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Market Capacity for electricity generation and transmission projects

A report from Infrastructure Australia's Market Capacity Program

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ACKNOWLEDGEMENT OF COUNTRY

Infrastructure Australia proudly acknowledges the Traditional Owners and Custodians of Australia, and their continuing connections to the land, waters and communities. We pay our respects to them and to their Elders past, present and emerging. In preparing for the future of our infrastructure, we acknowledge the importance of looking beyond the immediate past to learn from Aboriginal and Torres Strait Islander peoples' unique history of land management and settlement, art, culture and society that began over 65,000 years ago.

As part of Infrastructure Australia's commitment to reconciliation, we will continue to develop strong, mutually beneficial relationships with Aboriginal and Torres Strait Islander partners who can help us to innovate and deliver better outcomes for Aboriginal and Torres Strait Islander communities, recognising their expertise in improving quality of life in their communities.

EXECUTIVE SUMMARY

Infrastructure Australia has partnered with the Australian Energy Market Operator (AEMO) to assess and understand the labour and material requirements for the transmission and generation projects identified in AEMO's 2020 Integrated System Plan. This new analysis, scoped collaboratively with AEMO, and commissioned by Infrastructure Australia from the University of Technology Sydney, aims to improve the understanding of labour and material requirements to inform and assist governments, transmission network providers, project developers and market bodies.

A series of Renewable Energy Zones (REZs) in regional areas have been identified by AEMO as the best locations for large-scale renewable energy generation and storage. In addition to inter-state transmission connections to enable power flows across states, investment in new transmission and generation capacity will be coordinated to unlock resources within the REZs and connect them with population and demand centres. The New South Wales (NSW), Queensland and Victorian Governments are each developing programs to implement REZs within their states.

Data derived from AEMO's 2020 Integrated System Plan (ISP) indicate that under a Step Change scenario, an estimated that over the next 15 to 20 years $66 billion will be invested in large-scale renewable energy generation and storage (mostly in regional areas) and $27 billion in rooftop solar and battery storage.

The build-out of electricity generation and transmission infrastructure will create pressures on market capacity to deliver the supply of labour and materials required for a smooth, efficient energy system transition.

This analysis forms part of Infrastructure Australia's broader Market Capacity Program considering risks and constraints associated with the demand and supply of plant, labour, equipment and materials across the Major Public Infrastructure Pipeline nationally. This sector report on electricity generation and transmission infrastructure does not provide an integrated analysis with the resource demands forecast for the broader Major Public Infrastructure Pipeline, and for an understanding of those risks this report should be read in conjunction with the *Infrastructure Market Capacity* report separately published by Infrastructure Australia.

Key findings:

- Labour and skill shortages may become a significant factor for the build out of renewable generation and transmission infrastructure, especially in regions with tight labour markets.
- There is significant volatility forecast in labour demand (reflecting primarily the peaks and troughs in construction), especially within states and regions.
- Labour demand in the electricity sector grows over time, fluctuating from 80,000 to 95,000 with the primary source of growth in large-scale renewable energy. Growth occurs across all major occupation groups except machine operators.
- Key risks for shortages and constraints are identified both in the larger occupational groups (such as electricians, construction managers, electrical and grid engineers), but also some more specialised jobs (such as line workers for transmission construction or crane operators for wind power construction).
- Occupations currently listed on skills shortage and skills needs lists (electricians, telecommunications engineers) present a higher level of risk exacerbated by prolonged border closures or limits on skilled migration.
- Industry stakeholders identified a range of challenges and barriers for skill development through the REZs, but also opportunities for better co-ordination of training, skills and workforce development to reduce the labour supply risks, improve regional economic outcomes and job quality.
- The current projections for labour demand in the energy sector could significantly underestimate growth, especially under ‘energy superpower’ scenarios where there is mass electrification and growth in renewable hydrogen for heavy industry, transport fuels and export with associated demand on labour and materials. For example, in the National Hydrogen Strategy, electricity requirements for renewable hydrogen are projected to range from one-third to over four and a half times the current size of the National Electricity Market (NEM).[1]
- Renewable energy will significantly increase consumption of steel and concrete. Australia produces 29 million m^3 of concrete per year and 5.6 million tonnes of crude steel per year (in 2018).[2][3] Electricity generation and transmission demand for steel peaks at just over 1 million tonnes, reaching about a fifth of the Australian yearly production, and demand for concrete peaks at just over 4 million m^3. The largest source of steel consumption is wind turbine towers but solar farms, rooftop solar, pumped hydro storage and transmission towers are all notable sources of demand for steel. Importantly, most of the steel is currently imported although there are local wind tower manufacturers and a transmission tower factory is being established. For concrete, the primary source of consumption is pumped hydro storage and secondarily wind turbines.
- Based on a case study of NSW, State REZ programs could significantly bring forward material requirements with the peak consumption of steel more than doubling and concrete consumption over 50% higher in the mid-2020s.

1. INTRODUCTION

Infrastructure Australia has partnered with the Australian Energy Market Operator (AEMO) to assess and understand the labour and material requirements for the transmission and generation projects identified in AEMO's 2020 Integrated System Plan. This new analysis, scoped collaboratively with AEMO, and commissioned by Infrastructure Australia from the University of Technology Sydney, aims to improve the understanding of labour and material requirements to inform and assist governments, transmission network providers, project developers and market bodies.

This analysis forms part of Infrastructure Australia's broader Market Capacity Program considering risks and constraints associated with the demand and supply of plant, labour, equipment and materials across the Major Public Infrastructure Pipeline nationally.

Objectives

In 2019-2020, the Institute for Sustainable Futures at the University of Technology Sydney conducted a large-scale survey of renewable energy labour to generate labour demand estimates based on Integrated System Plan (ISP) scenarios.[4]

This report extends this work to develop an integrated analysis of energy generation and transmission construction. This report provides:

- Estimates of the volume and occupational composition of labour demands for transmission line and generation construction, operation and maintenance associated with the 2020 ISP, the associated labour demand indicators and a framework for classifying and measuring occupations.
    - Labour demand is projected for the electricity sector as a whole, renewable energy generation technologies and transmission construction, both by states in the NEM (that is, not including Western Australia (WA) and the Northern Territory (NT)) and by occupation.
- Estimates of the volume of steel and concrete demanded for the construction of renewable technologies associated with the 2020 ISP, as well as material demand indicators for projects utilising wind generation, solar or hydro power.
- Identification and estimates of critical inputs for transmission line and generation construction.
- A framework for assessing the capacity of regional labour markets to meet labour demand for the REZs, applied through a case study of the Central-West Orana REZ.

The scope does not include up-stream elements of the supply chain (e.g. minerals for renewable energy technologies, manufacturing) or down-stream elements of the supply chain (e.g. end-of-life recycling, disposal).

Approach

This analysis and report was informed by:

- Surveys with transmission networks and construction firms to generate labour demand indicators for transmission construction, collect data on recruitment difficulties and qualitative information on barriers and issues for skill and labour development (undertaken from March-April 2021).
- Desktop research to include fossil fuel generation and fuel supply to enable labour demand projections, for the entire energy sector, including coal and gas generation and fuel supply, clean energy generation, storage, and transmission construction.
- Research on the concrete and steel requirements for rooftop solar photovoltaics (PV), solar farms (PV), wind farms, hydroelectricity and pumped hydro storage and transmission construction to generate volume estimates under ISP scenarios.
- An industry workshop (featuring renewable energy and transmission stakeholders, and training providers) held in April 2021 to consider the challenges and opportunities for skills development and labour requirements in REZs and transmission construction.

Context

The ISP, Energy Transition Scenarios and Renewable Energy Zones

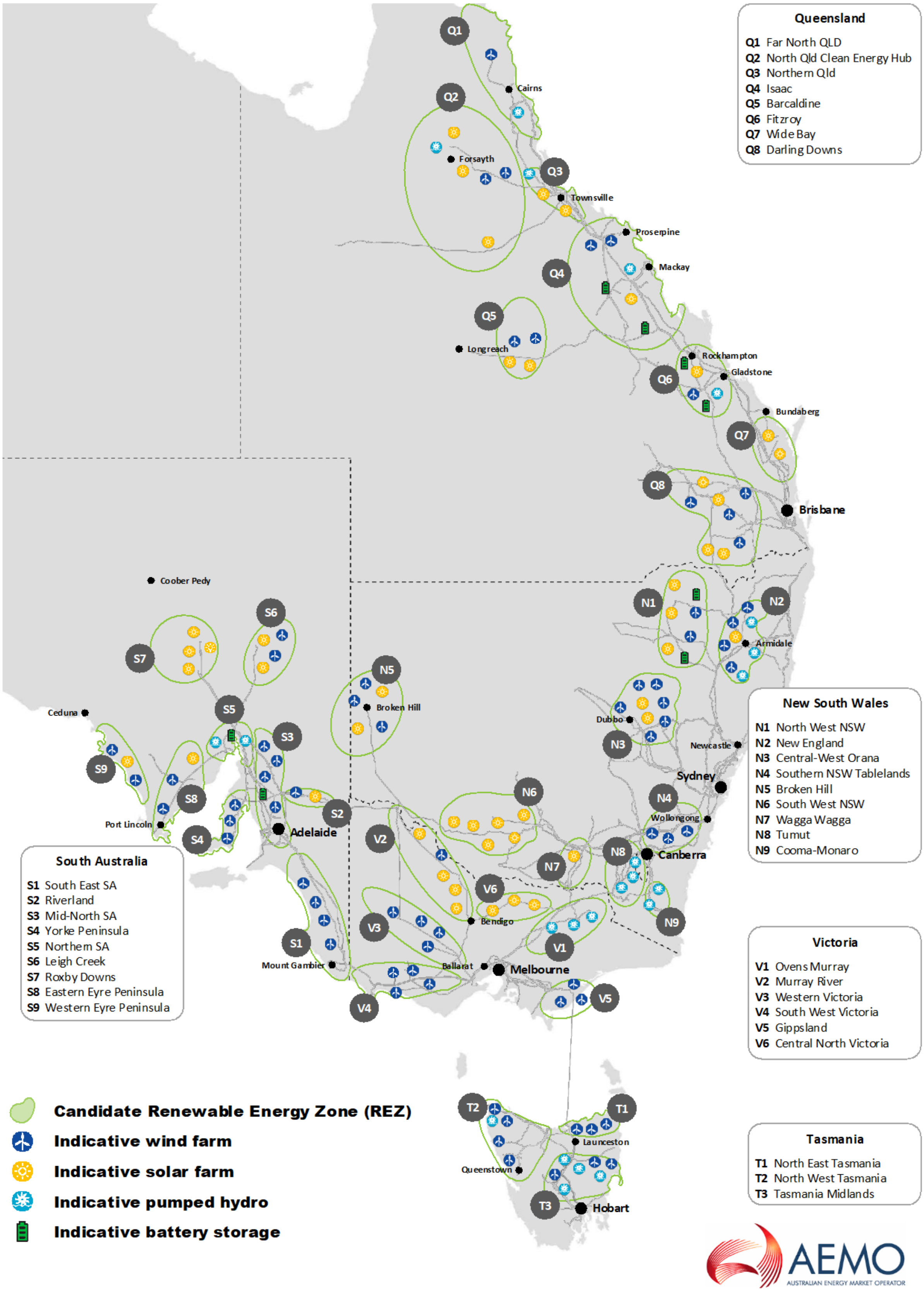
The Australian Energy Market Operator produces a whole-of-system plan (the Integrated System Plan, or ISP) for the NEM and transmission network every two years. The ISP includes a collection of five scenarios on the future development of electricity generation and transmission network using least-cost optimisation modelling: [5]

1. Central scenario – determined by market forces and current federal and state government policies.
2. Slow Change scenario – slower economic growth and emission reductions.
3. High distributed energy resources (DER) scenario – more rapid consumer adoption of generation technologies such as rooftop solar.
4. Fast Change scenario – greater investment in grid-scale technology.
5. Step Change scenario – both consumer-led and technology-led transitions occur in the midst of aggressive global decarbonisation.

Ultimately, the purpose of the ISP is to provide a dynamic roadmap of how the NEM and transmission system could change over the next two decades to support the decisions of market participants, investors, policy-makers and consumers.

AEMO identified a series of potential REZs in the 2020 ISP based on a range of factors, such as the quality of renewable energy resources and network access. At a national level, the Energy Security Board is developing a framework for the implementation of REZs. [6] As shown in Figure 1 these candidate REZs are distributed across eastern Australia.

Figure 1: Renewable Energy Zones, Integrated System Plan



Source: Australian Energy Market Operator Limited. [7]

At a state level, the NSW, Victorian and Queensland Governments have each released programs to coordinate and accelerate generation and transmission investment in REZs. For example, the NSW Government has passed the *Electricity Infrastructure Investment Act (2020)* to facilitate the delivery of 12 GW of renewable energy generation and 2 GW of long-duration storage by 2030. [8]

The development of the REZs point to an acceleration of the renewable energy development profile relative to the Step Change scenario. As AEMO's Chief Systems Design Officer has noted, renewable energy development is outstripping the Step Change scenario and the development of the REZs is likely to further accelerate investment and resource demands. [9] Consequently, whereas labour demands peaks in the early 2030s in the Step Change scenario, the development of the REZs could lead to a higher, earlier demand growth pattern that peaks in the 2020s.

The case for a 'Step Plus REZs' scenario

$66 billion is projected to be invested in large scale electricity generation, transmission and storage over the next 15 to 20 years, and up to $27 billion invested in rooftop solar and batteries.

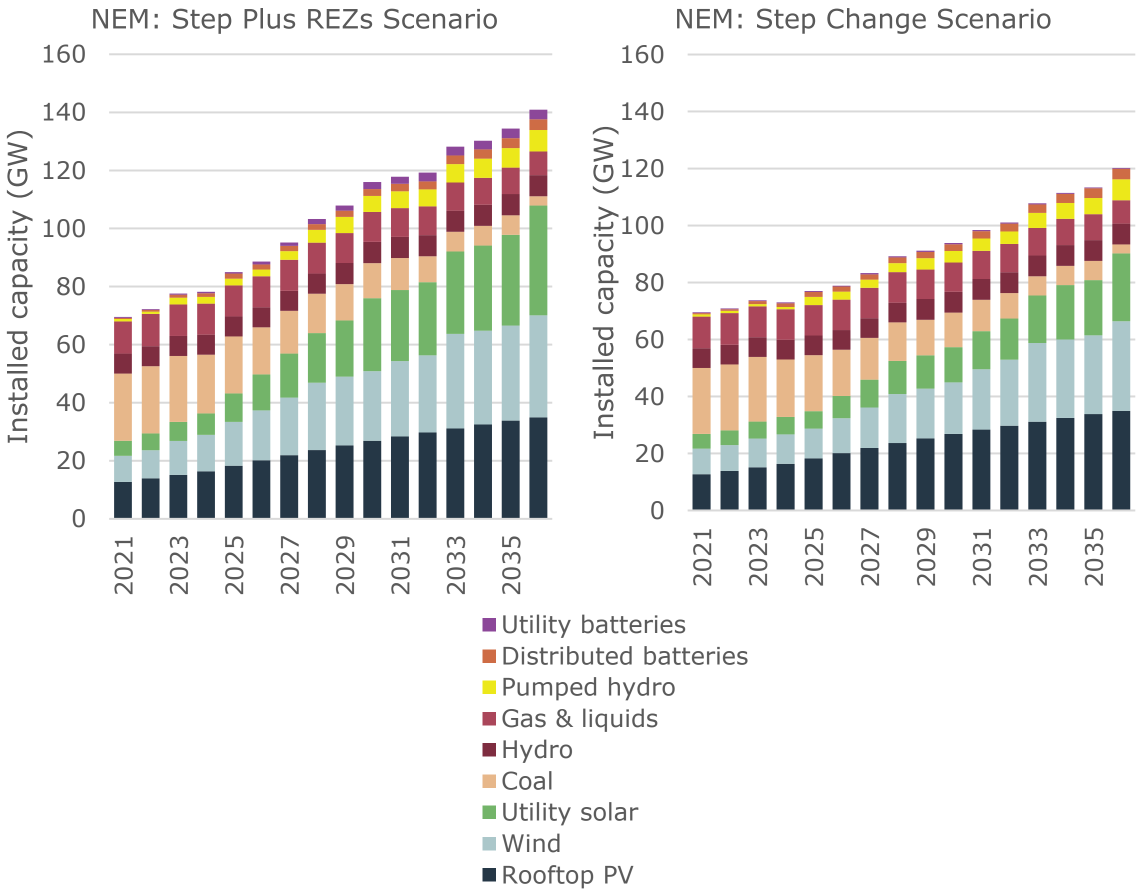
Projecting labour and material requirements for the energy sector is subject to significant uncertainties. An historic transition is underway as we shift from an electricity system based on coal-fired power to a mix of large-scale renewable energy, distributed renewable and storage, and firming technologies to complement the supply of lower-cost renewable energy sources to ensure grid resilience. Australia's electricity networks – built around transporting power from coal regions to consumers, primarily in the major cities and industrial centres – are also being reconfigured with major new interconnectors to transport power between states, new lines to unlock renewable energy in regional areas and investment to integrate the two-way flows of distributed energy resources. Under the Step Change scenario ISP, it is estimated that around $66 billion of capital expenditure will be invested in large-scale energy generation, storage and transmission.

The pace of change within the electricity sector and uncertainty over the development of renewable energy makes forecasting resource demands challenging. The direction of change is clear – all of the scenarios considered by AEMO end with 80 to 95% renewable energy by 2040 – however there are many different transition pathways. For example, the clean energy transition could be faster or slower, or there could be a higher or lower share of distributed or large-scale renewable energy. The labour and material requirements for energy generation and transmission will depend in part on which pathway is taken. Consequently, the starting point of this analysis is the energy transition scenarios of AEMO which underpins the labour and material demand projections.

Under the most rapid scenario in the 2020 ISP, the Step Change scenario, the market share of renewable energy would grow to 90% by 2035. In reality, the current and planned development of renewable energy is occurring even more rapidly. The Clean Energy Regulator has identified nearly 7 gigawatts (GW) of committed and probable projects which are likely to be built in the next few years.[10] The NSW, Victorian and Queensland Governments are each developing programs to implement large volumes of renewable energy and storage in REZs before 2030 (see Appendix A) with the result that renewable energy growth is likely to occur faster than forecast even in the Step Change scenario in the 2020 ISP.

Consequently, a Step Plus REZs scenario is included and the projections in this report are mostly based on this scenario. The installed capacity for each technology under the two scenarios is shown in Figure 21.

Figure 2: Forecasts of total capacity, Step Plus REZs and Step Change Scenario (2021–2036)



The key differences between the two scenarios are:

- **AEMO’s Step Change scenario**: renewable energy generation and storage grows modestly during the 2020s and then rapidly from the late 2020s and early 2030s based on coal-fired power station closures, emissions reductions and cost reductions for renewable energy technologies.
- **Step Plus REZs scenario:** this is based on the Step Change scenario which has been modified based on the State REZ targets for NSW, Queensland and Victoria. Only NSW has released detailed modelling for its REZ program and therefore the volume and timing for wind power generation, solar, pumped hydro and large scale batteries is based on the NSW Government Electricity Infrastructure Roadmap modelling, which brings forward development and increases the overall volume of renewable capacity. Adjustments are made for Victoria and Queensland in line with their targets:[11]

- The scenario assumes that Victoria will install 75% of the NSW wind and solar generation capacity, adding 9.5 GW by 2030 which is close to the Victorian target of 10 GW in the REZ Development Plan.
- Queensland is assumed to install 50% of the NSW additions towards the 50% 2030 Queensland Renewable Energy Target.
- In 2036 the capacity in Queensland is just 0.5 GW greater than the Step Change, while in Victoria capacity is 11.5 GW greater.

The projection for rooftop PV in both the Step Change and the Step Plus REZ scenarios has been increased in line with more recent projections from Green Energy Markets, which were commissioned for the 2022 ISP by AEMO.[12]

This scenario is not a prediction – AEMO is currently preparing the next iteration of the ISP for 2022. The purpose is to illustrate the trajectory of labour demand that could occur if the REZs are implemented under this scenario which is broadly aligned with state government targets for 2030.

Study Limitations

The overall labour demand projections in this study are conservative.

Electricity demand and growth opportunities for large scale renewable energy could be several times larger under 'energy superpower' scenarios currently being developed by electricity market forecasters in which there is large-scale electrification (industry, homes, transport) and/or the development of renewable hydrogen for heavy industry, transport fuels and export. In the National Hydrogen Strategy, electricity requirements for renewable hydrogen are projected up to almost 450 tera-watt hours – around two and a half times the current size of the National Electricity Market. [13] If this occurs, the labour demand would also be correspondingly higher, most likely during the 2030s and into the 2040s. AEMO is developing a scenario for the 2022 ISP to model the implications of electrification and hydrogen growth. Furthermore, it is important to note that the assumptions within the 2020 ISP on which this report is based predates the Australian Government's gas-fired recovery policy, which will affect the projections of resource demands within the coal and gas energy sub-sector.[14]

The scope of the study is the NEM which covers the Eastern Seaboard across to South Australia and south to Tasmania. There are significant renewable generation plans in both the Northern Territory and Western Australia in addition to large-scale projects under development to connect undersea cables to South-East Asia.

While the estimates of transmission construction labour are considered to be the best available for the labour demand volumes and occupational composition for construction in the electricity transmission sector, they should be taken as indicative rather than absolute. These estimates should not be taken as definitive for any particular project.

Non-line projects are particularly difficult to estimate. Costs were not able to be obtained for many of the smaller project elements – for example cutting in and capacitor banks – so these are excluded altogether. Cost data could also not be obtained for some of the larger projects in the ISP, in particular substations. The AEMO workbook information was not suitable as the metric is cost per hectare and there was nothing available on area for these projects. [15] Therefore an average cost for these projects was used rather than excluding them, meanwhile acknowledging that costs for substation infrastructure are extremely variable in practice. The labour demand indicators for specific non-line projects have a similarly wide range, both in our survey data and in the literature review (see Appendix 2 for a discussion of transmission indicators from literature), reflecting the variable nature of the projects themselves. For all these reasons non-line labour demand should be taken as indicative only. It is however, a far smaller proportion of transmission construction labour compared to line work.

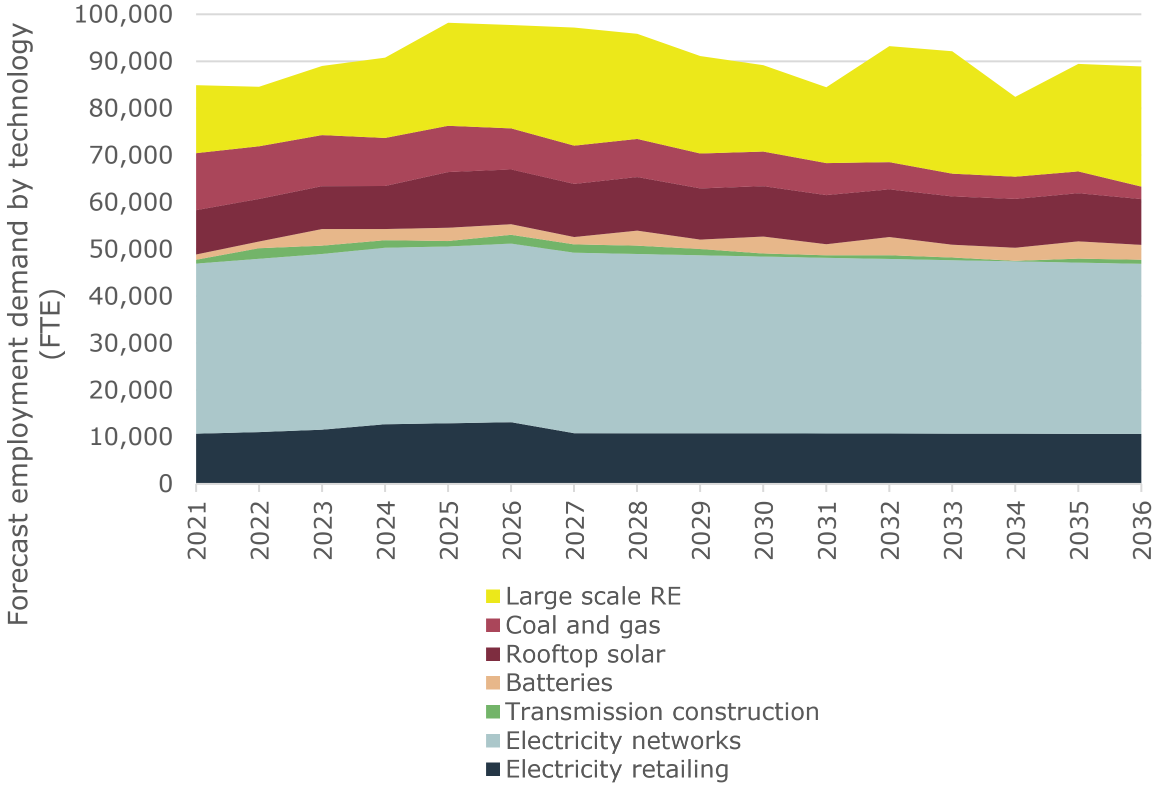
An indicator for subsea cable was not obtainable due to commercial confidentiality, so the double circuit line indicator for land projects was used instead. This approach is reasonable as the outcome using the multiplier for land projects is close to the totals estimated for Marinus Link and published by TasNetworks; within 10% in Tasmania and within 20% in Victoria. [16]

2.LABOUR DEMANDS

Power sector labour demand grows over time, driven primarily by large-scale renewable energy

Total power sector labour increases over time, albeit with some major fluctuations between 80,000 and 95,000. As shown in Figure 32, the largest source of labour demand is the operation of the electricity networks, primarily the distribution network which employs around 33,000 people. Electricity retailing employs around 11,000 people.

Figure 3: Forecast total labour demand, power sector (by sub-sector), Step Plus REZs (2021-2036)

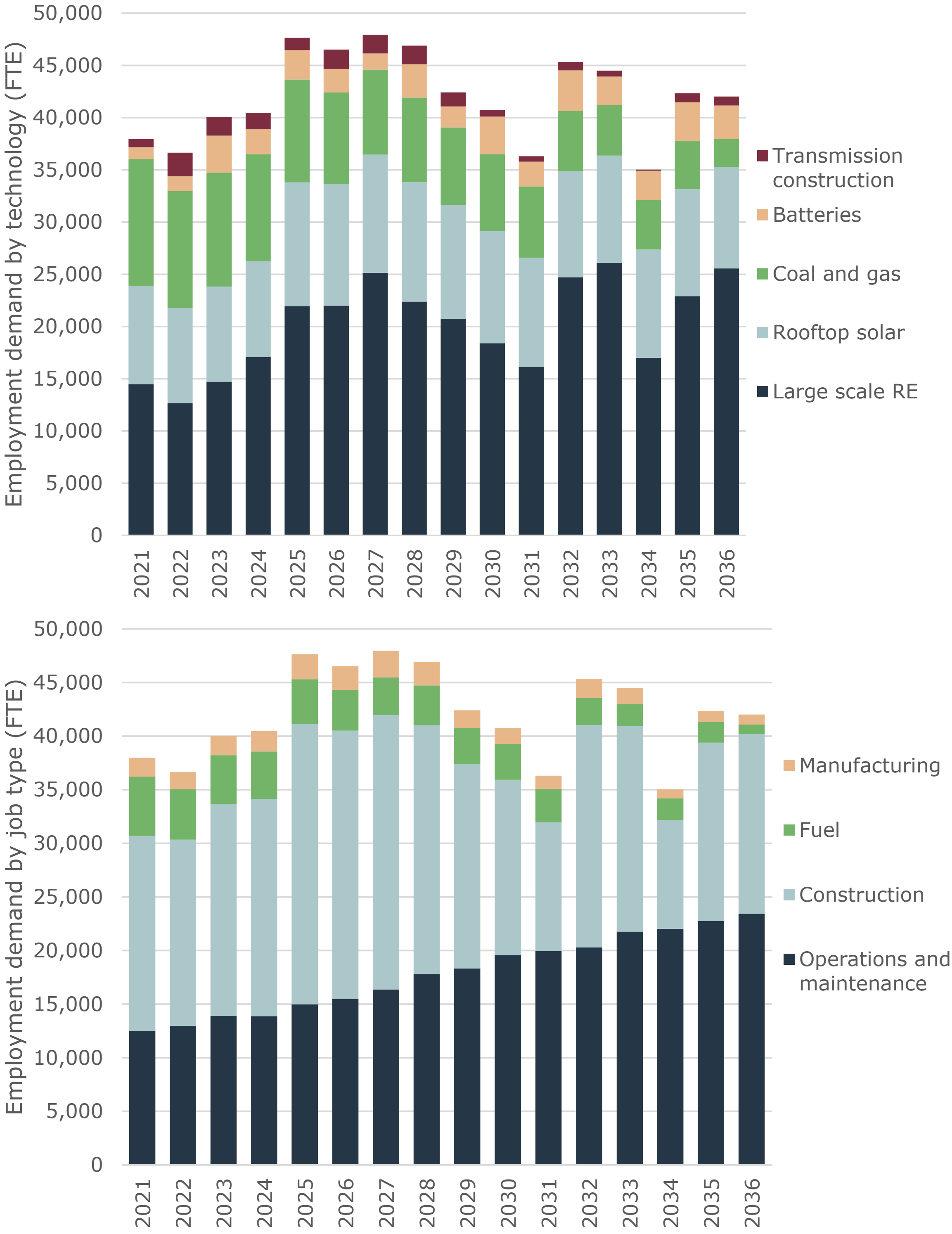


Note: The source for labour demand in the operation of the transmission and distribution network and electricity retailing are IBIS projections, as these sub-sectors were not included in the study.[17] IBIS projects labour demand until the mid-2020s, after which demand is assumed to decline in line with trend for each at the average rate for the preceding decade (-0.7% p.a. for electricity distribution, -0.3% p.a. for transmission and -0.1% p.a. for electricity retailing).

Key findings related to the demand for skills and labour highlighted by this analysis across the electricity generation and transmission construction sector include (Figure 43):

- Growth in demand for labour within large-scale renewable energy, rooftop solar, battery storage and transmission construction is projected to climb to over 40,000 for most of the study period and towards 50,000 jobs at times.
- There is high volatility across all the growth sectors apart from rooftop solar. The volatility primarily reflects the high proportion of labour demand in construction which scales up rapidly and then subsides as projects are completed. The volatility in labour demand presents challenges for suppliers, Engineering, Procurement and Construction firms (EPCs), workers and local communities. Attracting and retaining skilled workers across cycles is difficult. Although there is a core workforce with ongoing demand, many workers and contractors are engaged project-to-project. Strategies to reduce and manage volatility are an important consideration for the industry to reduce skill shortages, improve the quality of jobs and support regional economic outcomes.
- As the asset base of the energy market grows steadily over time, so too does the demand for operation and maintenance labour required to run these facilities. Labour demand in operation and maintenance in coal and gas is currently around 11,000. At the level of a single project, renewable energy does not employ large numbers of operation and maintenance staff but the growth in the volume of operating projects means that by the mid-2030s there are over 20,000 jobs in operation and maintenance. Over time, as the renewable energy segment grows, the level and proportion of people demanded in operation and maintenance increases from one-third to over half of electricity generation labour (Figure 43).

Figure 4: Forecast labour demand by technology and job type, transmission construction and electricity generation (Step Plus REZs) (2021–2036)

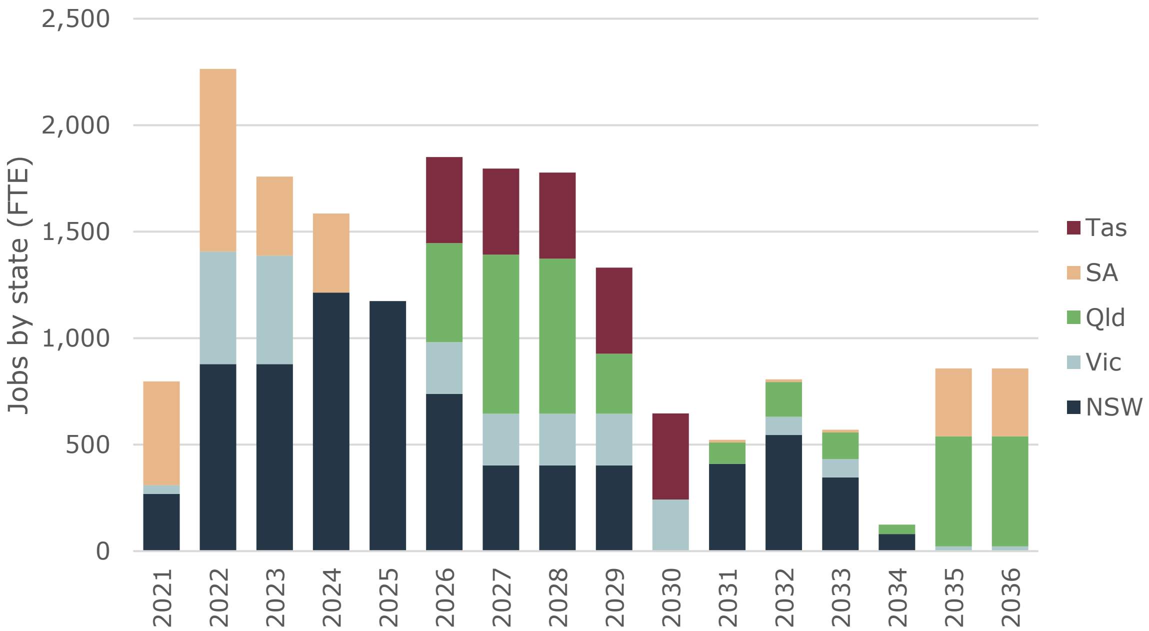


There are major variations between the technologies underpinning the trends in energy sector labour demand (Figure 43):

- The key source of growth in labour demand is large-scale solar and wind farms (utility-scale renewable energy). Demand is projected to climb sharply to 25,000 by 2027, subsiding after a wave of construction before a series of sharp cycles of growth and decline during the 2030s (around 25%).

- Rooftop solar labour demand is relatively stable. Historically, rooftop solar demand was highly volatile as activity was heavily influenced by government programs. Rooftop solar is now a cost-effective technology with high demand from consumers. The forecast of Green Energy Markets which underpins this projection assumes gradually declining demand, falling slowly from just under 2 GW per annum through much of the 2020s to closer to 1 GW per annum by 2036.[18] This decline is compensated by an increase in labour demand in domestic batteries associated with PV systems.
- As Australia's energy mix pivots to renewables, demand in the domestic coal and gas sector (including fuel supply for electricity production) is projected to decline from around 11,000 throughout the 2020s and more rapidly in the 2030s. As there is expected to be less project activity relative to other energy sub-sectors, most of these jobs are in operation and maintenance of power stations with a smaller level of demand in mining and gas supply. It is important to note that the assumptions within the 2020 ISP on which this report is based predate the Australian Government's gas-fired recovery policy, which will affect the projections of resource demands within the coal and gas energy sub-sector.[19]
- There are several thousand workers demanded in battery storage construction, operation and maintenance. These numbers are indicative only as the data on demand intensity was collected in 2019 when it was an emergent sector. Although there is a decline factor applied to account for increased scale and productivity, it may be conservative.
- The growth in battery storage is also sensitive to assumptions about the costs relative to pumped hydro storage, which are competing for market share as sources of storage to complement intermittent renewable energy.
- Transmission construction is a smaller source of labour demand but there are also some significant fluctuations with the workforce forecast to scale up rapidly to over 2,000 in the early 2020s (Figure 54).

Figure 5: Forecast transmission construction labour demand by state, Step Plus REZs (2021–2036)

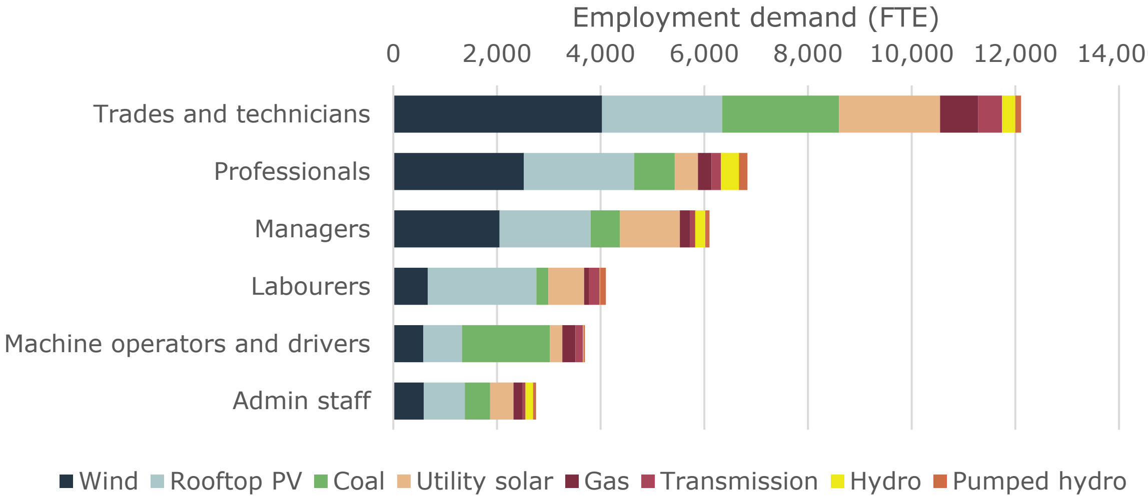


Demand growth occurs across occupational groups

There is a spread of demand between occupational groups across the energy sector (Figure 65) with:

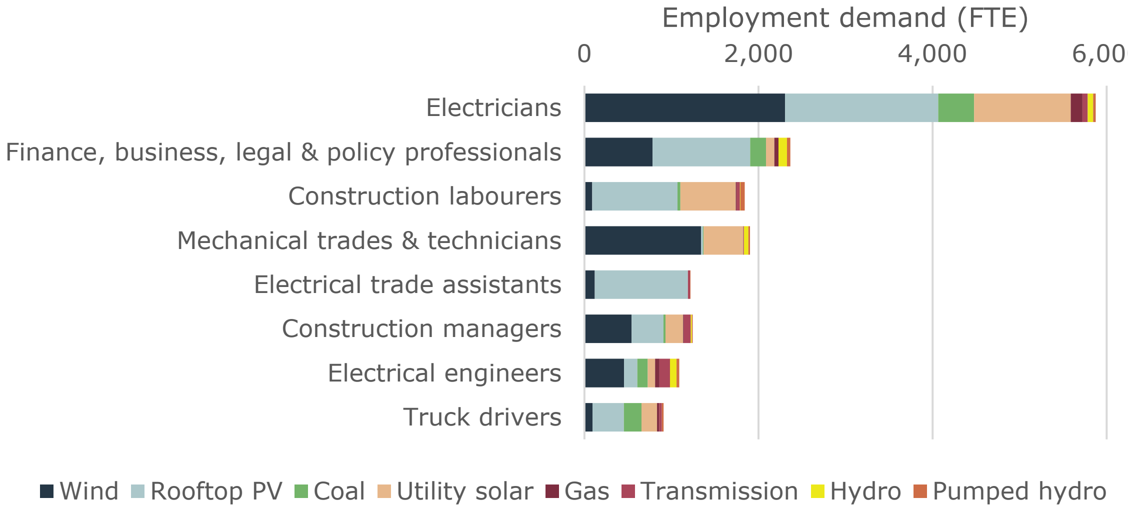
- The largest grouping of trades and technicians average around 12,000 per annum (around one-third of total demand).
- Professionals (an average of over 6,000 per annum) and managers (over 5,000 per annum), together comprise just over one-third of total demand.
- Machine operators (4,000 per annum) and labourers (3,500 per annum) which together account for just over one-quarter of total demand.
- Machine operators are the only group which experiences decline over the forecast period (40%) reflecting the higher volume of current demand in coal and gas (e.g. drillers).
- Just under 3,000 administrative staff are demanded on average.

Figure 6: Forecast average labour demand, grouped occupations (2021-2036)



The occupations in the energy sector projected to have the highest growth include electricians, construction managers, finance and business professionals, electrical engineers (including grid engineers), mechanical trades and truck drivers (Figure 7).

Figure 7: Forecast average labour demand, key occupations (2021–2036)



Industry assessments of skill shortages

Through surveys of recruitment difficulties with generation and transmission companies and an industry workshop, the major jobs at risk of shortages are identified below (Table 1).

Table 1: Recruitment difficulty and skill shortage assessments, selected occupations

Occupation	Solar and wind survey (2019)	Transmission survey (2020)	Industry trends and observations
Construction managers	High	High	High competition has been observed across infrastructure sectors for construction managers.
Electrical and grid engineers	High	High	One wind power company estimated there were less than 150 grid engineers in Australia with the full suite of skills required.
Civil engineers	High	Medium	National skill shortage status changes from year to year illustrating fluctuations in supply-demand balance.
Telco engineers	High	Medium	Listed on the National Skills Needs List with eligibility for the Rural and Regional Skills Shortage List.
Electricians	Medium	Low	Listed on the National Skills Needs List with eligibility for the Rural and Regional Skills Shortage List.
Mechanical technicians	Medium	Low	Industry reports wind blade technicians are recruited internationally (an apprenticeship is being established in Victoria).
Transmission lineworkers	n/a	High	All survey respondents noted these were in shortage in Australia and a heavy reliance on international recruitment.
Riggers	Low	Medium	Transmission EPCs were recruiting riggers internationally.
Crane operators	Medium	Low	Not all wind generation developers experienced shortages, but some said high crane operator shortages had delayed projects.

Note: The classification of jobs is based on the responses to surveys conducted by Institute for Sustainable Futures.[20]

It is not always the occupations with the largest demand volumes (e.g. electricians) that can create constraints. High-crane operators were not a widespread shortage for wind farms during the boom conditions of 2018-2019 but where they did occur they created project delays. Industry concerns in relation to shortages were especially acute in relation to transmission lineworkers and electrical specialists for substations due to a combination of factors:

- a rapid scale-up in construction projects and a strong reliance on international and inter-state recruitment.
- Significant lead-times for retraining lineworkers from other sources (e.g. electricity distribution workers, electricians) or new entrants.
- Limited training providers and training packages, many of which have been identified as requiring updates.

- Disincentives to on-the-job training (e.g. project length is shorter than apprenticeship length).
- A fragmented approach to skill development between industry and public agencies without an overriding plan.

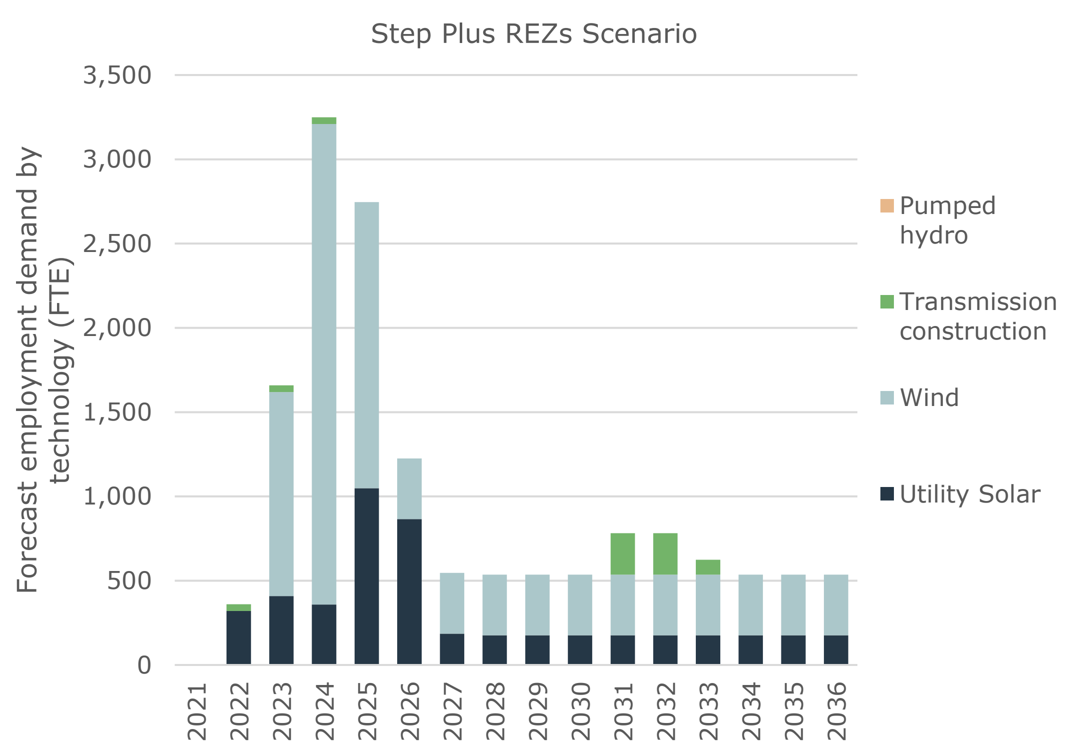
Stakeholders identified a number of key factors shaping skill development in the generation sector including:

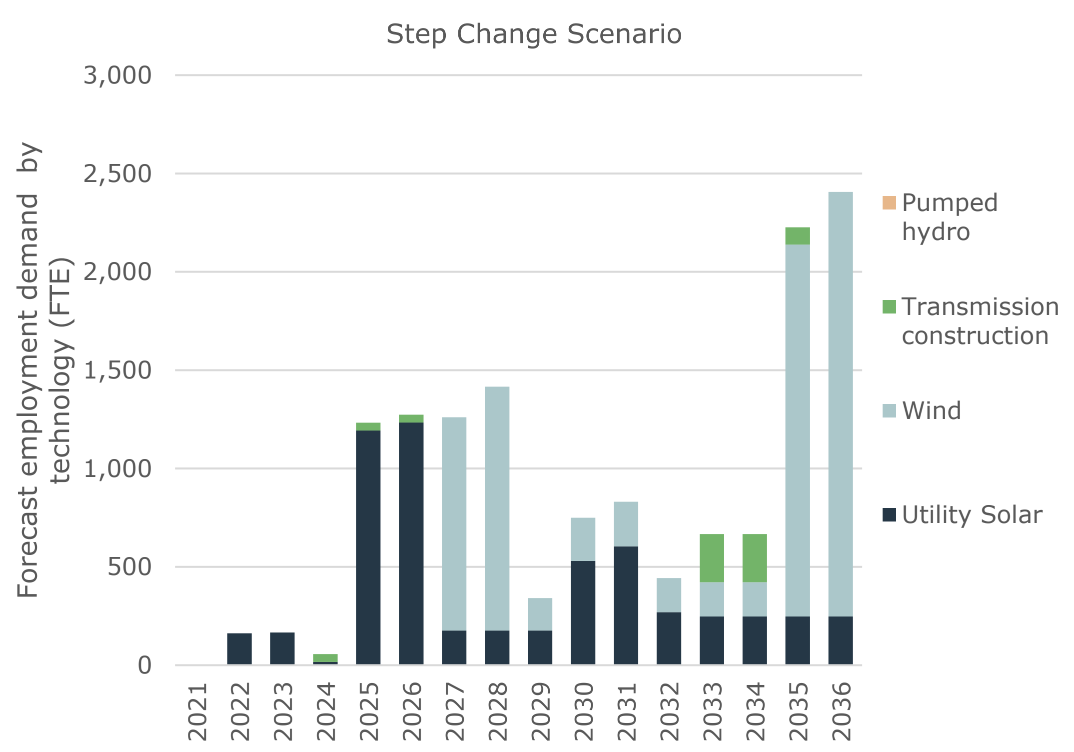
- A decline in the role of public sector training of apprenticeships without a reciprocal increase from the private sector.
- Disincentives leading to insufficient training investment at firm level such as short project lead times, policy and labour demand uncertainty, projects of shorter duration than the length of apprenticeships, and the risks of not realising the value of training investment and high levels of cost competition.
- Labour retention challenges such as competition from other sectors that pay higher wages (e.g. mining) and short-term construction project employment without career paths leads to workers pursuing alternative options.
- Issues with training system capacity for key occupations (e.g. electricians, lineworkers, turbine technicians) – some of which are being currently addressed, though it was observed that the investment in training system capacity has been low.

Case-Study: Central-West Orana Renewable Energy Zone

The Central-West Orana Renewable Energy Zone (CWO REZ) illustrates both the challenges and opportunities for local employment. The CWO REZ will be the first REZ to be rolled out under the NSW Government's Electricity Infrastructure Roadmap. Consequently, as seen in Figure 87, whereas labour demand fluctuates from 500 to almost 1,500 in the next few years under the Step Change scenario, demand for labour scales up very rapidly to annual labour demand of over 2,000 with a peak close to 3,000 under the State REZ scenario.

Figure 8: Forecast transmission construction and renewable energy labour demand, Central-West Orana REZ





Note: The transmission construction labour demand includes only the Central-West transmission project.

The challenge for creating local jobs is that the labour market in the CWO REZ is relatively tight (the unemployment rate in Orana and Central-West regions are 1.8% and 4.2% respectively), the workforce is ageing (around half are over 55) and there could be significant competition for trades and technicians, machine operators and labourers with other industries like civil construction and mining.

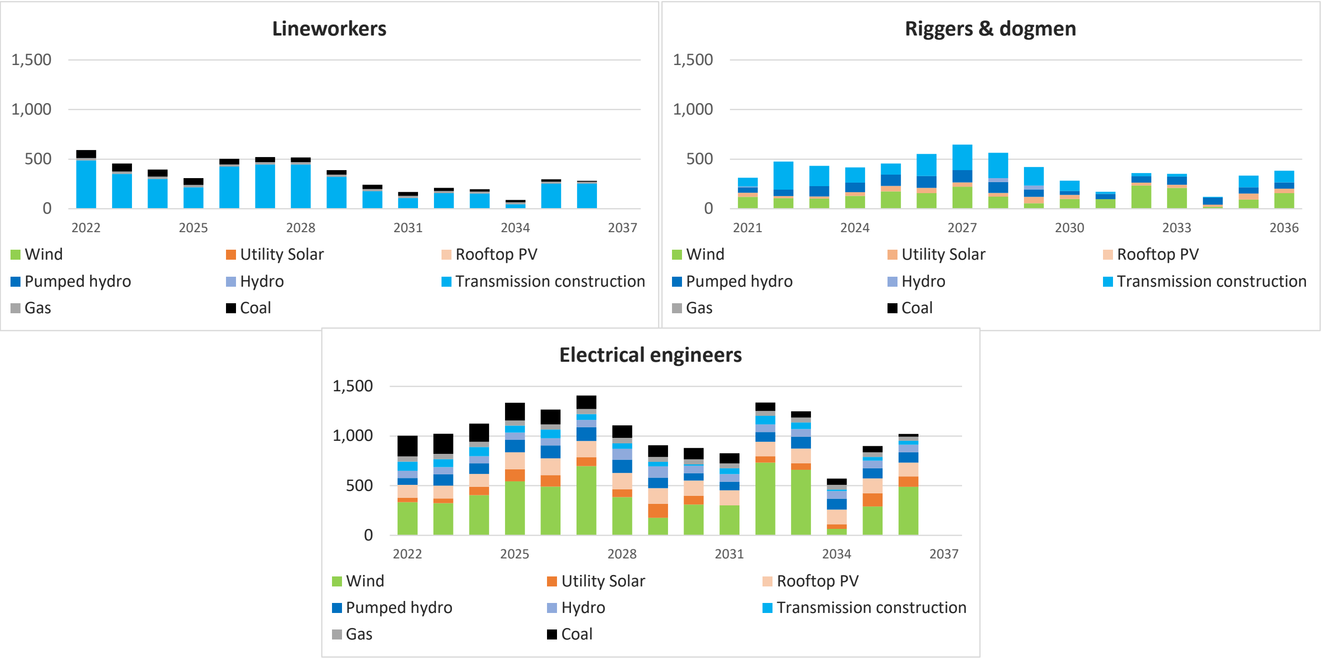
Specialist skill shortages and constraints

The build-out of renewable energy generation, storage and transmission under the Integrated System Plan and the REZs represent a major scale-up for the industry. For example, very few major transmission lines have been built in recent decades. As one transmission industry participant noted, "$100 million used to be a large contract, now a large contract would be $1 billion." The rapid growth and peakiness of the labour demand profile for both generation and transmission construction creates a higher risk of skill shortages. Specific issues, and industry feedback in relation to constraints are highlighted below in relation to the following three categories:

- Grid Engineers, Transmission Lineworkers and Riggers
- Electricians and Mechanical Technicians
- Construction and Operation Managers

Grid Engineers, Transmission Lineworkers and Riggers

Figure 9: Projected labour demand for key specialist roles



Extensive industry engagement for this project highlighted extreme concern about skill shortages as the segment scales up. As one transmission network survey respondent noted:

> *"The bit that really worries me is future demand for the same type of resources - all of these major projects that are in the final throes of approval. If they hit the ground at once there will be a shortage in the transmission industry. We don't have enough substation specialists, commissioning specialists or lineworkers across Australia. There are going to be huge substation [construction, something] that we haven't seen for quite a long time. It's going to be tricky."*

Although the labour demand volumes for specialist roles are not especially high, shortages can become a constraint on project progress.

The risks of skill shortages are high for transmission jobs due to the following factors:

1. Transmission roles involve specialised skills with a long lead-time

Transmission roles involve specialised skills with a long lead-time to train new workers: training a Certificate 3 lineworker usually takes 4-years but some EPCs said in practice workers require much longer periods of on-the-job training. A transmission EPC survey respondent noted:

> *"There is a lack of technical trades in Australia – assembly and erection riggers, transmission line builders. We look to train where we can, and [source from the] overseas market otherwise. You can't train them in 3, 6 12 months - it's a long trade because the risks are significant. For example in Canada it's a minimum of 4 years on-the-job training. You can't just train workers in two years – you really need 10-15 years as it's a high risk activity and you need to train people well and*

> *find the right people."*

2. Available pathways to transition require a lead-time

There are pathways to develop the workforce from adjacent industries but these also require a lead-time:

- Electrical distribution workers: around 12 – 18 months (a distribution worker may hold as many as 14 out of 17 units for a Certificate 3 transmission lineworker qualification).
- Electricians: electricians take longer to train as lineworkers as they generally hold few of the 17 core units for a Certificate 3 lineworker qualification.
- Electrical commissioning: this is a specialised role but electricians can also be retrained. An engineering firm survey respondent noted that 'it would take 2-3 years to train someone for electrical commissioning, it's basically a trade. TNSPs (transmission network service providers) could do it in 12-18 months'. The reason nominated for the shorter period for TNSPs is the greater diversity of projects and opportunities to train.
- Construction labourers (e.g. riggers, crane operators): the ability to use construction labourers from other sectors varies depending on the project characteristics. For example, whereas civil construction workforce on foundations have shared skills across sectors and can therefore transfer quite quickly, riggers require specialist knowledge and therefore require 1 to 3 years to upskill depending on experience level.

For substations, on-the-job training and upskilling can be an option. As a transmission network survey respondent noted:

> "*In substations, we have our guys to isolate the network and have electricians to do the substations and non-trade labour to install cables … electricians with the trade qual, we train them in our systems to be able to bring them up to speed and authorised for the higher levels to isolate the network. It's a 6-month process. If we bring them in as a trade, there's no qual to become a substation specialist. Once they've trained and then show [their] competency, they can get a higher level of authorisation."*

3. Limited training system capacity

Current training packages were identified as not being fit-for-purpose with very few registered training organisations in Australia able to deliver them. One EPC noted this had been a constraint on plans to increase training. There are also variations in eligibility for training funding between states. Transgrid is working with EPCs to develop training capacity. Another EPC summed it up:

> *"The training market is neither mature nor organised. Can it mature itself quick enough to deliver workers? There are TAFE system issues and only a couple of city-based RTOs."*

4. Competition for workers, and retirements

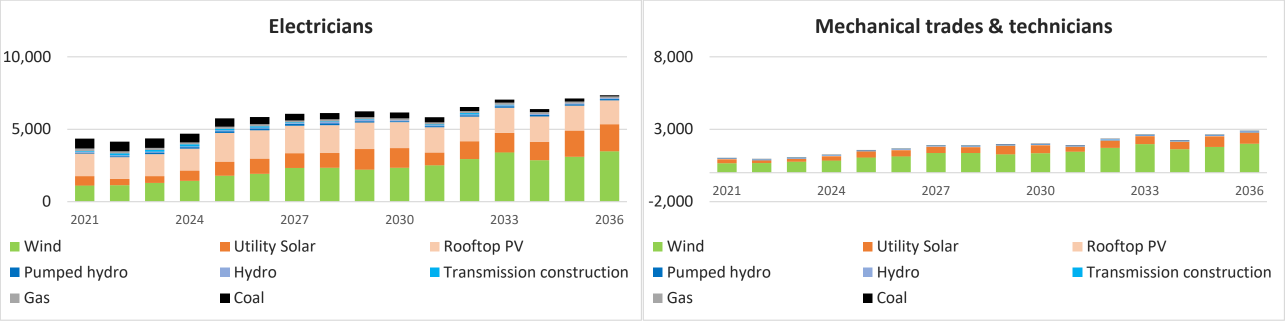
There is competition from other sectors for apprentices and lineworkers, and the lineworkers workforce is ageing. Another EPC observed rail projects can be more attractive than transmission projects:

> *"There are adjacent workforces like rail workers so if someone has a choice between a FIFO or live in Sydney or Brisbane and work on overhead rail then what would you choose - rather jumping on a plane and living in a camp to do a 12-hour day? We lose a lot of workers to the mega-projects on the east coast. The workforce is ageing, it's heavy work, there are not many 60 year olds still working."*

There were also reports of challenges in developing site supervisors and a training gap in developing them. The primary concern was the management and communication skills to lead teams and pass on knowledge and skills. Consequently, there has been a significant reliance on international recruitment. If there are extended border closures, this will increase the requirement for local workforce development. Awareness of the shortages and constraints is high in regions where projects were currently under development such as NSW.

Electricians and Mechanical Technicians

Figure 10: Electricians & Mechanical Technicians, Transmission Construction & Electricity Generation, 2021-36



As shown in Figure 10 electricians are the largest single occupation across renewable energy generation and transmission, led by wind farms, rooftop solar and solar farms. During the renewable energy survey, concerns were shared about the alignment between the training system and industry needs. The Tasmanian Energy Workforce Development Plan has also noted: [21]

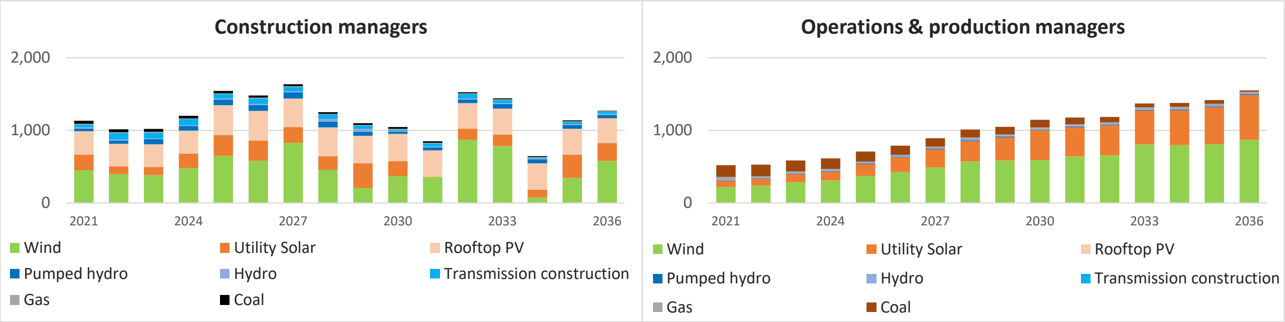
> *"Concerns remain with the current electrical qualifications: the qualification is considered too long, with a high level of time and commitment required for completion. Additionally, it is reported that there is protectionism around the qualification and a requisite dated training model. The qualification is seen as inflexible and does not meet local industry needs. Training needs to be customisable: there is potential to look at basic electrical skills, with potential cross-sector application, plus on-the-job training as a model to address real needs."*

Stakeholders noted opportunities to ease constraints and build better career paths by enabling transfer of electricians between sectors. Electrical commissioning specialists can work across transmission and generation. Cross-sector movement has also been identified as a key priority for the Tasmanian Energy Workforce Development Plan: [22]

> *"The confluence of a range of pipeline projects will likely create a bottleneck for key occupations such as electricians. TasNetworks is seeking cross sector collaboration, with consideration for working together on pooling resources and developing specialist skills. An opportunity exists to look at core skills in renewable energy that cut across solar, wind and hydro to address the entire industry."*

As the number of renewable energy projects increases, there will also be significant increases in electrical and mechanical technicians working in wind farms in particular. Demand for mechanical technicians consequently rises steadily. Blade technicians have been an identified shortage but Federation TAFE is establishing the first apprenticeship through partnership with a group of wind industry companies.[23]

Construction and Operations Managers



Construction managers

Operations & production managers

Figure 11 Construction and Operations Managers, Transmission Construction & Electricity Generation, 2021-36

Figure 11 shows that the demand for construction and project managers is highest amongst managers but demand for operations managers gradually increases over time and overtakes construction managers in the mid-2030s. Experienced, quality construction managers have been identified as a shortage or an occupation that can be difficult to recruit for in the surveys. Reflecting the requirement for project management expertise across sectors there is a greater diffusion across technologies than most occupations for construction managers. National skill shortage reports have periodically highlighted shortages in construction managers, noting it is hard to track supply and demand because of the diffuse sectors and pathways for the development of skilled construction managers.

No skill shortages have been identified for operations managers, but they are a group that will grow over time and there may be an opportunity for transitioning operations managers from other sectors with retraining. The sectoral composition of operations managers changes significantly over time. Currently, the mix is split mostly between coal and wind energy, but over time the majority of demand is from wind farms with secondary demand from solar farms and residual demand from coal power stations.

Considering a skill ecosystem approach for the REZs

Renewable energy, transmission and training stakeholders agreed that there is a need for greater coordination and collaboration between industry, government and training authorities to improve local skill formation and employment:

> *"The industry does not have a collective vision… there is a need for an organised, long-term and unified approach with strategies and actions that are supported by industry… a collaborative system to education, training with industry playing a part in guiding course development and providing spaces for workplace experience is necessary to support workforce development."* [24]
>
> *"We want to have that partnership at regional level to be able to attract staff … there is incredible scope for the long-term opportunity to develop workforce – but it needs a holistic view, collaborative approach to industry and training workforce. We have a highly fragmented workforce in Australia. An additional layer of consideration is project work within a fragmented industry – people try to stitch together careers or otherwise we seek the international workforce."* [25]

A range of opportunities were highlighted in an industry workshop (featuring renewable energy and transmission stakeholders, and training providers) for improving local and regional labour supply and job quality including:

- Improved project sequencing, smoothing the development pipeline and visibility of worker skills (e.g. digital passports) to facilitate redeployment between projects.
- Worker transition from declining industries through skill mapping, micro-credentials and coordinated programs.
- Increased use of apprenticeships models such as Group Training which reduce the risks and costs for host employers.
- Creating better pathways into the industry from schools and under-represented groups in the labour force (e.g. local indigenous community).
- Collaboration between the states to efficiently develop training capacity to cover key skill requirements across generation and transmission to accelerate development and reduce overall costs.
- Investing in core skills and creating pathways between clusters of energy, construction and manufacturing businesses to create career paths, labour sharing and retention.

As the International Labour Organisation has noted:

> *"Training targeted on the renewable energy sector should invest in skills that are portable. Even with efforts taken to adopt a smooth transition approach, employment in development, construction and installation may be volatile. In occupations linked to operations and maintenance, there may also be periods when scope to employ newly trained workers will be limited. Education and training courses should therefore be built around a core qualification that will be useful in a broader range of sectors."* [26]

The REZs create a platform for a more collaborative approach – what has elsewhere been described as a skill ecosystem approach which typically includes the following key elements:[27]

- Collaboration between the training sector and industry to improve workforce sustainability and align training with industry needs.

- An approach to skill development that includes not just increasing training supply but also workforce development to encompass the acquisition, use and renewal of skills on-site and in the workplace.
- A holistic perspective that includes other labour market and workplace dimensions that impact on labour supply and skill development, such as influences on labour retention (e.g. career paths, job quality), ensuring other workplace or labour market features that means the sector cannot develop and retain labour are overcome.
- Designing interventions across an industry and/or region – not just at an individual firm level.
- Building the capacity of industry and training organisations to more systematically plan and manage skill development to avoid skill shortages.

Stakeholders agree that there is no one-size-fits-all solution to the skills and labour development needs of the renewable energy and transmission sector. There are common elements and scope for greater collaboration across the industry and states, but the mix will vary depending on the regional and industry context. Whatever the exact solutions, greater collaboration is essential, and the REZs were seen as creating a platform for a skill ecosystem approach.

It is important to note this estimate of energy-sector jobs does not include all Australian energy sector labour demand (e.g. end-of-life, recycling and circular economy for renewable energy technologies) and there are significant other demand drivers.

Electricity demand and growth opportunities for large scale renewable energy could be several times larger under scenarios currently being developed by electricity market forecasters (including AEMO for the 2022 ISP) in which there is large-scale electrification (industry, homes, transport) and/or the development of renewable hydrogen for heavy industry, transport fuels and export. In the National Hydrogen Strategy, electricity requirements for renewable hydrogen are projected to range from 65 terawatt hours to 912 terawatt hours, or around one-third to over four and a half times the current size of the NEM[28] [29]. If this occurs, the labour demand creation also be correspondingly higher, most likely during the 2030s and into the 2040s.

Case Study: Energising Tasmania Initiative

Energising *Tasmania* is a cross-sectoral, regional initiative which aims to develop the workforce within and across wind power, hydro, transmission, hydrogen, civil construction and advanced manufacturing. The goal is to build a workforce with nationally accredited qualifications that reflect the project pipeline of the next decade and build career paths for workers that can move across sectors with shared core skillsets. It could serve as a model for other states. [30]

As the Workforce Development Strategy (2020: 15) notes:

> ***"Opportunity exists to align the core skills around common work that will allow workers to move between sectors and projects. Exposure to various sectors would allow workers to develop a buildable knowledge and experience base, with skills development allowing workers to progress through novice roles to those requiring greater proficiency." (p. 40).***

Some of the core elements of the Energising Tasmania initiative include:

- **The establishment of a Tasmanian Energy and Infrastructure Workforce Advisory Committee with cross-sector representation to oversee implementation of the agreement: one of the key recommendations of the Workforce Development Plan is to consider establishing a collaboration mechanism;**
- **Testing the applicability of national training package pathways and otherwise using state accreditation to underpin the skills development of the workforce for portability;**
- **Under a 4-year, $16.1m agreement between the Tasmanian and Australian Governments, three funds have been established to subsidise training through Registered Training Organisations, training system capacity development and workforce development**
- **Increasing the supply of new entrants through schools programs** and **apprenticeships**.
- **Multi-level education strategies and career paths to improve local employment outcomes and 'future-proof' the industry.**

3.MATERIAL DEMANDS

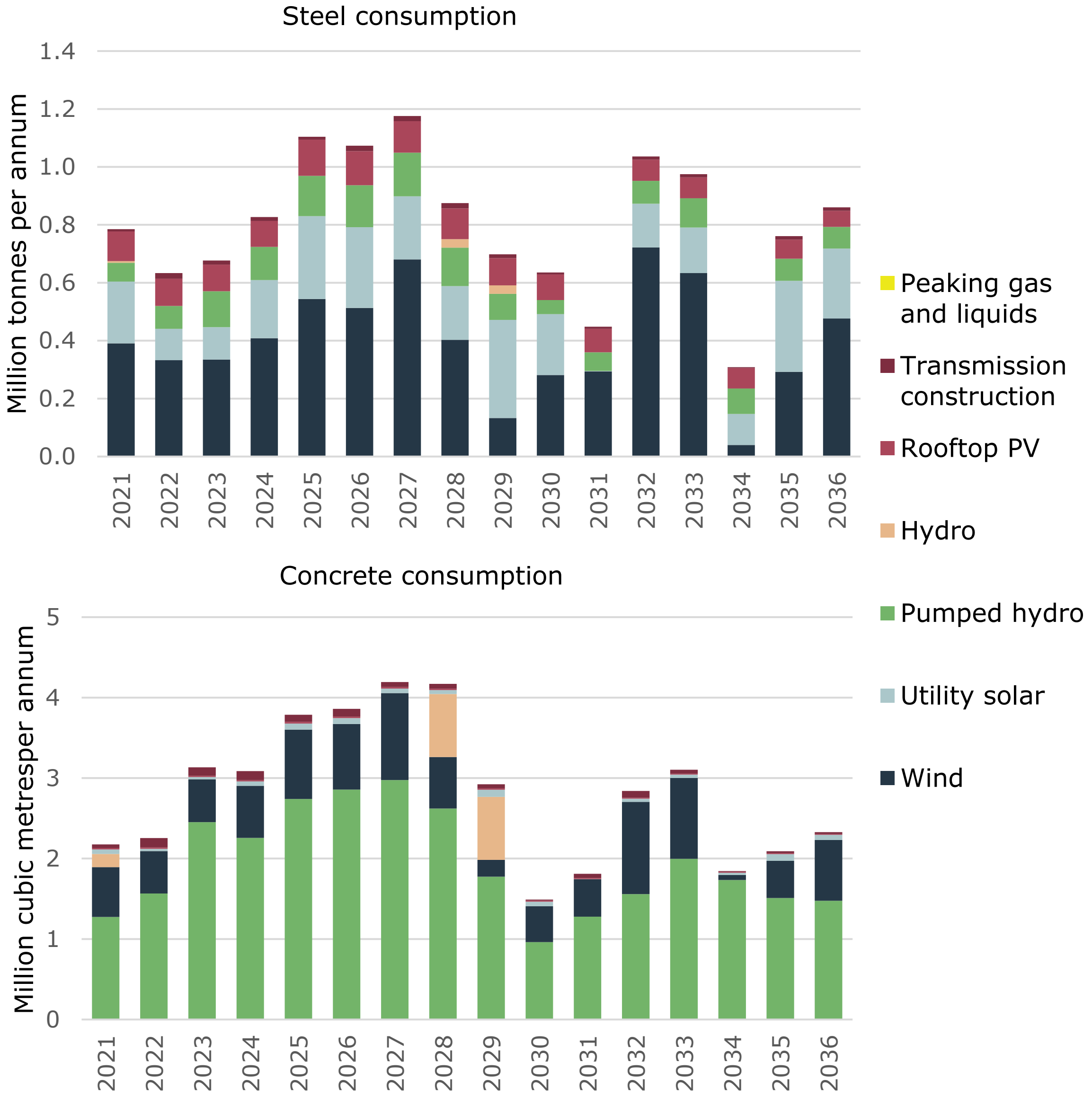
Renewable energy will significantly increase consumption of steel and concrete

Australia produces 29 million m^3 of concrete per year 5.6 million tonnes of crude steel per year (in 2018) (see Figure 128).[31] [32] The demand for steel peaks at just over 1 million tonnes, reaching about a fifth of the annual production in Australia.

For concrete, the main source of demand in the energy sector in the next 15 years is for pumped hydro (1 million – 3 million m^3 annually). Wind turbines also use significant volumes of concrete for their foundations (500,000 – 1 million m^3 annually). Smaller quantities are used for utility-scale solar.

For steel, the major source of demand is wind turbines (ranging from around 300,000 – 700,000 tonnes), but there is a greater diversity of demand across technologies. Most of the steel demand for wind farms is for towers with a small proportion for the concrete foundations. There are two wind tower manufacturing facilities in Australia, but most towers are imported (up to around 15-20% of turbine towers are made locally) due to lower cost. Solar farms use significant amounts of structural steel (e.g. mounting structures), generally 150,000 – 300,000 tonnes, which was manufactured locally in the early stages of the industry but is now imported. Pumped hydro (100,000 – 150,000 tonnes) and commercial and industrial rooftop solar (50,000 – 125,000 tonnes) also generate steel demand. Transmission towers are a smaller demand source (15,000 – 20,000 tonnes) which has been imported but a transmission fabrication factory is being established in SA.

Figure 12: Forecast steel and concrete consumption by technology (NEM, Step Plus REZs)

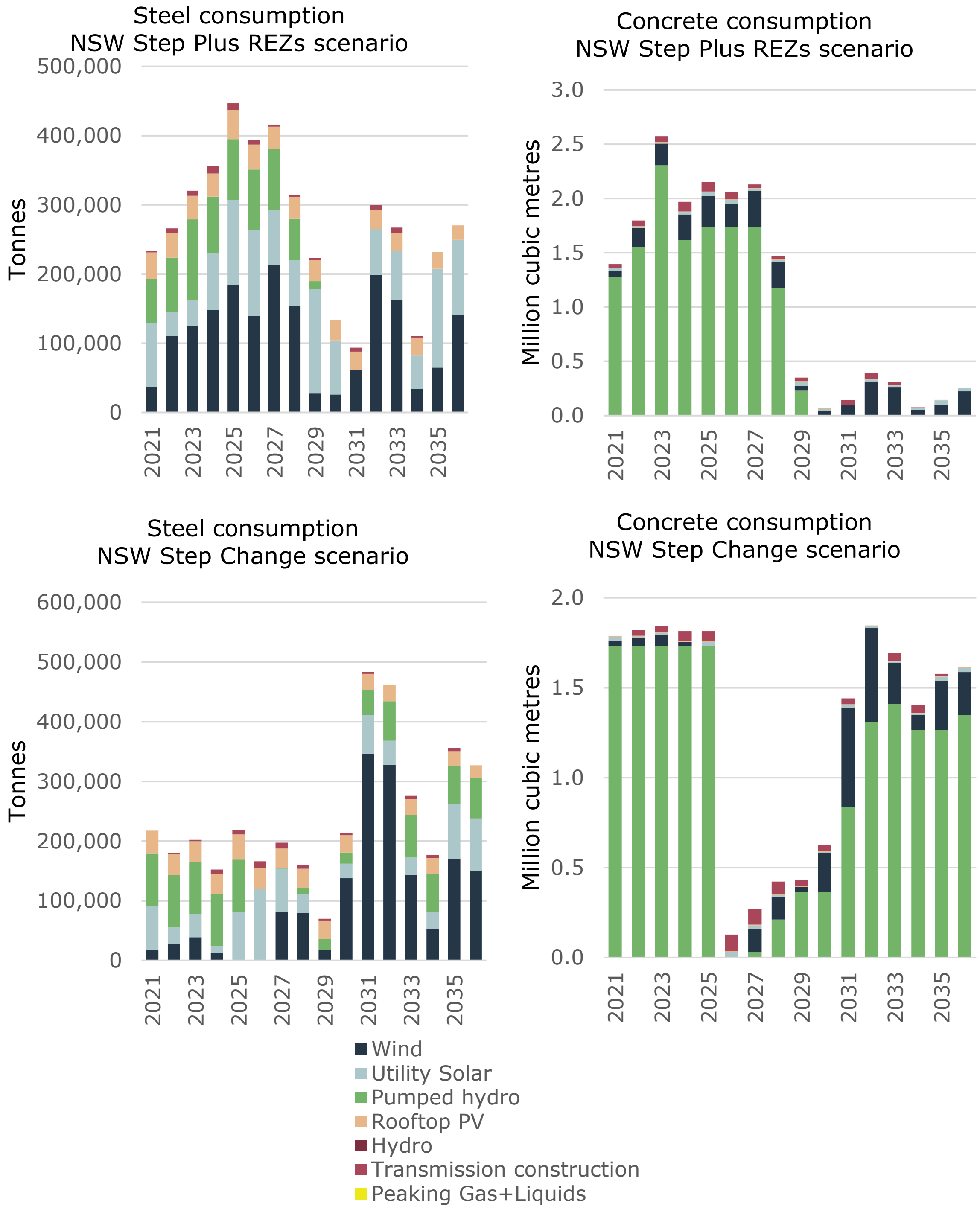


Steel consumption

Concrete consumption

Focussing on NSW to illustrate the impact of REZ developments at a state level, consumption of both steel and concrete is brought forward with major peaks in the mid-2020s under the Step Plus REZs scenario (see Figure 139). Steel consumption is double at 450,000 tonnes by 2025. The increase in concrete requirements is less pronounced but rises from a flat profile of 1.8 million m^3 to 2.5 million m^3. The major drop-off in concrete consumption in the mid-2020s reflects the forecast end of Snowy 2.0 construction.

Figure 13: REZ scenarios with forecast material demands for NSW



4.CONCLUSIONS

Australia's energy system is going to be re-shaped throughout the next 10–15 years. The transition of Australia's energy system will place considerable demand on key skills, labour, and material supplies.

A timely and efficient supply of labour and materials could significantly influence the achievement of the optimal development path in AEMO's Integrated System Plan, its costs and the regional economic and social outcomes. The key conclusions drawn from this study are:

There is high uncertainty and volatility with the level of labour demand

The direction of change is clear but there are many different transition pathways. For example, the clean energy transition could be faster or slower, there could be a higher or lower share of distributed or large-scale renewable energy. The labour and material requirements for energy generation and transmission will depend in part on which pathway is taken. Most of the uncertainties point to a larger energy market and therefore greater scaling up of the workforce and material supply.

The development of REZs will require a rapid scaling-up of the workforce which could create shortages

Energy sector labour demand fluctuates between 80,000 – 95,000 over the next 10 years. For particular sectors, the scale-up is more rapid. Large-scale renewable energy and transmission construction in particular will need to scale-up quickly for state REZ targets.

At a regional level, the level of labour demand growth creates both opportunities and challenges. The largest source of labour demand is amongst trades and technicians, and together with machine operators and labourers account for around 60% of labour based on the survey data. The industry workshop highlighted other barriers to local employment (including project timeframes and durations, competition for labour and training system capacity) but also a range of opportunities through coordination of skills training and labour market adjustment programs.

The surveys of renewable energy generation and transmission have highlighted some occupations that are at risk of shortages:

- Construction managers
- Engineers – all types but especially power system and grid engineers
- Electricians – the largest occupation with growth required in specialised skills for substations and transmission lines, large-scale renewable energy, solar PV, project commissioning for both transmission and generation
- Mechanical technicians
- Transmission lineworkers and riggers
- Certain types of machine operators (e.g. high crane operators)

It is not always the occupations with the largest demand that can create constraints. High-crane operators were not a widespread shortage for wind farms during the boom conditions of 2018-2019 but where they did occur they created project delays. A similar situation could occur with transmission lineworkers and electrical specialists for substations.

Both electricity generation and transmission have developed a significant reliance on international skilled migration due to insufficient training and local shortages which reduces the level of local employment and increases the supply risks in the context of Covid-19 border closures or restricted movement.

Renewable energy and transmission construction will add significantly to steel and concrete consumption

Australia produces 29 million m^3 of concrete per year and 5.3 million tonnes of crude steel per year (in 2018).[33] [34] Click or tap here to enter text.Under the two energy transition scenarios, the maximum projected requirements for energy generation and transmission concrete are just above 4 million m^3 and the demand for steel peaks just over 1 million tonnes, reaching about a fifth of the Australian yearly production in this year and in the early 2030s. The Step plus REZ development scenario illustrates there could be a significant increase for steel and concrete consumption in particular arising from State REZ programs. The key sources of increased consumption for steel are wind farms (predominantly wind towers), solar farms, pumped hydro, rooftop solar and transmission towers. Most of the steel is currently imported with some local wind tower manufacturing and new capacity to manufacture transmission towers being established. The increase in concrete consumption arises primarily from pumped hydro storage and secondarily from wind farms.

APPENDIX A - ISP-BASED DEMAND SIDE ANALYSIS OF THE ENERGY SECTOR

REZ Programs and targets

State	RE Target	Renewable Energy Zones	Other key programs
NSW	n/a	The *Electricity Infrastructure Investment Act 2020* has declared five REZs with a target of 12 GW (generation) and 2 GW (storage).[35] - Hunter Valley-Central Coast - Illawarra - Central-West Orana - New England - South West NSW	Under the Act, the NSW Government has established a Consumer Trustee, Electricity Infrastructure Jobs Advocate and NSW Renewable Energy Sector Board to maximise local supply chain and employment.[36]
Victoria	40% by 2025 50% by 2030	Six REZs to facilitate 10 GW (generation) - Central North - Gippsland - Murray River - Ovens Murray - South Victoria - Western Victoria	A $540 million program to support the development of the six REZs.[37] An auction for 600MW of renewable energy for Government consumption.
Queensland	50% by 2030	Three Renewable Energy Corridors that include eight REZs nominated by the ISP: - Southern Queensland (Darling Downs) - Central Queensland (Fitzroy, Wide Bay) - Northern Queensland (Isaac, Barcaldine, North Queensland, North Queensland Clean Energy Hub, Far North Queensland)	$145 million program to support the development of the Renewable Energy Corridors.

Transmission Labour demand – Methodology

Overview

There is a significant gap in available data on the workforce requirements for transmission line construction in Australia. While the ABS publishes occupational data every five years, classified under the 'Electricity Transmission' sector, this is unlikely to include the construction workforce, as most, if not all of these workers will be classified under construction. A detailed breakdown of both the occupational volume and composition in transmission construction is needed to understand the workforce requirements associated with new transmission construction under the AEMO Integrated System Plan (ISP) for the NEM.

Consequently, Infrastructure Australia commissioned the Institute for Sustainable Futures, University of Technology Sydney to undertake a survey of labour in transmission infrastructure in Australia. This follows on from a survey on renewable energy infrastructure undertaken for the Clean Energy Council in 2020.[38]

Labour demand in transmission infrastructure is calculated using labour demand factors, with the factors derived for this project. Industry surveys were used to develop the labour demand factors for line projects (in FTE jobs/km) and non-line projects (in FTE jobs/$ million) to cover transmission construction projects in Australia, which are then compared with data from literature.

Three steps were used to estimate the labour demand volume and occupational composition for the construction of new transmission infrastructure assets:

1. Literature review: research was undertaken to gain background information on labour demand in transmission construction from international studies and projects, gather any available data, and identify whether there were labour demand factors for the development and construction phases of line and non-line transmission projects. A combination of academic literature, industry reports, environmental reports and project specific fact sheets were used to gather project specific information and derive labour demand indicators where possible. However, data is scarce, results are highly variable, there are considerable data gaps, calculation methods use industry averages, and generally combine a number of different asset classes and project phases into the project labour demand total.
2. Derivation of labour demand factors using industry surveys:
    a. Develop a classification index for line and non-line assets and an occupational concordance for new construction projects in the electricity transmission sector, to inform the design of an industry stakeholder survey.
    b. An industry survey was undertaken with Transmission Network Service Providers (TNSPs) and EPCs in Australia to derive labour demand volumes and composition according to the asset classification index and occupational breakdown.
    c. Analysis of survey data and calculation of labour demand factors, verified with international literature.
3. Collate scenarios for the transmission infrastructure pipeline from the AEMO ISP for the NEM, supplemented by publicly available information on project timing.

4. Calculate labour demand projections and occupational composition using an excel model built during previous projects.

Calculating the labour demand

As shown in Figure 14, the calculation is simple. However, the accuracy of the final labour demand calculations are dependant on the accuracy of the data used to derive the labour demand factor.

Figure 14: Total labour demand calculation: methodological overview

Transmission construction labour demand for year	=	KM installed per year (line projects) $m value per year (non-line projects)	x	Construction labour demand factor	/	Project construction time
Generation construction labour demand for year	=	MW installed per year (generation)	x	Construction labour demand factor for that year	/	Average construction time
Operation and Maintenance jobs	=	Cumulative capacity	x	Operation and maintenance labour demand factor for that year		
Fuel supply jobs	=	GWh generated per year	x	Fuel labour demand factor for that year		
Labour demand factor for year	=	Base year labour demand factor	x	$(1 - \text{average technology decline factor})^{\text{years after base year}}$		

Previous research

Institute for Sustainable Futures collaborated with the Clean Energy Council on stage one of the first major national survey of renewable energy labour demand in Australia.[39] Stage one focused on labour demand in the construction and operation of new renewable energy generation and storage technologies such as onshore wind power, solar, hydro and batteries. This project extends this research to employment in transmission connection assets required to integrate new renewable energy generators into the NEM grid.

Transmission industry survey

An industry survey was used to collect data for the electricity transmission sector to derive labour demand factors, occupational composition and key skills shortages that might be experienced with the roll out of transmission infrastructure projects outlined in the ISP.

A total of nine surveys were conducted with TNSPs and their EPCs across the NEM member states. Respondents contributed data for line and non-line transmission projects at various stages of completion. The survey collected data on:

- **Transmission infrastructure characteristics**: line, non-line, voltage, line length, non-line cost, terrain, new or uprate (upgrading the capacity of an existing asset);
- **Project data**: project timeline, workforce numbers for each project stage (development, civil construction and electrical construction/commissioning) and occupational breakdown;
- **Skills shortages and recruitment risks**: level of difficulty recruiting for job types and the causes for recruitment issues;
- **Other skill information**: skills shortages, training issues, opportunities and perceived risks associated with skills shortages.

We were able to collect detailed labour demand data on 23 transmission projects across a range of line and non-line categories. Survey coverage is outlined in Table 2.

Table 2: Transmission survey coverage

Project type	No. of respondents	No. projects	Length (km)	Total value ($m)
Line projects (all)	6	9.8	2454	-
Line projects (double circuit)	2	4.8	1907	-
Line projects (single circuit)	4	5.0	547	-
Non-line projects (all)	7	6.1	-	$697m
Non-line projects (high voltage)	5	4.6	-	$635m
Non-line projects (medium voltage)	1	1.0	-	$61m

The survey collected data on the attributes of transmission projects, total labour demand volumes in FTE per construction phase, and labour demand numbers at a more detailed level according to the ANZSCO. Labour demand data was then grouped based on common transmission characteristics to derive labour demand factors in FTE per km for line assets and FTE per million $ for non-line assets. These characteristics are shown in Table 3.

Table 3 Transmission asset types

Transmission asset type	Definition and notes
Line	Includes transmission lines, towers and associated civil and electrical works
Non-line	Includes substations and other non-line transmission projects and associated civil and electrical works
Line project attributes	New / uprate, single / double circuit, new / existing transmission corridor, transmission tower height, tower type, number of towers, total line length in km
Non-line	Capital cost in million $
Voltage	High (500 kV / 330 kV / 275 kV), medium (220 kV / 132 kV) or low (under 220 kV /132 kV)
Terrain type	Forested, mountainous, flat, and/or wetland

Labour demand and occupational composition data was collected based on FTE jobs per project and combined with data on project years per phase to derive FTE labour demand indicators in job-years. These project phases are defined in Table 4.

Table 4 Project phases

Phase	Definition and notes
Development	Development of projects up until financial close
Construction (civil works)	Civil construction includes works required to establish the site and build transmission infrastructure. This includes: Site clearing, Constructing access roads and tracks, Constructing foundations, Installation of transmission towers and substation structures, Site cleanup.
Construction (electrical installation and commissioning)	This phase includes line stringing, electricial installation and final electrical commissioning of transmission assets.

Further information was gathered through the survey covering skills shortages, recruitment risks and training requirements.

Transmission labour demand indicators derived from survey data

We produced weighted data for the gross labour demand indicators for the lines/ non-line project by averaging the total labour demand years (FTE) per project and divided this by the average length of kilometres for line assets and $ million for non-line assets:

$$\text{Labour demand factor} = \frac{\text{average total labour demand for asset classification}}{\text{average length of line OR average \$ million}}$$

A summary of the labour demand factors derived from the survey data are given in Table 5. The number of circuits for lines appeared to give a genuine variation for labour demand per km, so this distinction was retained in the later calculations. No consistent variations in labour demand levels occurred as a result of voltage, new or uprated lines or terrain type. Non-line assets were extremely variable, and a consistent relationship was not found between different characteristics; this may be because there were insufficient numbers of projects in each category, and the projects themselves are extremely variable.

A number of assets were excluded from labour demand factor calculations due to a lack of data. Accordingly, labour demand indicators were derived for three classifications of transmission assets:

- double circuit lines (with length as indicator)
- single circuit lines (with length as indicator)
- all non-line projects grouped together (with value as indicator)

Table 5. Labour demand indicators derived from survey data

	Average line (all)	**Average line (double circuit)**	**Average line (single circuit)**	**Average non-line (all)**	**Average non-line, High voltage**	**Average non-line, Medium voltage**
Type	Line	Line	Line	Non-line	Non-line	Non-line
Line length (km)	227	330	110			
Non-line value $ million				M$ 96.4	M$ 109.4	M$ 60.5
Circuits	Any	Double	Single	-	-	-
Voltage	Any	Any	Any	Any	High	Medium
Average project years	2.9	4.4	1.4	2.7	2.8	2.5
Number in category	10.8	5.8	5.0	6.1	4.6	1.0
Average FTE	376	646	46	67	74	21
Job years/km	3.0	3.7	0.7	n/a	n/a	0.0
job years/m$				1.9	1.9	0.9
	0.3 – 13.7	0.4 – 13.7	0.3 – 2.5			
Range Job years/km				0.9 - 41	0.9 - 41	n/a

Transmission labour demand indicators from literature

Of the literature available, very few studies are published in recent years and most studies use Input Output (IO) analysis over survey methods to estimate labour demand volumes. The IO method calculates labour demand volumes based on dollars spent in a certain sector and uses industry averages to estimate labour demand – in contrast, survey methods gather data directly from industry participants or workers, and can be more representative of workforce numbers if data quality is high. The majority of literature sources identified in the review are focused on the US transmission sector. This is primarily due to the rapid energy transition, age of transmission infrastructure, scale of transmission projects in the pipeline, and concerns over grid reliability in the US – prompting increased research interest in recent years.

Two literature sources focus on other regions. One source focuses on 'Project Energy Connect' in Australia.[40] Another focused on 'Powerlinks Transmission Limited' in India.[41] Both of these sources use the IO method, combining multiple transmission asset types to derive labour demand estimates. The labour demand factor used for India is also significantly higher than other regions due to the higher number of workers used for construction projects in the region. For example, the 'Powerlinks Transmission Project' - a combination of 400 kV (high voltage) and 220 kV (medium voltage) double circuit transmission lines from Siliguri to Mandaula in India - combines multiple transmission line asset types to calculate total labour demand volume and the resulting labour demand factor is significantly higher than other studies due to the higher labour demand intensity in the region. Given the high level, aggregated nature of the IO method and the regional variations impacting the labour demand factors found in the literature, the labour demand factors from these studies are indicative only and best used as a sense check for the labour demand factors derived through our survey method.

A few industry reports provide better representations of labour demand requirements for transmission asset construction.[42] [43] [44] The method used breaks down construction projects into tasks and provide estimates of crew numbers for each task, the reports also provide a total timeline for the project. This method is a slightly more accurate measure of the workforce structure and volume required for these projects. However, line and non-line asset types are still combined into one category in these studies and detailed occupational information is not provided. These studies are therefore best used as test cases against which a more detailed Australian survey can be compared.

Additional studies from the EU and US have provided job numbers at a national/regional scale for transmission line construction and Operation and Maintenance (O&M).[45] [46] However, for the EU study, industries are not sufficiently disaggregated, and for both studies, there is a lack of detailed information on the length or size of transmission infrastructure under construction during the study period.

The labour demand factors derived from survey data for transmission projects were compared with international literature and found to be within the same range. As shown in Table 6, factors from international studies fell between 0.8 job-years/km and 14.6 job-years/km with an outlier study reporting 36.7 job-years/km, possibly because the project was in India which may have generally higher labour demand intensity for construction. Job-years/$m were available for a few studies, these fell between 0.8 job-years/$m and 20.2 job-years/$m, showing the high variability of an labour demand in these assets.

Table 6 Transmission labour demand indicators from international and Australian literature

Project name	Study date	Region	Voltage	Line/non-line	Single or double circuit	Job-years/$m	Total Job-years/km	Method	Reference
Energy Gateway South	2016	US	High	Line	Single	n/a	0.8	Industry Estimate	(PacifiCorp, 2016)
Southline	2010	US	High	Mix	Double	n/a	0.9	Industry Estimate	(Southline Transmission LLC, 2010b, 2010a)
Southline	2010	US	Medium	Mix	Double	n/a	1.4	Industry Estimate	Southline Transmission LLC, 2010b, 2010a)
Project Energy Connect	2019	Aus	High	Mix	Mix	n/a	2.3	Hybrid Input/Output (Tasman Global Model)	(ACIL Allen Consulting, 2019)
Grain Belt Express Clean Line	2013	US	High	Mix	-	n/a	10.6	Input/Output (IMPLAN Model)	(Loomis et al., 2013)[47]
Wyoming Study	2011	US	High	Line	Mix	n/a	14.6	Input/Output (JEDI Model)	(Lantz and Tegen, 2011)[48]
Powerlinks Transmission Limited Project	2012	India	Mix	Mix	-	n/a	36.7	Input/Output	(IFC, 2012)
MISO	2015	US	High	Line	Mix	0.8	-	Input/Output	(MISO, 2015)[49]
Transmission in the SPP region	2010	US	High	Line	-	20.2	-	Input/Output (IMPLAN Model)	(Pfeifenberger et al., 2010)[50]

Deriving occupational breakdowns

Survey data was used to estimate the percentage of total labour demand attributed to different occupations. Occupational labour demand was estimated at two levels:

- ANZSCO, 1-digit: labour demand was calculated for six occupational categories – managers, professionals, trades and technicians, clerical and administrative staff, machine operators and drivers, and labourers[51]
- Composite profile: occupations at the 6 digit level according to the ANZSCO classification, based on the concentrations of labour demand.

The occupational composition for each phase of labour demand (development, civil works, and electrical works) was calculated from the average for the projects in that category, that is, for each double circuit line project, for each single circuit line project, and for all the non-line projects. Weighting by km or value was not applied.

The overall occupational breakdown for that category of transmission was then calculated using the weighted split of job-years between development, civil works, and electrical works.

The resultant percentages are applied to the gross number for the relevant type of project, for any given year to produce time series, averages, and snapshots of the occupational mix overall and per technology.

Integrating the ISP transmission projects into the labour demand model

Splitting projects into individual elements

Project descriptions were extracted from the ISP and separated into line and non-line elements. Each project element retained its project title identifier and was then coded according to the asset type.

Projects were coded as double circuit lines, single circuit lines, or non-line projects further classified into "substation" or "other". Some project elements were excluded due to a lack of available data.

Table 7 summarises the types of transmission projects included or excluded.

Table 7 Transmission asset types included/ excluded from the modelling

Asset classification	**Further classification**	**Description**
INCLUDED		
Line	Single circuit	New or uprate single circuit, all terrain types, all voltages – included
Line	Double circuit	New double circuit, all terrain types, all voltages – included
Transmission (other, non-line)	Substation	New substations and substation augmentation works – included
Transmission (other, non-line)	-	Transformers, reactors and capacitors - included where a value can be assigned
EXCLUDED		
Transmission (other, non-line)	-	Tapping, cutting-in, turning-in lines – excluded
Transmission (other, non-line)	-	Ambivalent descriptors for project elements (e.g. 'special protection scheme') – excluded
Transmission (other, non-line)	-	Power flow controllers – excluded

Project elements describing 'tapping, cutting-in, and/or turning-in' lines were excluded in the model due a lack of data at this granularity. It was also assumed that these elements could be accounted for under labour demand data for new transmission lines.

We were unable to obtain financial data for power flow controllers, although efforts were made through stakeholder engagement without result, so these were excluded from the final modelling. Additionally, some project parts with ambivalent descriptors were also excluded.

Allocating to state

ISP projects were allocated to states based on their geographical location. Where a project crossed state boarders, the project elements were assigned according to how much lies in each state. For example, for Project EnergyConnect, the respective portions of the 'new Bundey–Buronga–Dinawan–Wagga Wagga 330 kV double circuit' transmission line were assigned to NSW and SA using the kms of line located in each state. Likewise, non-line project elements were assigned to each state based on their geographical location. For example, the non-line project element ‘augmentation of the existing substation in Wagga Wagga’ was assigned to NSW, whereas transformers at Bundey were assigned to SA.

Identifying length and costs

To estimate line length and attribute km line portions to different states, a combination of the AEMO transmission map and the google maps distance measurement feature was used.

For example, as part of the QNI Minor project, the following project elements were described:

- Uprate Liddell-Tamworth 330 kV line
- Uprate Liddell-Muswellbrook-Tamworth 330 kV

The AEMO transmission map was used to locate these lines and the associated transmission corridor. [52] The next step was to roughly follow the prescribed transmission corridor, according to the AEMO map, and measure the distance of the proposed transmission line infrastructure corridor. The total distance was rounded to the nearest 5 km, in this case 290km. Where a transmission corridor crossed state borders, the length of line was split between states.

Allocating start time and duration

The impact of construction on labour demand is of course highly influenced by timing.

The ISP gives a 5 or 10 year window for most transmission projects, and although some project specific information is available in public documents, there is very little information on exact project start dates and project timelines beyond the indicative dates represented in the ISP.

The start dates used for modelling labour demand for each major project identified in the ISP are listed in Table 8. Where information is publicly available or the project is already under construction, the project timeline and start date was set firmly in the model. Where project durations were unavailable, default values of 2 years for non-line projects and 3 years for line projects were set. Those projects that fall outside the 2021-2035 window were excluded from the modelling results.

Table 8: Project start dates and timelines used to model transmission labour demand

Project name	Modelled start date	Project duration (years)	Timing notes
Central VIC	2020/ 2022	2	Timing confirmed (2020-2023)
QNI Minor	2020	2	Project commenced (due to be commissioned Dec 2021)
Eyre Peninsula	2021	2	Timing confirmed
VNI minor upgrade	2021	2	Timing confirmed (commissioning expected 2022-2023)
Central NSW	2022 - 2031	2 years non-lin 3 years line	Project partly commenced (next element at 2026, remainder commence 2031)
Project EnergyConnect	2022	4	Timing confirmed (commencement set 2022, completion expected during 2025)
Humelink	2024	3	Timing confirmed (2024-2026)
Far North Queensland	2026	3	One line elements set at 2026 for Step Change, post 2035 for other scenarios. Some elements excluded from model as thought too late.
Gladstone Grid section	2026	2 years non-line 3 years line	Timing confirmed (2026 for earlier elements, 2031 for others)
Northern West NSW	2026	4	Timing confirmed (brought forward to 2026)
Central to Southern Queensland	2027	3	Timing adjusted through stakeholder engagement
QNI Medium	2031	2 years non-line 3 years line	Commence at 2031, complete 2035
South East SA	2031	3	Step change scenario only, commence 2031
Marinus Link	2026	5	Timing advised by AEMO
Mid North SA	2035	3	Only included in Step Change
QNI Large	n/a	-	Post 2035, not included in model
South West Victoria	n/a	-	Post 2035, not included in model
North Queensland	n/a	-	Post 2035, not included in model
VNI West Option 6	n/a	-	Post 2035, not included in model
VNI Option 7	n/a	-	Post 2035, not included in model

Data on non-line assets

In order to calculate labour demand or materials for non-line transmission assets a cost had to be assigned. Some financial data was able to be obtained for specific substations identified in the ISP, but by no means all. Where data was unavailable, average figures were used based on the data from other projects in the survey and publicly costed ISP projects. However, the cost of substations is extremely variable, so these costs are indicative at best.

We used the cost guide provided in the ISP inputs and assumptions workbook for transformers, reactors and capacitors wherever possible as no project specific data was available for these asset types.

Given the highly variable nature of non-line transmission asset works and the average data used to estimate both labour demand for non-line assets, and costs of the infrastructure, total labour demand figures produced in the model should be taken as indicative only.

Table 9: Occupational classifications and corresponding ANZSCO code

ANZSCO 1 digit classification	ANZSCO 6 digit code	Labour demand Title For Projections
Managers	111111	Executives
Managers	133111	Project Management Professionals (Office)
Managers	133112	Construction Managers (Site)
Managers	133211	Engineering Managers
Managers	133611	Procurement Managers
Managers	132000	Business Administration Managers (Finance, Human Resources, etc)
Professionals	234399	Community Engagement
Professionals	221100	Finance and Business Professionals
Professionals	232212	Surveyor
Professionals	233112	Materials Engineer
Professionals	233211	Civil Engineer
Professionals	233212	Geotechnical Engineer
Professionals	233213	Quantity Surveyor
Professionals	233214	Structural Engineer
Professionals	233311	Electrical Engineer
Professionals	233512	Mechanical Engineer
Professionals	263300	Telecommunications Engineers
Professionals	263200	IT Support and Test Engineers
Professionals	233999	Other Engineers
Professionals	234300	Environmental Professionals
Professionals	234400	Geologists, Geophysicists and Hydrogeologists
Professionals	251300	Environmental and Occupational Health Professionals
Professionals	220000	Other Professionals
Administrative staff	500000	Administrative Staff
Trades and Technicians	312611	Safety Officer
Trades and Technicians	312911	Maintenance Planner
Trades and Technicians	342400	Telecommunications Technicians (Field Staff)
Trades and Technicians	332211	Painting Trades
Trades and Technicians	341100	Electricians
Trades and Technicians	342211	Electrical Linesworkers (Transmission)
Trades and Technicians	312512	Mechanical Trades and Technicians
Trades and Technicians	342212	Technical Cable Jointer
Trades and Technicians	899914	Electrical Trade Assistants
Trades and Technicians	899915	Telecommunications Trade Assistants
Trades and Technicians	300000	Site Supervisor
Trades and Technicians	349900	Other Trades and Technicians
Machine Operators and Drivers	712111	Crane Operator
Machine Operators and Drivers	712211	Driller (Pilings, Foundations Etc)
Machine Operators and Drivers	721200	Earthmoving Plant Operators and Forklift Drivers
Machine Operators and Drivers	733100	Truck Drivers

ANZSCO 1 digit classification	ANZSCO 6 digit code	Labour demand Title For Projections
Machine Operators and Drivers	712112	Elevated Work Platform Operators
Machine Operators and Drivers	712900	Other Machine Operators and Drivers
Labourers	821100	Construction Labourers (Certificate 2 Level)
Labourers	821211	Concreter
Labourers	821711	Rigger and Dogmen
Labourers	821714	Structural Steel Erector (Steel Fixer)
Labourers	899900	Other Labourers

Material indicators – methodology

Introduction

Material indicators for the energy generation by renewable technologies utilising wind generation, solar or hydro power were developed using international and national literature, environmental impact statements/reports, installation standards and consultation with industry experts. A special consideration was taken for the Australia specific technology installation trends as well as the technological advancement direction. The focus materials of this study are concrete and steel, the materials playing a significant role in all renewables.

Zepf et al. (2014) showed materials pathways along the supply chain for the energy generation technologies including wind power, solar and hydro focus of this study. [53] While that work illustrated the pathways for materials along the whole supply chain, it focused on the final product and not on extraction.

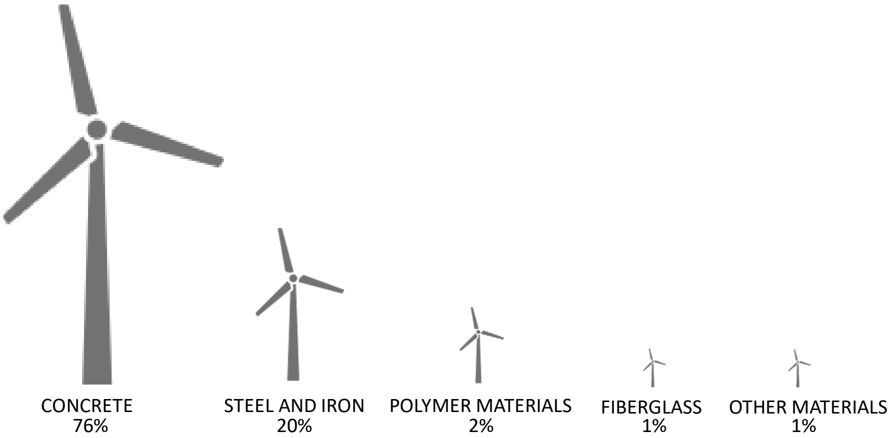
This section describes the method used to estimate the material indicators for concrete and steel for wind generation, solar and hydro as well as transmission lines and for the supporting infrastructure. Estimates are listed for material indicators for rooftop solar, coal, oil and gas as stated in the literature but have not analysed them for the Australian context.

Utility-scale wind power

Scaling up electricity from renewables is crucial for decarbonisation of world’s energy system. Wind and solar power would lead the way with wind power to supply more than one third of total electricity demand by 2050, which represents nearly a nine-fold rise in the wind power share in the total generation mix by 2050 compared to 2016 levels.[54] It is predicted that onshore wind generation will play a significant role worldwide in renewables installations for the next few decades. Offshore installations, predicted to be a fifth of yearly onshore capacity installations, will also increase significantly over the next few decades. Most of the offshore wind power installations so far have been on the North Sea and nearby Atlantic Ocean and there are only a small number of installations projected for Australia by 2050. Therefore, this study focuses on onshore wind generation only.

Wind turbines are predominantly made of steel, fiberglass, resin or plastic, iron or cast iron, copper and aluminium, with concrete as a foundation (Figure 15). Onshore wind turbines use concrete as a foundation and concrete and steel is used in the foundations of the offshore wind turbine installations. Concrete and steel are the most prominent materials required for wind turbines and foundations. Manufacturing of the main components of the wind turbine requires specialised equipment and welding, lifting and painting machines that are also used in other industries such as construction and aeronautics. The foundations also require specialised equipment for rolling, drilling and welding. Special equipment is also needed to move these big structures.

Figure 15: Proportion of materials used to build a wind turbine

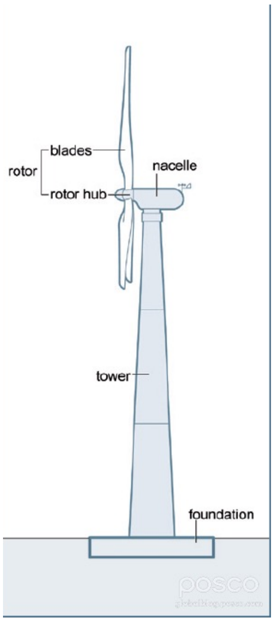


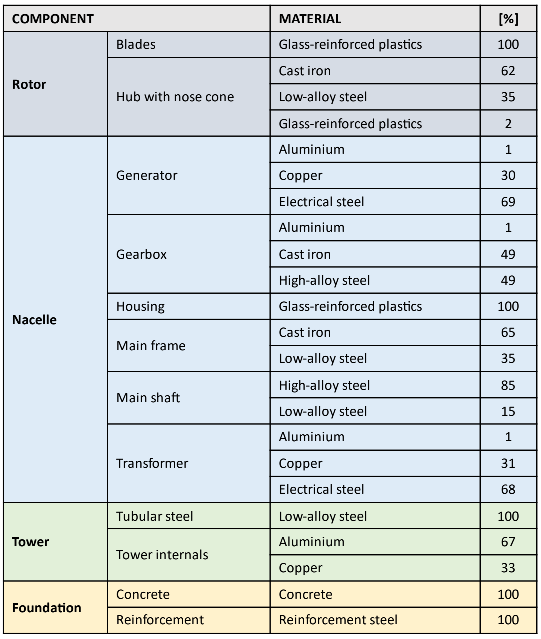
Note: Based on a 50 MW onshore wind plant. Adapted from International Renewable Energy Agency (2019). [55]

Wind turbines convert kinetic energy of moving air to electrical energy, with incoming air flow activating the rotation of rotor blades that in gearbox transfers to higher speed spinning the electricity producing generator. There are a number of variations in the designs of wind turbine and consequently the material requirements. One of the main distinctions is between geared and gearless converters, with further variations within each of the options. Gearless generators offer greater reliability and require less maintenance but are bigger and heavier (nacelle of direct drive synchronous generator (DDSG) is approximately one third higher than that of geared generator). However, the weight of the gearless generator is significantly reduced with the use of the rare earth elements (as in the direct drive permanent magnet synchronous generators' nacelles which are two thirds lighter than DDSG's).[56]

It is estimated that wind turbines require around 200 kg/MW of rare earths, which have been a driving force for innovation in the wind technology due to an increase in the rare earth prices. Lighter nacelles have also lower material requirements for the tower and foundations. Breakdown of components and material requirements for a typical 2.5 MW turbine is shown in Figure 16.

Figure 16: Material distribution in wind turbines based on onshore 2.5 MW turbine



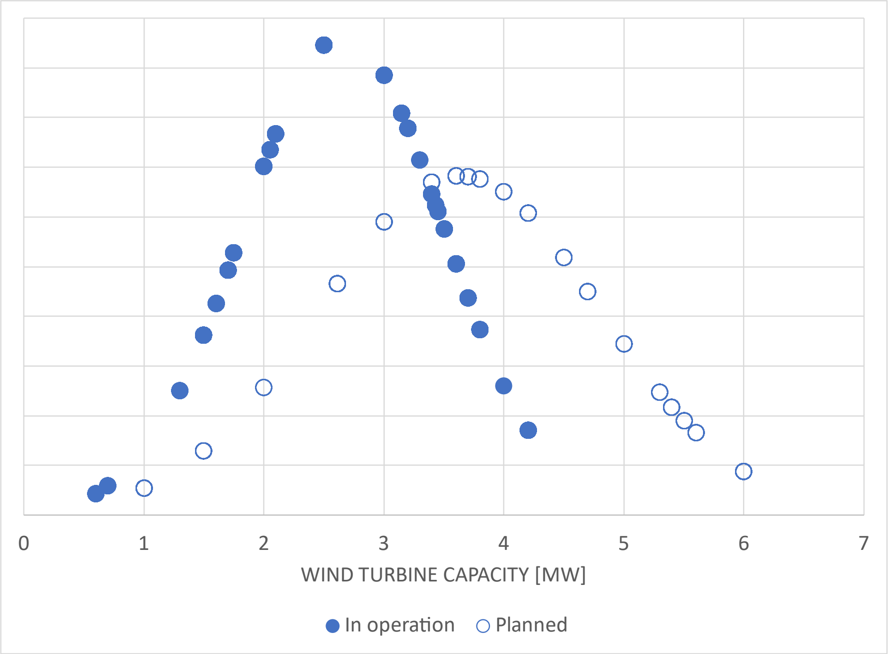


COMPONENT		MATERIAL	[%]
Rotor	Blades	Glass-reinforced plastics	100
	Hub with nose cone	Cast iron	62
		Low-alloy steel	35
		Glass-reinforced plastics	2
Nacelle	Generator	Aluminium	1
		Copper	30
		Electrical steel	69
	Gearbox	Aluminium	1
		Cast iron	49
		High-alloy steel	49
	Housing	Glass-reinforced plastics	100
	Main frame	Cast iron	65
		Low-alloy steel	35
	Main shaft	High-alloy steel	85
		Low-alloy steel	15
	Transformer	Aluminium	1
		Copper	31
		Electrical steel	68
Tower	Tubular steel	Low-alloy steel	100
	Tower internals	Aluminium	67
		Copper	33
Foundation	Concrete	Concrete	100
	Reinforcement	Reinforcement steel	100

Source: United Nations Environment Plan (2016)[57]

The capacity of the wind turbines has been increasing over the years. At the same time there has been a development towards lighter nacelle unit for the same capacity lowering the material requirement of the supporting tower and foundation. Therefore, while the turbine capacity is increasing over the time (Figure 17), the material requirements per MW capacity have remained similar (Figure 18).

Figure 17: Current wind turbine capacity in MW in operation and planned based on NEM



Source: AEMO, Generation Information (2021)[58]

Material indicators for steel and concrete for wind generation (Table 10) were determined based on the data published in literature and are plotted as a function of wind turbine capacity in Figure 18.[59] [60] [61] [62] [63] [64] [65]

Figure 18: Material indicators for steel and concrete as a function of wind turbine capacity

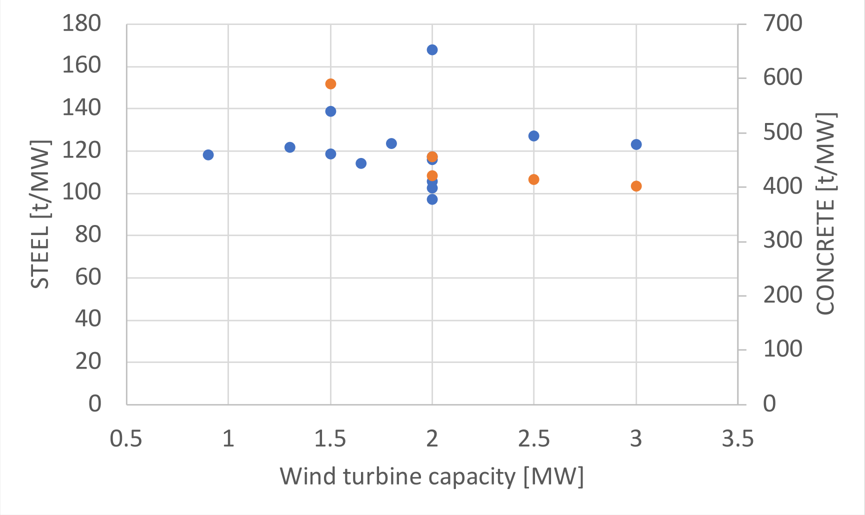


Table 10: Material indicators for wind power

Technology	STEEL [t/MW]	CONCRETE [m^3/MW]
Wind power	120	190

Utility-scale solar

Utility-scale solar farm constitutes of an array of **solar modules** (PV panels) arranged in strings. Modules include cells organised in a series on the panels. They differ in cell type, ranging from monocrystalline cells, polycrystalline cell, thin-film cells etc., using different materials. With the aim of increasing the efficiency and reducing costs, the technology has been evolving over time and will continue so in the future.

Modules are either mounted on fixed angle frames or sun-tracking systems. Mounting structures are typically fabricated from steel or aluminium, although there are examples of wooden beams.[66]

Fixed frames are simpler to install, cheaper, and require less maintenance. However, the tracking systems can increase yield up to 45%.[67] Single-axis track system better matches the grid energy profile and stability of the grid but requires 35% more steel as oppose to the fixed frame system.[68] In addition to the single-axis tracking systems there are also dual-axis tracking systems on the market. Dual-axis tracking maintains the optimum alignment to the sun, but is technically more complicated and requires more materials than single tracking system.[69]

Foundation options for ground mounted PV systems include:

- Concrete piers cast in-situ – small systems and uneven sloping terrain.
- Pre-cast concrete ballasts – large systems, grounds difficult to penetrate, low tolerance to uneven and sloping terrain.
- Driven piles – low-cost, quick, large scale installations.
- Earth screws – large-scale installations, tolerant to uneven or sloping terrain.
- Bolted steel baseplates – existing concrete ground slabs.[70]

Australian solar farms use predominantly single axis tracking technology and the driven piles for foundations.

The direct current electricity produced by the modules is converted to alternating current (AC) with the inverters to the voltage and frequency that are compatible with the AC grid. The inverters vary whether they are connected at the modular, string or sub-array level and whether they include a transformer.

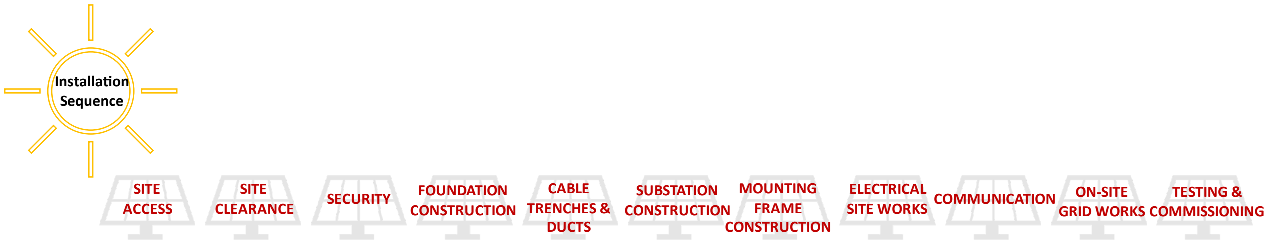
In addition, there are two different types of transformers at the utility-scale solar farm: the distribution transformer, installed after each inverter, and a substation transformer, used to set up voltage for transmission. They are both housed in a metal container and placed on a concrete foundation.

The panels and other components are connected with cables (copper or aluminium).

A solar farm also includes supporting equipment such as electrical protection devices (overcurrent protection, disconnection protection, lightning/surge protection), junction/combiner boxes (connecting cables from modules to the inverter). Equipment for metering as well as system monitoring, known as the Supervisory Control and Data Acquisition (SCADA) system is important in the operation of the solar farm.

Stages and sequence of solar farm installation are summarised in Figure 19. In addition, a temporary infrastructure is established, including laydown, storage and site compound for which the materials are not accounted in this study and the components are generally leased for the duration of the construction.

Figure 19: Installation sequence works for utility-scale solar farm



Solar farms use only minimal quantities of concrete in Australia due to use of driven piles for foundations. Concrete is predominantly used in foundations for the substation construction.

Solar farms use only minimal quantities of concrete in Australia due to use of driven piles for foundations. Concrete is predominantly used in foundations for the substation construction.

Most of utility-scale solar farm components are imported from overseas but some are produced locally.

Imported from overseas:

Solar panels

- Tracking system – integrated onshore but components are predominantly manufactured in China.
- Mounting structure, including the piles – the metallic part could be manufactured anywhere, including Australia, but a competitive cost is the barrier.

- Inverters – include a more sophisticated technology and it is less likely that the suppliers would open manufacturing facilities in Australia. European and US companies that dominate the market set offshore facilities in China to lower the costs.

Electrical equipment, combiner boxes

- Cables and conduits – can be supplied from Australia but are normally supplied from India or SE Asia due to cost

Components manufactured in Australia:

- Transformers - some of the big companies have manufacturing facilities for transformers in Australia and supply smaller transformers from Australia.
- Monitoring systems – supplied from Australia or overseas, depending on the design origin
- Security system
- Weather stations
- Fencing – predominantly steel
- Site Facilities

Most components of the solar farm last the lifetime, except for the inverters and other electrical devices that have 25 year warranty.

Figure 20 is showing the mass breakdown for a utility-scale solar farm. Steel is the main component by mass. From the global consumption of steel in 2017, only 0.4% were used for PV and the authors concluded that steel production far exceeds the demand for steel in PV systems.[71]

Figure 20: Component mass breakdown for utility-scale 100 MW solar farm system including 295 W panels mounted on single-axis tracking system

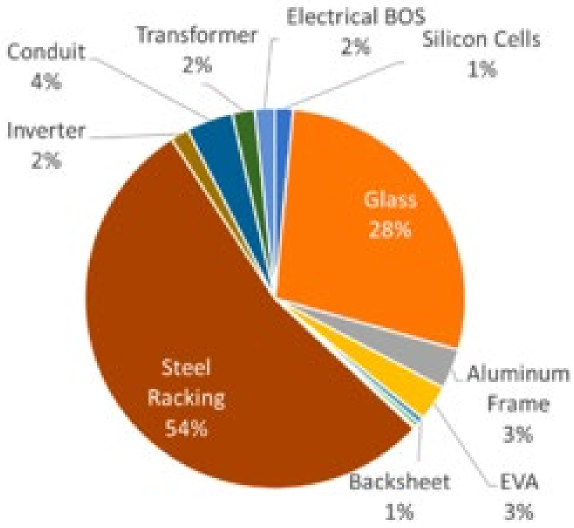
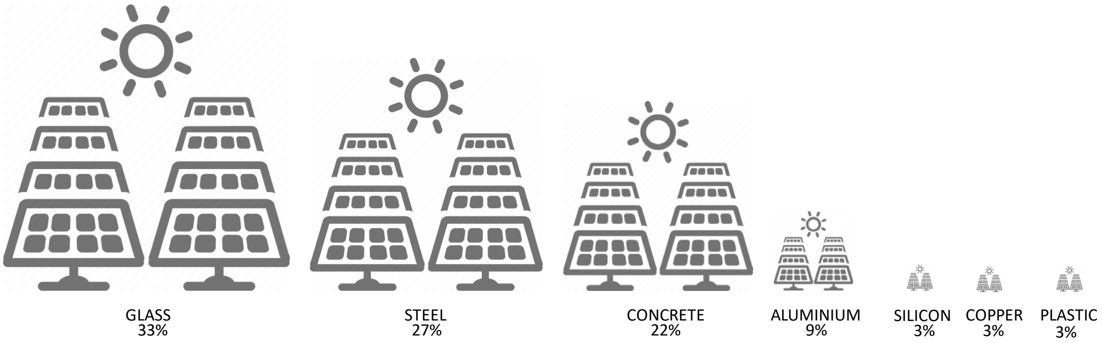


Figure 21 illustrates the proportion of materials used to build a solar farm. The main component is glass that is used for the solar panel and steel, a supporting structure for the panel and as listed above in the other supporting infrastructure on the solar farm. See Table 11 for the material indicators for solar.

Figure 21: Proportion of materials used to build a solar farm



Note: Adopted from (IRENA, 2019b).72 Based on a 1 MW solar PV plant (Si-wafer).

Table 11: Material indicators for solar

STEEL [t/MW]	**CONCRETE [m³/MW]**
96 [73]	-
56 [74]	20
- [75]	4
169 [76]	-
69 [77]	38
120 [78]	-
67.5 [79]	25
82	**22**

Hydro and pumped hydro

Hydro and pumped hydro use a large quantity of concrete to construct dams and reservoirs. The required building material quantities are very project specific and depend on the local topographical features, such as naturally occurring reservoirs, porosity of the material lining the reservoirs and the hydrology features.

A wide range of literature was explored in an attempt to derive the material indicators for hydro and pumped hydro. Reported numbers for concrete requirements in literature differ widely and indicate a large uncertainty in the numbers.

As hydro and pumped hydro are mature technologies and are not predicted to significantly evolve in the future, use of the data from historical installations was thought that could be used to predict material requirements. However, the majority of the currently installed hydro technologies in Australia are dams (Table 12) but the future planned projects are almost exclusively pumped hydro (Table 13).

Table 12: Current installed hydro and pumped hydro in Australia

STATE	Project	Type	Capacity [MW]	Storage [MWh]
NSW	Copeton	Dam	20	
	Glenbawn	Dam	5	
	Gutega	Dam	60	Does
	Hume Dam NSW	Dam	29	
	Jindabyne	Dam	1.1	
	Jounama	Dam	14.4	
	Keepit	Dam	7.2	
	Nymboida	Dam	0.686	
	Oaky	Dam	2.4	
	Pindari	Dam	5.772	
	The Drop	Run of River	2.5	
	Tumut	Dam	2116	
	Wyangala	Dam	24	
QLD	Kareeya	Run of River	84.6	
	Kareeya	Dam	7	
	Lake Somerset	Dam	4.3	
	Wivenhoe Small Hydro	Dam	4.5	
SA	Cultana	Pumped hydro	225	1800
	Baroota	Pumped hydro	250	2000
	Seacliff Mini Hydro	Dam	1.35	
	Terminal Storage Mini Hydro	Other	250	
TAS	Catagunya/Liapootah/Wayatinah	Dam	170.1	
	Cethana	Dam	85	
	Cluny	Dam	19	
	Devils Gate	Dam	60	
	Fisher	Dam	43.2	
	Gordon	Dam	432	
	John Butters	Dam	144	
	Lake Echo	Dam	32.4	
	Lake Margaret	Dam	8.4	
	Lemonthyme/Wilmot	Dam	81.6	
	Lower Lake Margaret	Dam	3.2	
	Mackintosh	Dam	79.9	
	Meadowbank	Dam	40	
	Midlands	Dam	6	
	Paloona	Dam	28	

	Poatina	Dam	300	
	Reece	Dam	131.2	
	Repulse	Dam	28	
	Rowallan	Dam	10.5	
	Tarraleah	Dam	90	
	Trevallyn	Dam	93	
	Tribute	Dam	82.8	
	Tungatinah	Dam	125	
VIC	Bogong/Mackay	Dam	150	
	Clover	Dam	29	
	Dartmouth	Dam	185	
	Eildon	Dam	135	
	Eildon Pondage Power Station	Run of River	4.5	
	Glenmaggie	Dam	1.9	
	Hume Dam VIC	Dam	29	
	Belgrave-Hallam Rd	Dam	0.25	
	Mount Waverley Mini Hydro	Dam	0.355	
	Murray	Dam	1502	
	Rubicon Mountain Streems	Dam	13.5	
	Wantirna Mini Hydro	Dam	0.132	
	West Kiewa	Dam	68	
	William Hotel	Run of River	1.8	
	Yarrawonga	Dam	9.5	

Table 13: Planned projects for hydro and pumped hydro in Australia

STATE	Project	Type	Capacity [MW]	Storage [MWh]
NSW	Bells Mountain	Dam	250-500	
	Oven Mountain Pumped Storage	Pumped Hydro	600	7200
	Armidale Pumped Hydro	Pumped Hydro	600	
	Snowy 2.0	Pumped Hydro	2040	349980
	Walcha Energy Project Storage	Pumped Hydro		
	Shoalhaven Expansion			3853
QLD	Kidston Pumped Hydro	Pumped Hydro	250	
SA	Baroota Pumped Hydro	Pumped Hydro	250	
	Kanmantoo	Other	250	
	Goat Hill Pumped Hydro	Pumped Hydro	230	1840

	Higbury Pumped Hydro	Pumped Hydro	300	
	Middleback Ranges	Pumped Hydro	90	390
TAS	Battery of the Nation	Pumped Hydro	3150	60000
VIC	Port Phillip Heads Tidal Energy Project	Tidal	34	

Source: AEMO, Generation Information (2021)[80]

The concrete requirements for pumped hydro will vary depending on whether there is one or two reservoirs and if they could be lined by natural material or if they need to be lined/build with concrete. Weather there is one or two reservoirs used depends on the location of the hydro station, if there is a naturally occurring reservoir and the penstock height to length ratio.

Steel is used for the pumps, equipment and pipes, which are usually coated with concrete, usually needing larger quantities when the pumped hydro is underground.

Due to the variation and uncertainty in concrete and steel requirement indicators for hydro and pumped hydro, the indicators used in Life Cycle Assessment (LCA) literature were applied based on a range of studies covering hydro, pumped hydro and underground pumped hydro and compared to the LCA database Ecoinvent (Table 14).

Table 14: Material indicators for concrete and steel for hydro and pumped hydro

Source	**Type**	**Steel [t/MW]**	**Concrete [m^3/MW]**
Ecoinvent	Hydro	135	3542
(Vidal, O., 2017)	Hydro	96	3167
(Guo et al., 2020)	Pumped Hydro	35	64
	Pumped Hydro Underground	72	132
(Immendoerfer et al., 2017)	Pumped Hydro	44	1236
(Jiang et al., 2018)	Hydro	20	930
	Hydro	115	1064
	Hydro	111	1886
	Hydro	55	810
(Krüger et al., 2018)	Pumped Hydro	50	1249
ADOPTED	**Hydro**	**76**	**2027**
	Pumped Hydro	**43**	**850**
	Pumped Hydro Underground	**72**	**132**

Transmission lines and supporting infrastructure

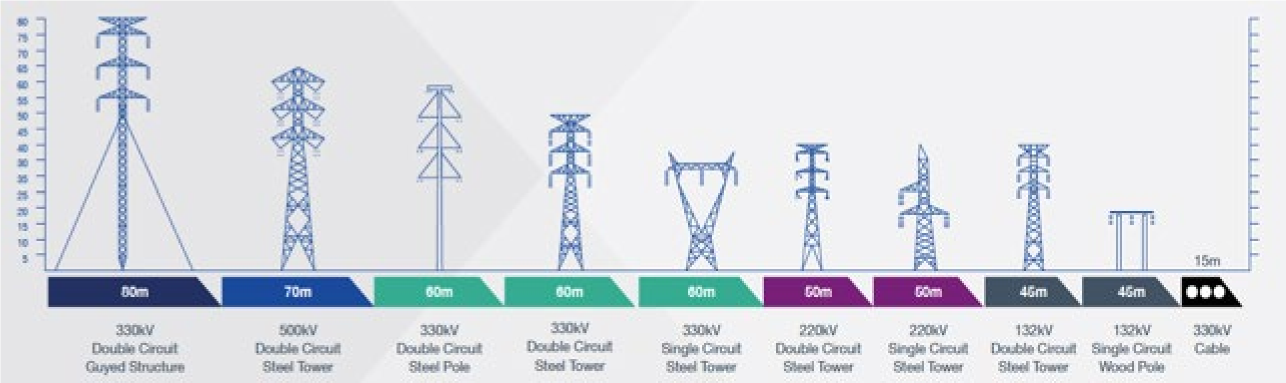
High voltage and medium voltage transmission line assets were used to estimate the material requirements for transmission lines in Australia – low voltage lines were excluded due to the limited availability of data for these tower types and the high variability in material use (i.e. concrete, steel, wood).

Based on the literature available it was determined that high and medium voltage transmission line towers used in Australia are predominantly steel lattice towers with concrete foundations; projects featuring steel poles with concrete foundations appeared less frequently in literature sources and lacked available material intensity data.

The main differences between **single and double circuit transmission lines** are the tower height, foundation depth, and the frequency of towers built over a km of line.

See Figure 22 for a guide on transmission tower height and type according to voltage level taken from.[81]

Figure 22: Typical transmission tower design and height



Two main literature sources were used to derive estimates for steel per km of transmission line (Table 15). Some minor calculations were performed using the information provided by these sources to derive the final steel/km and concrete/km figures outlined in Table 15.

Table 15: Data sources used for transmission line infrastructure estimates

Transmission line type	Line type	Tower type	Tower height	Steel (tonnes)/km	Concrete (m^3)/km	Reference
330 kV Line	Double Circuit	Steel lattice tower	60-80m	46.2	71.3	(TransGrid, 2020a)
500kV/345kV Line	Double Circuit	Steel tower (lattice or pole)	60-80m	71		(Midcontinent Independent System Operator, 2019)
500kV/345kV Line	Single Circuit	Steel tower (lattice or pole)	60-80m	32.7		(Midcontinent Independent System Operator, 2019)
220kV Line	Double Circuit	Steel (lattice or pole)	50m	32.5	71.3	(TransGrid, 2020a)
230kV Line	Double Circuit	Steel (lattice or pole)	50m	33.6		(Midcontinent Independent System Operator, 2019)
220kV Line	Single Circuit	Steel (lattice or pole)	50m	17.3		(Midcontinent Independent System Operator, 2019)

TransGrid provided information on the total steel and concrete used for transmission lines over 135km for a 330 kV double circuit transmission line and over 22km for a 220 kV double circuit transmission line.[82] A weighting was applied to estimate the medium voltage and high voltage steel intensities for each tower type. This was achieved by averaging the total steel amount over the number of towers and then multiplying a height weighting of 62% for the high voltage transmission tower and 38% for the medium voltage transmission tower. These calculations provide estimates only and should be used as such.

Midcontinent Independent System Operator provided exact steel figures per tower type for 500 kV, 345 kV, and 230 kV double and single circuit lines.[83] Although the voltage between US transmission lines varies slightly, the 345 kV lines are treated as 330 kV equivalents and the 230 kV lines are treated as 220 kV equivalents. Tower types in the US study were classified as tangent, running and dead-end and the number of structure types per mile was provided per voltage class (see Table 16). These numbers were used to derive an average tonnage of steel per km of line, per voltage class.

Table 16: Number of structures per voltage class per mile

A/C Transmission
Structures per mile – steel tower and steel pole

Single circuit /
Double circuit

Voltage class	69 kV line	115 kV line	138 kV line	161 kV line	230 kV line	345 kV line	500 kV line
Tangent structures	9 / 9.5	8.5 / 9	8 / 8.5	7 / 7.5	5 / 7	4.5 / 6	3 / 5
Running angle structures	1 / 1	1 / 1	1 / 1	1 / 1	1 / 1	1 / 1	1 / 1
Non-angled deadend structures	0.25 / 0.25	0.25 / 0.25	0.25 / 0.25	0.25 / 0.25	0.25 / 0.25	0.25 / 0.25	0.25 / 0.25
Angled deadend structures	0.25 / 0.25	0.25 / 0.25	0.25 / 0.25	0.25 / 0.25	0.25 / 0.25	0.25 / 0.25	0.25 / 0.25
Total structures per mile	**10.5 / 11**	**10 / 10.5**	**9.5 / 10**	**8.5 / 9**	**6.5 / 8.5**	**6 / 7**	**4.5 / 6.5**

Concrete is used for **foundation of the transmission lines**. The amount of concrete required depends on the transmission tower size and weight. Double circuit towers are generally heavier and bigger than single circuit towers. Based on the Environmental Impact Statement for the Gateway West Transmission Line Project, USA, it is estimated that the amount of concrete required for the average tower with single circuit was 45% less – 39.2 m^3/km – than for the tower with double circuit (71.3 m^3/km).[84] Note that Dead-End structure refers to the position where the transmission line changes direction.

Table 17: Foundation excavation dimensions for transmission towers

500 kV	**SINGLE CIRCUIT**				**DOUBLE CIRCUIT**				
Tower Structure	*No of holes*	*Depth [m]*	*Diameter [m]*	*Concrete [m^3]*	*No of holes*	*Depth [m]*	*Diameter [m]*	*Concrete [m^3]*	*Difference [%]*
Tangent Lattice	4	6.7	1.2	31.3	4	7.9	1.5	58.1	***46***
Small Angle Lattice	4	7.5	1.2	35.2	4	8.7	1.5	63.5	***45***

Medium Angle Lattice	4	8.2	1.2	38.2	4	9.4	1.5	68.8	***44***
Medium Dead-End Lattice	4	9.0	1.5	65.8	4	10.2	1.8	107.0	***39***
Heavy Dead-End Lattice	4	9.8	1.5	71.1	4	11	1.8	115.4	***38***

Source: United States Department of the Interior.[85]

In addition to literature sources provided above, the American Iron and Steel Institute estimates between 18 and 30 tonnes of steel are used in high voltage transmission towers. At roughly two towers per km of line, this equates to between 36 and 60 tonnes of steel per km, confirming the estimates in Table 17 above.[86] [87]

Supporting infrastructure for transmission lines includes substations, transformers, capacitor banks, reactive plants and power flow controllers.

Only one source provided estimates of total concrete for a line project.[88] TransGrid provided total concrete figure of 11200 m^3 for the double circuit 157 km line (both medium and high voltage). An estimate was calculated per km based on this total figure of 71.3 m^3/km of line.

Supporting infrastructure is placed on concrete foundations. TransGrid estimated requirement of 448 m^3/ha of concrete for the supporting infrastructure[89]. Using AEMO indicative cost estimates for AC transmission assets for 2020 (Table 18) a concrete indicator was estimated to be 278 m^3/$mil.

Steel indicator was estimated based on average use of steel for steel frame in transformers. A 500 kV transformer requires 1.134t of steel for the frame Click or tap here to enter text.and based on the AEMO indicative cost estimates for AC transmission assets for 2020 (Table 18) a steel indicator was estimated to be 0.1t/$mil. [90]

Table 18: AEMO indicative cost estimates for AC transmission assets for 2020

Plant	Number of units	Indicative cost estimates ($ millions)
500 kV double circuit transmission line (3040 MVA each)[a]	$/km	2.46
500 kV single circuit transmission line (3200 MVA each)[a]	$/km	2.05
330 kV double circuit transmission line (1200 MVA each)[a]	$/km	1.92
330 kV single circuit transmission line (1200 MVA each)[a]	$/km	1.54
275 kV double circuit transmission line (950 MVA each)[a]	$/km	1.79
275 kV single circuit transmission line (800 MVA each)[a]	$/km	1.49
220 kV double circuit transmission line (800 MVA each)[a]	$/km	1.66
220 kV single circuit transmission line (800 MVA each)[a]	$/km	1.41
500/330 kV 1000 MVA transformer	1	20.43
500/220 kV 1000 MVA transformer	1	20.28
100 MVAr 500 kV line shunt reactor	1	5.93
50 MVAr 330 kV line shunt reactor	1	4.01
100 MVAr 330 kV line shunt capacitor	1	4.06
100 MVAr 220 kV line shunt capacitor	1	3.16
330 kV 300 MVAr SVC	1	28.39
220 kV 200 MVAr SVC	1	23.14
3CB diameter 3CBS – 500 kV	1	11.18
3CB diameter 2CBS – 500 kV	1	8.73
3CB diameter 3CBS – 330 kV	1	7.48
3CB diameter 2CBS – 330 kV	1	5.77
3CB diameter 3CBS – 275 kV	1	6.25
3CB diameter 2CBS – 275 kV	1	4.83

3CB diameter 3CBS – 220 kV	1	4.25
3CB diameter 2CBS – 220 kV	1	3.32
New substation establishment (10,000m^2)[b]	1	16.12
New substation establishment (20,000m^2)[b]	1	23.34
New substation establishment (30,000m^2)[b]	1	31.42

Note: All costs are indicative and in 2020 dollars including project overhead.
a: For each transmission line longer than 150 km, an economy of scale factor of 0.95 is applied to $/km cost estimate.
b: Earth works, secondary systems building, DC supply, AC supply auxiliary transformers/cabling, fire protection and communication systems.

Other energy generation technologies

Other energy generating technologies such as gas, coal, oil and PV rooftop were not in the scope of this study. However, these technologies have been included in the model based on the values derived in the book review of energy production.[91]

The numbers in Table 19 are based on the international literature and have not been evaluated for Australian context. For PV rooftop it assumes use of concrete. The use of concrete in rooftop depends on the type of mounting type of mounting system and whether the PV system is ballasted. Ballasted systems are normally deployed on flat concrete roofs and where the penetration of the roof material is not possible. Flat roofs are used in commercial buildings and an increase has been in solar PV installations particularly on the commercial buildings in the recent year. In ballasted systems, concrete blocks are used to hold the system down and are limited to low wind regions (in Australia to Wind Region A).[92]

Table 19: Material indicators for other energy producing technology

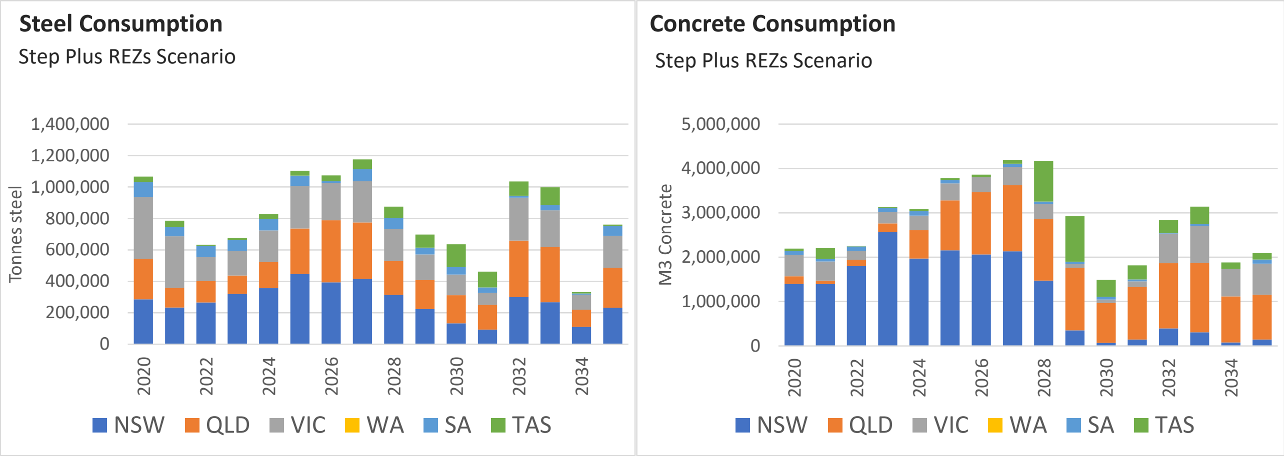
Steel [t/MW] **Concrete [m^3/MW]**	**Gas+CCGT**		**Coal**		**Oil**		**PV roof**	
	steel	concrete	steel	concrete	steel	concrete	steel	concrete
(Vidal et al., 2013)	-		52	75	-	-	169	494.2
Average lit data	-		56	65.4	51	29.6	217	-
min	-		68	30.8	51	29.6	250	-
max	-		40	81.3	51	29.6	200	-
(Hertwich et al., 2015)	77	54.2	72	85.4	-	-	24	29.2
min	-		103	130.8	-	-	35	30.4
max	-		48	57.1	-	-	19	23.8
Ecoinvent	-		106	135.4	73	100.8	24	-
min	-		92	104.2	73	100.8	18	-
max	-		120	166.7	73	100.8	35	-
ADOPTED	**77**	**54.2**	**70**	**80.4**	**70**	**80.4**	**88**	**14.6**

Adopted from (Vidal,O., 2017)

APPENDIX B – STEEL AND CONCRETE DEMAND BY STATE

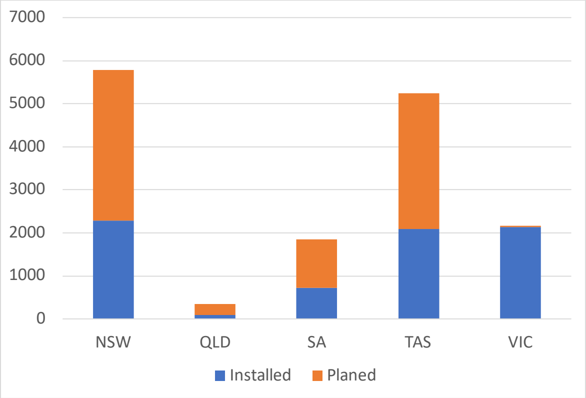
A high proportion of the consumption of steel and concrete for the energy sector will be in the largest states, NSW, Victoria and Queensland due to the scale of wind, solar and pumped hydro storage projects (Figure 23). The relative mix does vary as the profile of the build-out across states rises and falls. In coming years, NSW dominates the profile of consumption for concrete (driven by Snowy 2.0) whereas Queensland dominates the consumption profile from the mid-2020s. Tasmania is also a notable source of consumption for concrete in the late 2020s and early 2030s. The consumption profile for steel is more diverse across the states.

Figure 23: Steel and Concrete Consumption by State, 2021-2035



A key factor underlying the consumption profile for concrete is the projected location of pumped hydro. While Victoria, NSW and Tasmania have similar capacities in the installed hydro, most of the planned pumped hydro projects are projected for NSW and Tasmania (Figure 24).

Figure 24 Installed and planned hydro and pumped hydro projects capacity per state.

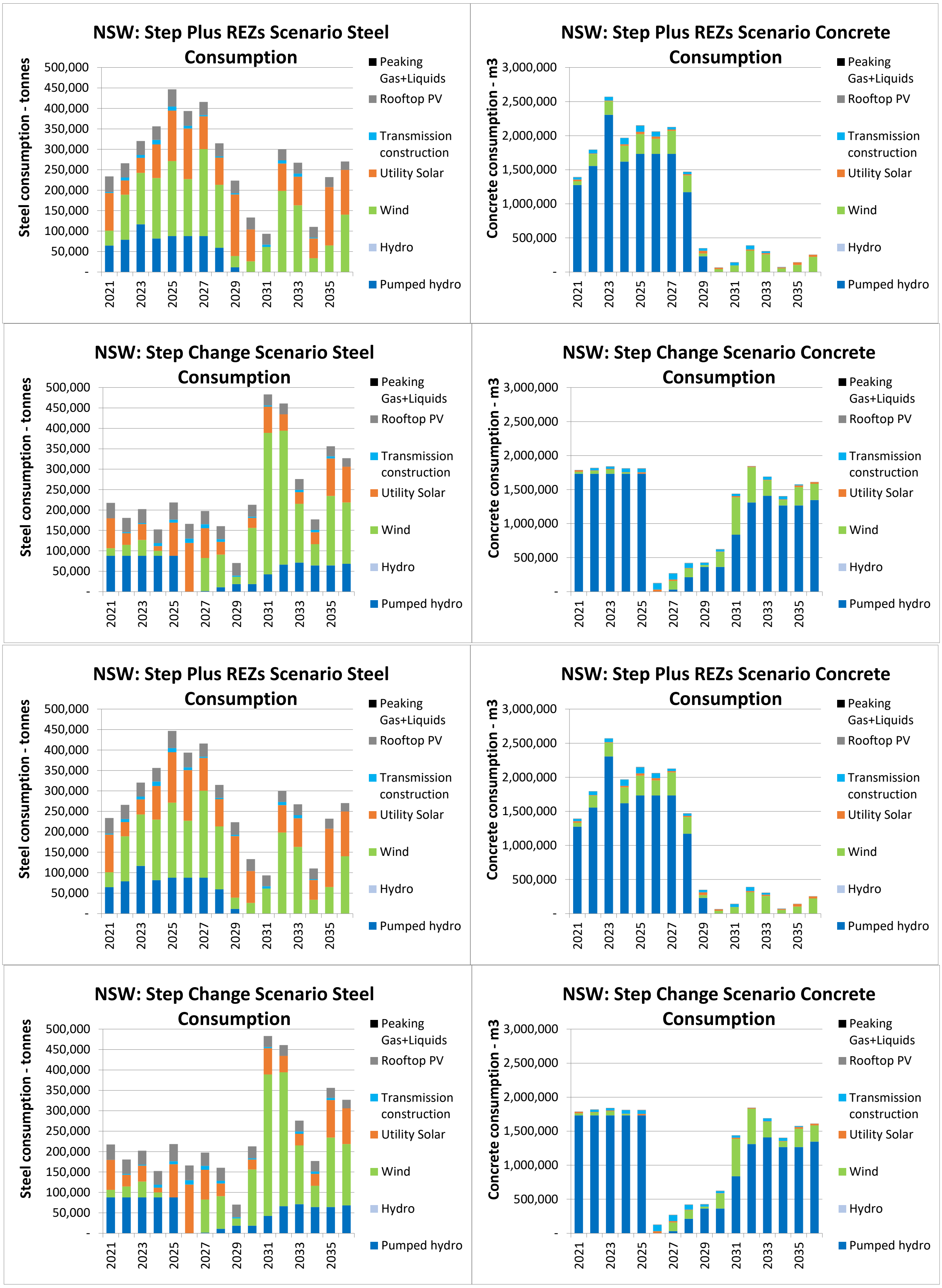


Detailed profiles of the consumption of steel and concrete by state can be found in Figure 25.

Figure 25 Concrete and steel consumption by technology and state, 2021-2036 (Step Plus REZs)

Focussing on NSW to illustrate the impact of REZ developments, consumption of both steel and concrete is also brought forward with major peaks in the mid-2020s. Steel consumption is double at 450,000 tonnes by 2025. The increase in concrete requirements is less pronounced but rises from a flat profile of 1.8m^3 to 2.5 m^3.

Figure 26: Steel and Concrete Requirements for the Step Change and Step Plus REZs scenarios, 2021-2036



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