooring System *Labor*	100%	100%	100%
Turbine *Vessel*	100%	40%	40%
Turbine *Labor*	100%	100%	100%
Array Cable *Vessel*	100%	40%	40%
Array Cable *Labor*	100%	100%	100%
Export Cable *Vessel*	100%	40%	40%
Export Cable *Labor*	100%	100%	100%
Offshore Substation *Vessel*	100%	40%	40%
Offshore Substation *Labor*	100%	100%	100%
Scour Protection *Vessel*	100%	40%	40%
Scour Protection *Labor*	100%	100%	
Ports and Staging			
Foundation	100%	70%	90%
Mooring System	100%	70%	90%
Turbine	100%	70%	90%

	International	Existing capacity	Potential capacity
Array Cable	100%	70%	90%
Export Cable	100%	70%	90%
Offshore Substation	100%	70%	90%
Scour Protection	100%	70%	90%
Development and Construction			
Construction Operations Plan	100%	100%	100%
Design Install Plan	100%	80%	90%
Site Assessment Plan	100%	80%	90%
Site Assessment Activities	100%	80%	90%
Onshore Transmission	100%	100%	100%
Construction Operations	100%	100%	100%
Commissioning	100%	100%	100%
Other/Miscellaneous	100%	100%	100%

Table 10 Local content for OPEX (inputs to JEDI model) – offshore wind

Total Operations and Maintenance	International	Existing capacity	Potential capacity
Maintenance			
Offshore Maintenance			
Technicians (Labor)	100%	100%	100%
Spare Parts	100%	0%	0%
Vessels	100%	10%	30%
Onshore Electric Maintenance	100%	100%	100%
Operations			
Operation, Management and General Administration	100%	100%	100%
Operating Facilities	100%	100%	100%
Environmental, Health, and Safety Monitoring	100%	100%	100%

Appendix 2 – Decline factors

Table 11 Decline factors calculated for the Step Change scenario

Technology	2023	2024	2026	2028	2030	2032	2034	2036	2038	2040	2042	2044	2046	2048	2050
Hydro	100%	98%	94%	90%	87%	84%	84%	84%	84%	84%	83%	83%	83%	83%	82%
Gas	100%	100%	99%	94%	93%	89%	88%	88%	87%	87%	87%	86%	86%	85%	85%
Batteries	100%	100%	85%	73%	64%	56%	54%	52%	50%	49%	47%	46%	45%	44%	43%
Pumped hydro	100%	98%	94%	90%	87%	85%	84%	84%	84%	84%	83%	83%	83%	83%	82%
Wind (onshore)	100%	100%	91%	82%	74%	71%	70%	70%	69%	69%	69%	68%	68%	68%	68%
Wind (offshore)	100%	96%	87%	79%	72%	69%	67%	66%	65%	64%	63%	63%	62%	61%	61%
Utility-scale PV	100%	96%	86%	78%	71%	66%	63%	59%	51%	45%	43%	41%	40%	38%	38%
Rooftop PV	100%	95%	85%	77%	69%	64%	57%	49%	44%	40%	38%	36%	35%	35%	34%

Table 12 Decline factors calculated for the Progressive Change scenario (technologies that vary from Step Change)

Technology	2023	2024	2026	2028	2030	2032	2034	2036	2038	2040	2042	2044	2046	2048	2050
Gas	100%	100%	99%	94%	93%	89%	88%	88%	87%	87%	87%	86%	86%	85%	85%
Batteries	100%	100%	85%	73%	64%	56%	54%	52%	50%	49%	47%	46%	45%	44%	43%
Wind (onshore)	100%	100%	91%	82%	74%	71%	70%	70%	69%	69%	69%	68%	68%	68%	68%
Wind (offshore)	100%	96%	87%	79%	72%	69%	67%	66%	65%	64%	63%	63%	62%	61%	61%
Utility-scale PV	100%	96%	86%	78%	71%	66%	63%	59%	51%	45%	43%	41%	40%	38%	38%

Table 13 Decline factors calculated for the Green Energy Exports scenario (technologies that vary from Step Change)

Technology	2023	2024	2026	2028	2030	2032	2034	2036	2038	2040	2042	2044	2046	2048	2050
Gas	100%	100%	99%	94%	93%	89%	88%	88%	87%	87%	87%	86%	86%	85%	85%
Batteries	100%	100%	85%	73%	64%	56%	54%	52%	50%	49%	47%	46%	45%	44%	43%
Wind (onshore)	100%	100%	91%	82%	74%	71%	70%	70%	69%	69%	69%	68%	68%	68%	68%
Wind (offshore)	100%	96%	87%	79%	72%	69%	67%	66%	65%	64%	63%	63%	62%	61%	61%
Utility-scale PV	100%	96%	86%	78%	71%	66%	63%	59%	51%	45%	43%	41%	40%	38%	38%

Appendix 3 – Additional results by occupational share

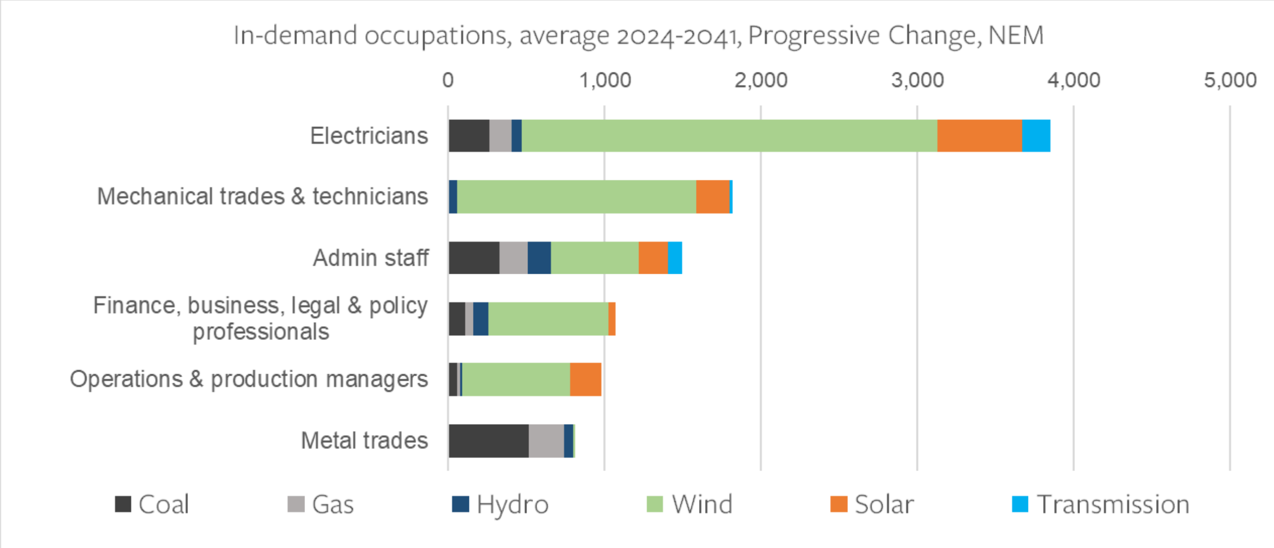

Figure 30 NEM, in-demand occupations average occupational structure 2024-2041, Progressive Change

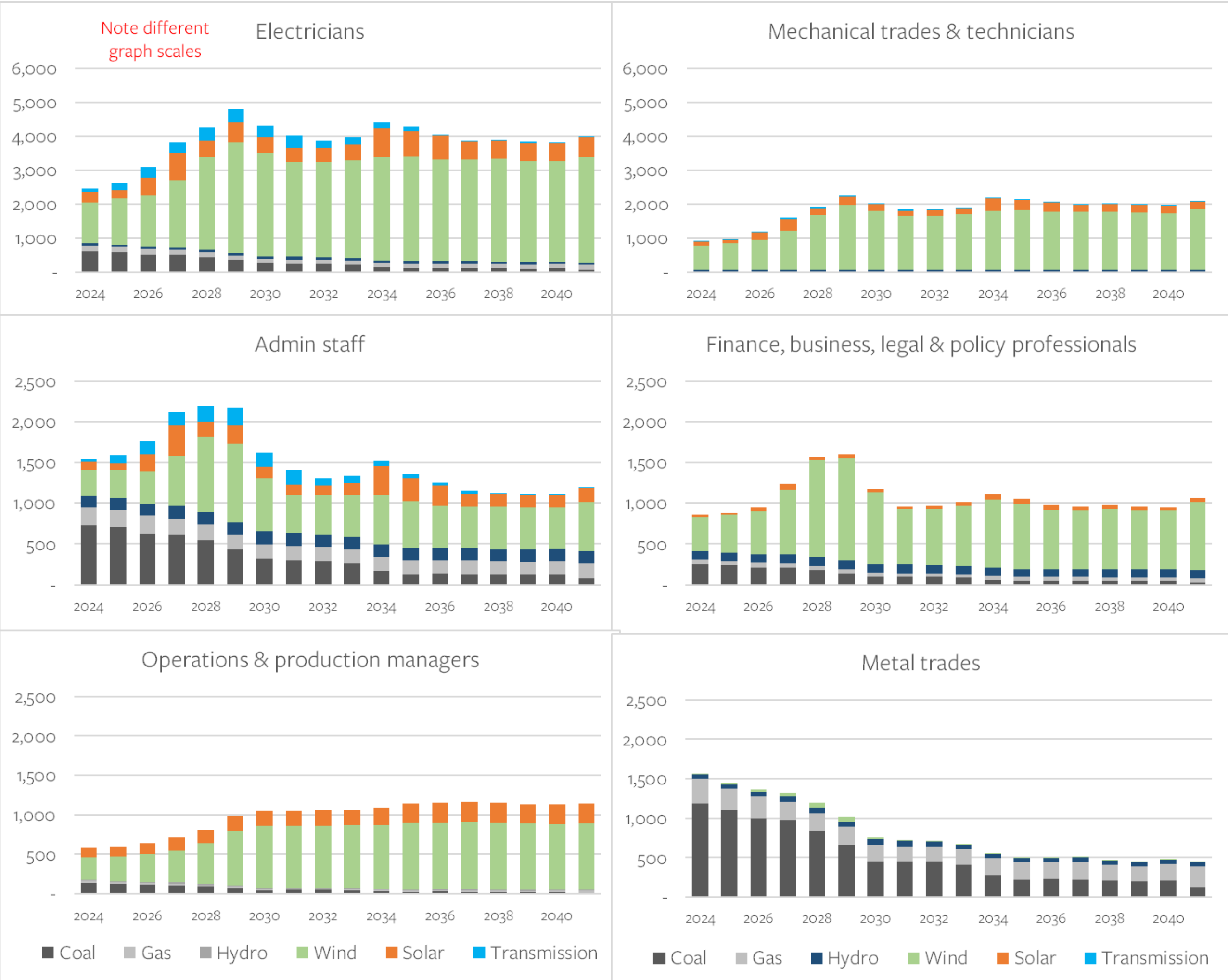

Figure 31 Annual requirements for in-demand occupations, Progressive Change

Note: scale of 0-6000 for total jobs for the top two occupations, and 0-2500 for the remainder.

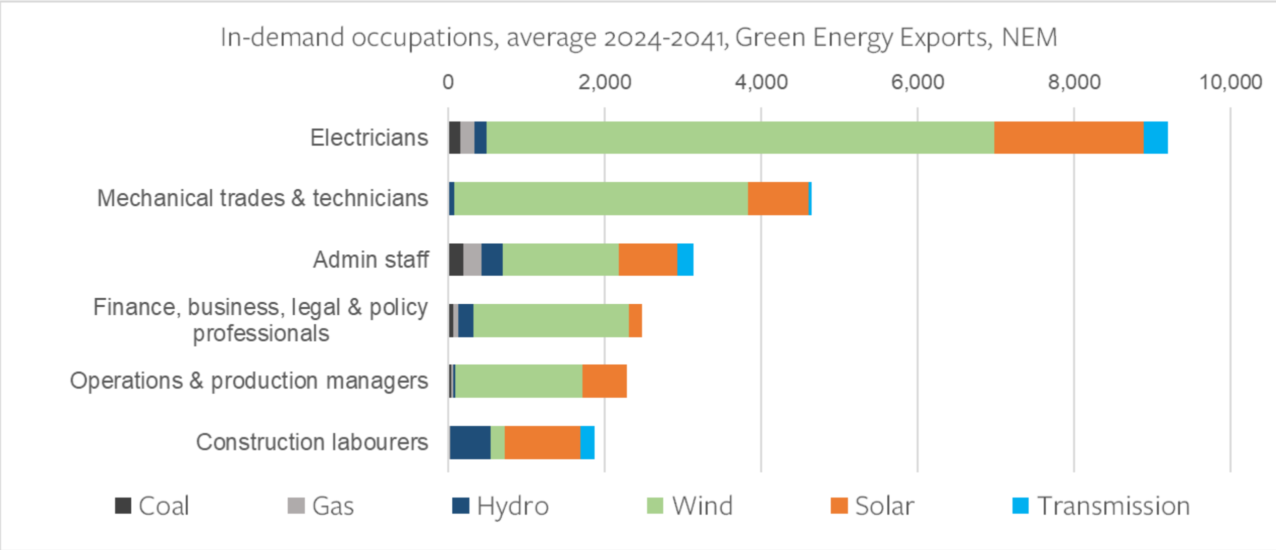

Figure 32 NEM, in-demand occupations average occupational structure 2024-2041, Green Energy Exports

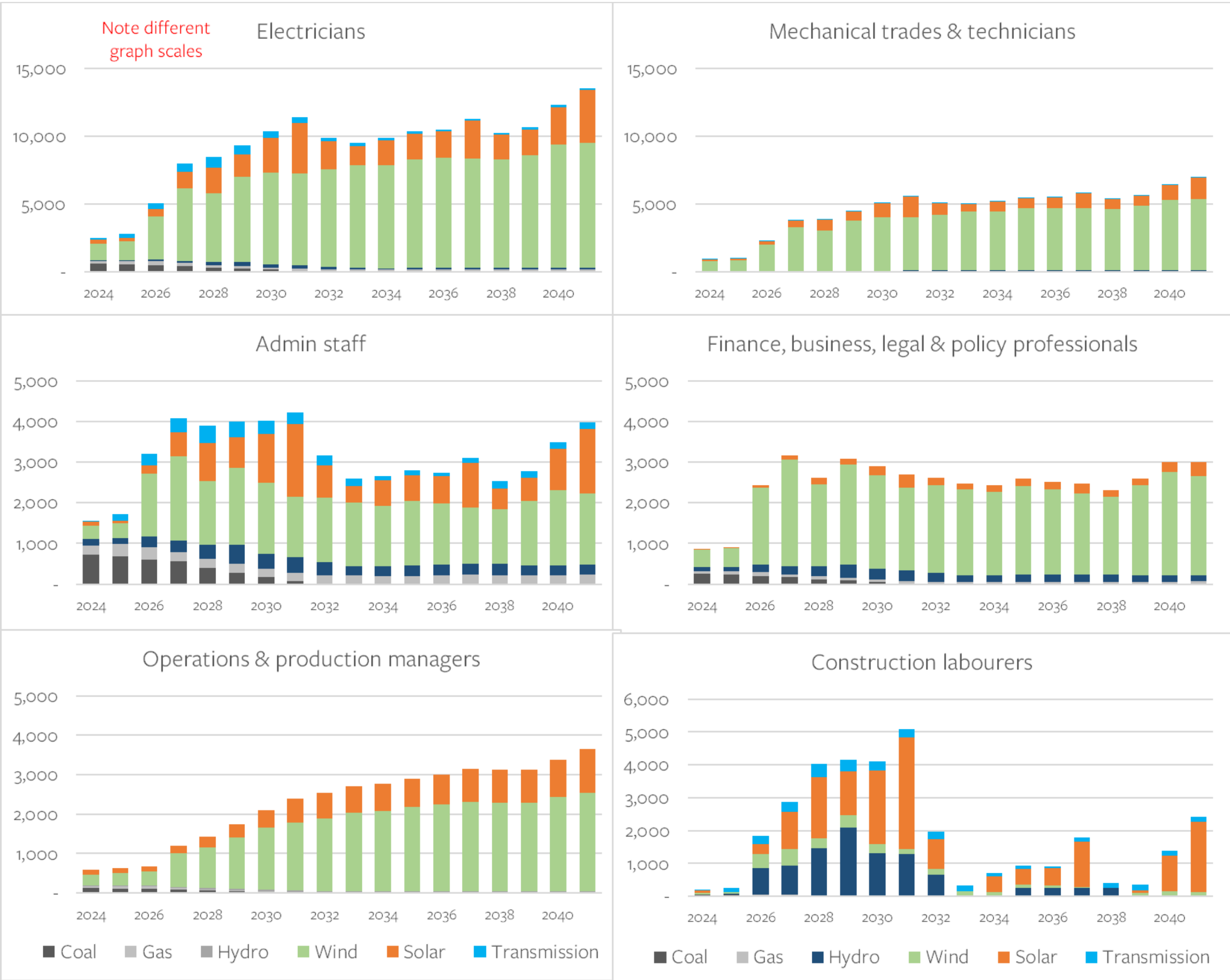

Figure 33 Annual requirements for in-demand occupations, Green Energy Exports

Note: scale of 0-15000 for total jobs for the top two occupations, and 0-6,000 for the remainder.

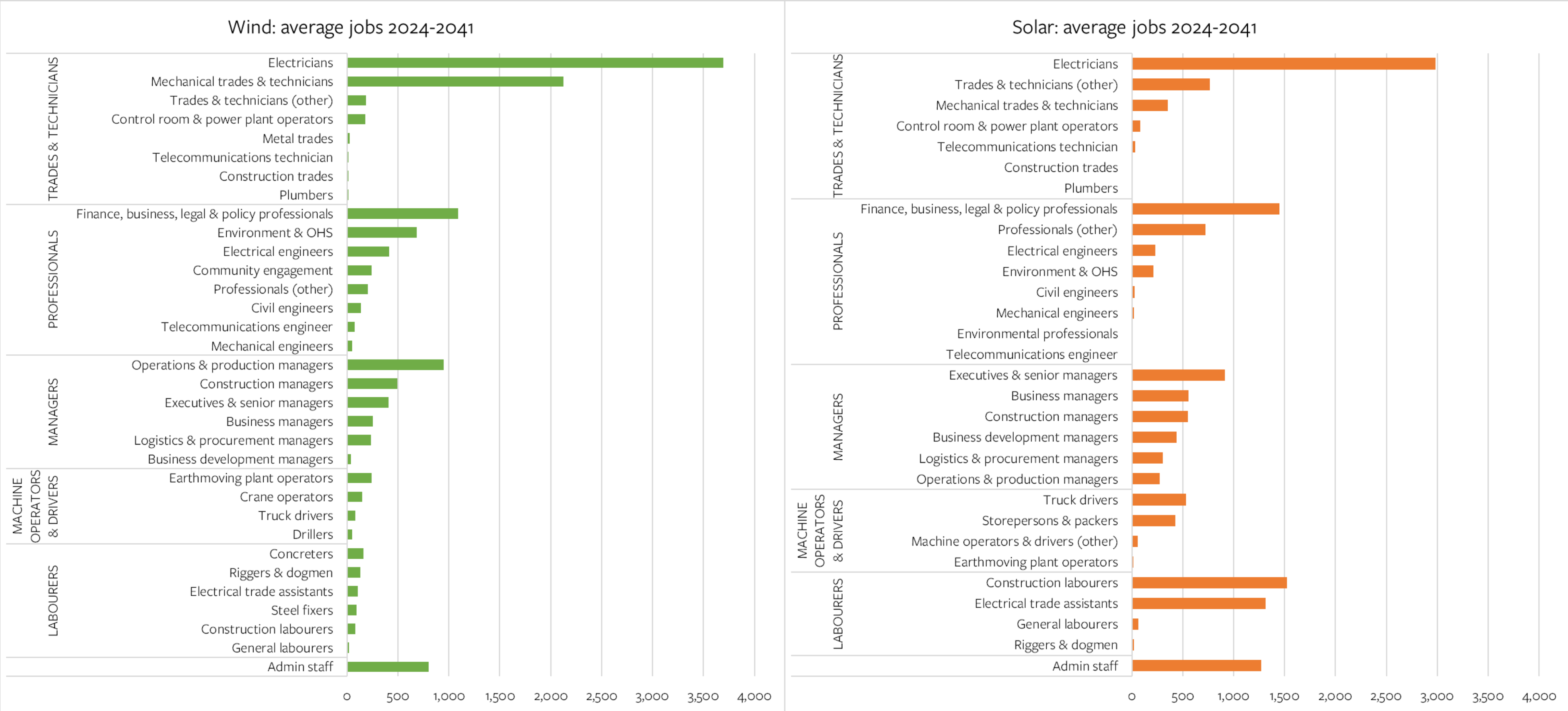

Figure 34 Average occupational mix for wind and solar, 2024 – 2041 (Step Change)

References

[1] Rutovitz, J., Visser, D., Sharpe, S., Taylor, H., Jennings, K., Atherton, A., Briggs, C., Mey, F., Niklas, S., Bos, A., Ferraro, S., Mahmoudi, F., Dwyer, S., Sharp, D., and Mortimer, G. (2021). *Developing the future energy workforce.* Opportunity assessment for RACE for 2030.

[2] Australian Government (2024) *Budget 2024-25: A Future Made in Australia*, https://budget.gov.au/content/factsheets/download/factsheet-fmia.pdf

[3] Rutovitz, J., Briggs, C., Dominish, E., Nagrath, K. (2020) *Renewable Energy Employment in Australia: Methodology.* Prepared for the Clean Energy Council by the Institute for Sustainable Futures, University of Technology Sydney.

[4] Jobs and Skills Australia (2023), *National Skills Priority List*, https://www.jobsandskills.gov.au/news/2023-skills-priority-list-released-0.

[5] International Energy Agency. (2023). *World Energy Employment 2023*. Page 9.

[6] Powering Skills Organisation (2024) *The New Power Generation: Challenges and Opportunities within Australia's Energy Sector*, https://poweringskills.com.au/wp-content/uploads/2024/07/Workforce-Plan-Report_2024_Final.pdf. p.11.

[7] Infrastructure Australia (2023), Market Capacity Report 2023

[8] Australian Energy Market Operator (2024). *2024 Integrated System Plan for the National Electricity Market.* https://aemo.com.au/-/media/files/major-publications/isp/2024/2024-integrated-system-plan-isp.pdf?la=en

[9] Op. cit. 1.

[10] Rutovitz, J., Langdon, R., Mey, F., Briggs, C. (2023) The Australian Electricity Workforce for the 2022 Integrated System Plan: Projections to 2050. Revision 1. Prepared by the Institute for Sustainable Futures for RACE for 2030.

[11] Op. cit. 8.

[12] APVI postode data by State (installation of systems <100kW), https://pv-map.apvi.org.au/postcode

[13] Australian Energy Market Operator, DER Data Dashboard. https://aemo.com.au/en/energy-systems/electricity/der-register/data-der/data-dashboard . Downloaded 26 July 2024.

[14] Op. cit. 3.

[15] Briggs, C., Rutovitz, J., Jazbec, M., Langdon, R & Nagrath, K. (2022) *Employment and Material Requirements for the Integrated System Plan: Electricity Generation and Transmission.* Revision 1.

[16] Australian Energy Market Operator. 2022. Draft 2023 Inputs, Assumptions and Scenarios Report. https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2022/2023-inputs-assumptions-and-scenarios-consultation/draft-2023-inputs-assumptions-and-scenarios-report.pdf?la=en

[17] Rutovitz J, Langdon R, Briggs C, Mey F, Dominish E, Nagrath K. (2024) Renewable Energy, Storage, and Transmission Construction Employment Factors and Occupational Employment Shares for Australia. 2024. (Preprint, currently undergoing peer review). http://ssrn.com/abstract=4828871 Note that decline factors for these projections are not contained in the preprint, they are derived from op. cit. 19 and op. cit. 20.

[18] NREL (2022) Jobs and Economic Development Impact Model – JEDI. *Offshore Wind Tool*. https://www.nrel.gov/analysis/jedi/wind.html

[19] Australian Energy Market Operator (2023). *Inputs and Assumptions and Scenarios Workbook.* https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2024-integrated-system-plan-isp/current-inputs-assumptions-and-scenarios

[20] Graham, P; Hayward, J; Foster, J. 2023. GenCost 2023-24: Consultation draft. Newcastle: CSIRO. Appendix Table B.2 Current and projected generation technology capital costs under the Global NZE by 2050 scenario

[21] Op. cit. 3.

[22] Op. cit. 15.

[23] Op. cit. 17.

[24] Op. cit. 10.

[25] Australian Government (2024) *Budget 2024-25: A Future Made in Australia*, https://budget.gov.au/content/factsheets/download/factsheet-fmia.pdf

[26] Australian PV Institute (2023) Silicon to Solar: Foundations for Solar PV Manufacturing in Australia, ARENA. https://arena.gov.au/assets/2024/02/APVI-Silicon-to-Solar-Detailed-Report.pdf; Gill, J., Briggs, C., Feenstra, M., Dwyer, S., Dominish, E., Zhou, T, Phua, R & Davies, E. (2024) *Towards a Renewable Energy Superpower: Industry Opportunities to Embrace the Clean Energy Revolution*, https://www.uts.edu.au/isf/news/towards-energy-superpower.

[27] Jobs and Skills Australia (2023) *The Clean Energy Generation*, p.162. https://www.jobsandskills.gov.au/publications/the-clean-energy-generation.

[28] Op. cit. 6, pp.31-32

[29] Op. cit. 5, p. 9

[30] Op. cit. 8, pp. 79 and 86

[31] Op. cit. 4.

[32] Infrastructure Australia (2023), *Market Capacity Report 2023* p.64.

[33] Ibid.

[34] Op. cit. 6, p.11.

[35] Op. cit. 27, pp.265-266.

[36] Ibid.

[37] Op. cit. 6.

[38] Briggs, C., Tjondro, M., Heard, R., Langdon, R., Frangos, M., Niklas, S., Trimble, M., Gill, J & Wensing, Ed. (2024) *Powering First Nations Jobs in Clean Energy*, Report for First Nations Clean Energy Network. https://assets.nationbuilder.com/fncen/pages/237/attachments/original/1722394132/FNCE_Jobs_Report_-_FINAL_%28Compressed%29.pdf?1722394132

[39] Jobs and Skills Australia (2023) *The Clean Energy Generation: Workforce Needs for a Net Zero Economy*, p.239.

[40] Sylvest, T. (2020). *Socio-economic impact study of offshore wind.* Prepared by QBIS for Danish Shipping, Wind Denmark and Danish Energy with support from The Danish Maritime Foundation

[41] Op. cit. 18.

[42] International Renewable Energy Agency (2018). *Renewable Energy benefits Leveraging local capacity for offshore wind.*

[43] Op. cit. 18.

[44] Op. cit. 40.

[45] Op. cit. 10.

[46] Ørsted (2018) *Hornsea Project Three Offshore Wind Farm Environmental Statement: Volume 3, Chapter 10 – Socio-economics.* (expected commissioning is 2026, although the report is 2018)

RACE for 2030

RELIABLE
AFFORDABLE
CLEAN
ENERGY

www.racefor2030.com.au

Australian Government
Department of Industry, Science and Resources

Cooperative Research Centres Program