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Research Paper

Predicting the workforce requirements for residential electrification and electric vehicle charging infrastructure

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ABSTRACT

This research presents a method and data to estimate labour requirements for residential electrification and electric vehicle (EV) charging infrastructure using survey data from Victoria, Australia. Whereas workforce projection methods for electricity generation, storage and transmission are relatively established, the ability to forecast the workforce for electrification, energy efficiency and flexible demand technologies (the demand-side workforce) remains underdeveloped and there is scant information on the EV workforce. Using installer surveys, employment factors were developed for electrification of residential hot water heating, space conditioning and cooking, and for installation, operation, and maintenance of EV chargers. The three key trades for residential electrification (electricians, plumbers and air-conditioning technicians) are already experiencing persistent skill shortages in Australia, highlighting the risks for the energy transition. The research found the labour intensity of EV charger types is considerably higher for fast DC chargers, so the composition of charging infrastructure has significant implications for workforce requirements. While further surveys are needed to build the evidence base, this study provides the first detailed analysis of workforce requirements for these aspects of electrification. The information enables forecasting of workforce requirements, so that policy makers and education providers can develop appropriate workforce development programs.

1. Introduction

The need for a rapid and far-reaching energy transition is well established to avoid the worst impacts of climate change. This can benefit communities via employment opportunities and improvements in health and wellbeing because of improved buildings and air quality. Over the last three years the number of jobs in clean energy surpassed those in fossil fuels and are set to increase rapidly over coming decades (International Energy Agency, 2023a). The demand for labour is both a benefit from and a risk for the energy transition: “Labour and skills shortages are already translating into project delays, raising concerns that clean energy solutions will be unable to keep pace with demand to meet net zero targets” (International Energy Agency, 2023a).

The ability to plan for the future workforce is likely to become increasingly critical (Rutovitz et al., 2021). The transformation is occurring worldwide, albeit at different rates, so there is rising demand for the same categories of labour and much of the work involves installation and construction services, with no possibility for offshoring (International Energy Agency, 2023a).

The energy sector can be broken down into three subsectors: energy supply (including generation and storage), energy transmission and distribution, and energy demand management, including energy efficiency and electrification. The generation and storage workforce requirements are the best characterised to date, with established methods to estimate labour volumes; transmission construction is also characterised to a reasonable level of detail (Briggs et al., 2021; Rutovitz et al., 2025). However, workforce characterisation on the demand side is severely lacking (Rutovitz et al., 2021).

Energy efficiency, demand management, and electrification of mobility, heat, and industry is key to all net zero scenarios. In the International Energy Agency’s (2021) Net Zero 2050 scenario, for example, key energy efficiency initiatives include the retrofitting of homes to create zero-carbon buildings, minimum energy performance standards for appliances, fuel economy standards and the switch to electric vehicles (EVs), and process efficiencies for manufacturing.

This demand-side workforce is already playing a crucial role in the energy transition, with at least 16 % of the total energy workforce involved in demand side activities (International Energy Agency, 2023a). Although many studies recognise at a general level that labour

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Nomenclature

Abbreviation	Description
AEMO	Australian Energy Market Operator
ANZSCO	Australian and New Zealand Standard Classification of Occupations
EF	employment factor
EV	electric vehicle
FTE	full-time equivalent
kW	kilowatt
MW	megawatt
RBS	residential baseline study

requirements will be high for retrofitting buildings, it remains the least understood element of the energy workforce (Hanna et al., 2022). The demand-side energy workforce is dispersed across the economy and cannot be easily identified as they are diffused across standard industry or occupational classification frameworks. This workforce includes, for example, construction workers, architects, heating engineers, and many tradespeople to retrofit the building stock, highly specialised engineers undertaking design and installation right across industrial sectors, and energy auditors and managers at many different scales.

Developing employment indicators based on primary research for sub-sectors of this workforce to enable projections is the object of this research. Employment factors are developed for two applications: residential electrification and the installation of EV charging infrastructure.

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1.1. Methods for energy workforce projections

Rutovitz et al. (2021) provide a summary of different methodological approaches for workforce projections. The choice of a method depends on the objectives, data availability and accuracy of results needed. The employment indicator method is well suited to offer insights on jobs and occupational requirements for targeted sectoral changes, and to provide workforce projections based on alternative sector scenarios.

The employment indicator (or employment factor) approach uses an average number of jobs per unit of the scenario (Fragkos and Paroussos, 2018; International Renewable Energy Agency, 2011; Malik et al., 2021; Meyer and Sommer, 2011). On the supply side, the scenarios will generally be framed in capacity of different technologies (MW). Here, the scenario units are numbers of residential appliances or EV chargers installed, so the employment indicator is in terms of jobs per appliance (e.g. jobs per heat pump installation, jobs per cooktop installation, etc.) and per EV charger (jobs/charger). The employment factor enables projections of direct jobs. If the employment factor is accompanied by or includes detailed occupational shares, then these projections can be per occupation.

The employment factor itself is derived from surveys. The calculation is simple; the gross employment factor (total employment for each technology) is shown in Eq. 1:

$$EF_{tech} = \frac{\overline{h}_{tech}}{Y} \quad (1)$$

where EF_{tech} is the gross employment factor for a given technology, $\overline{h}_{tech}$ is the average person hours per technology, and Y is the total working hours in a year. The final results are given in job-years per unit of technology, where one job-year is equal to one year of full-time equivalent (FTE) work.

The occupational employment factor EF_{occ} (Eq. 2) is the job-years per unit of technology in a particular occupation, with the sum of all the occupational employment factors equal to the gross employment factor, where N is the total number of occupations:

$$EF_{tech} = EF_{occ3} + EF_{occ2} + EF_{occ2} \dots + EF_{occN} \quad (2)$$

The occupational employment factor for a particular technology is shown in Eq. 3:

$$EF_{occ_{tech}} = \frac{\overline{h}_{occ_{tech}}}{Y} \quad (3)$$

where EF_{occ_tech} is the hours for a given occupation for a particular technology, $\overline{h}_{occ\_tech}$ is the average person hours per technology for a given occupation, and Y is the total working hours in a year.

The occupational employment share, or the percentage of total workforce requirement for a particular occupation, is shown in Eq. 4:

$$Employment\ share = \frac{EF_{occ_{tech}}}{EF_{tech}} \quad \%\# \quad (4)$$

The scenarios for numbers of residential appliances and numbers of EV chargers are required in order to undertake the workforce projections. Although it was not the focus of the research, these scenarios are presented.

1.2. What are the data and information gaps?

The importance of energy efficiency and electrification in the energy transformation is well recognised, as is the necessity to increase the energy workforce (Sovacool et al., 2023; International Energy Agency, 2023a; International Energy Agency, 2023b). However, characterisation of the workforce for energy efficiency and electrification is at a very early stage, with severe data limitations regarding employment in energy efficiency and electrification (Rutovitz et al., 2021; Malik et al., 2021). These information gaps lead to this aspect of the energy sector labour force usually being omitted despite being integral to achieving net zero emissions. A recent review of evidence on employment in the low carbon transition specifically mentioned employment in renewable energy and energy efficiency twenty-three times, but only one of the eighteen studies reviewed was focussed on energy efficiency, and only six included energy efficiency (Hanna et al., 2024). By comparison, the power sector was included in seventeen of the eighteen studies, and was an exclusive focus of eleven. In another study, an examination of the job creation potential of low carbon buildings reviewed twenty-eight energy employment studies; only eight included energy efficiency with just four of those being energy efficiency focussed (eighteen focussed on the power sector and twenty-four included the power sector) (Sovacool et al., 2023). One of the few studies that includes energy efficiency employment factors is Brown et al. (2020), which calculates employment factors for residential, commercial and industrial energy efficiency using a denominator of $USD million. That work does not provide information on occupational shares, nor cover residential electrification tasks such as replacing gas appliances. There are sources which evaluate the economy wide employment impacts of electrification of transport (Rajagopal, 2023; Alabi et al., 2022; Nieto et al., 2024). These are important for policy makers when assessing the overall impact of electrification policies, but do not provide the information needed for workforce planning. The authors were unable to find any literature on the labour hours or occupations associated with installation of EV charging infrastructure, although there is comparison of the employment impact of manufacturing EVs versus internal combustion engine vehicles (Cotterman et al., 2024). In summary, there is scant information on employment factors for residential energy efficiency and electrification, almost no information on employment associated with EV charging infrastructure, and very little quantification of occupational shares.

1.3. Objectives of this work

The lack of systematic employment factors for the demand side workforce leads to employment estimates that are widely divergent (Rutovitz et al., 2021; Green Energy Markets, 2019), and the lack of occupational information makes planning for the workforce very challenging. The objectives of this paper are to address some of the data gaps by:

- describing a methodology for calculating the workforce for residential electrification and EV charging infrastructure for road vehicles, and
- presenting a set of employment factors and occupational shares for installation and maintenance of residential water heating, space conditioning and cooking, and for public EV charging infrastructure.

This information could enable other researchers, policy makers, and training providers to model the workforce needed for these elements of electrification.

2. Material and methods

This research was developed in two streams: residential electrification and EV charging infrastructure. The former concerns the shift from gas to electric for residential services. The latter is related to the implementation of EV chargers both at private and public sites.

For the residential electrification stream, thirteen technologies were modelled, from three different technology categories.

2.1. Calculating residential electrification employment

Calculating the employment in residential appliances and for electrification required characterising the situations where appliances are installed and deriving corresponding employment factors. The basic unit is a single appliance installation (or maintenance visit). Fig. 1 summarises the employment calculation and the most important data inputs for the five situations identified, namely:

1) New homes installations
2) New installations in existing homes
3) Like-for-like appliance replacements at end of life
4) Replacements of gas appliances with electric
5) Appliance maintenance.

The calculations for total employment in each situation are given in Eqs. 5–9. The employment factors (EFs) all have units of job-years per appliance.

$$Installation\ employment\ in\ new\ homes = appliances\ installed \times EF_{new\_homes\_installation}\# \tag{5}$$

$$Installation\ employment\ in\ existing\ homes = appliances\ installed \times EF_{existing\_homes\_installation}\# \tag{6}$$

$$Employment\ replacing\ like - for - like = appliances\ replaced \times EF_{replacement\_with\_same}\# \tag{7}$$

$$Employment\ replacing\ gas\ with\ electric = appliances\ replaced \times EF_{replacing\_gas}\# \tag{8}$$

$$Maintenance\ employment = total\ stock \times EF_{maintenance}\# \tag{9}$$

2.1.1. Deriving employment factors

The research sought to derive employment factors for both the gross time involved and the occupational share for each element. Employment factors are derived from expert surveys, and appliance numbers are calculated from stock change scenarios and lifespans for different situations. These two elements provide the key inputs, following which there is a straightforward multiplication.

Employment factors are derived from surveys in terms of hours per appliance and then converted to a full-time equivalent job-years/

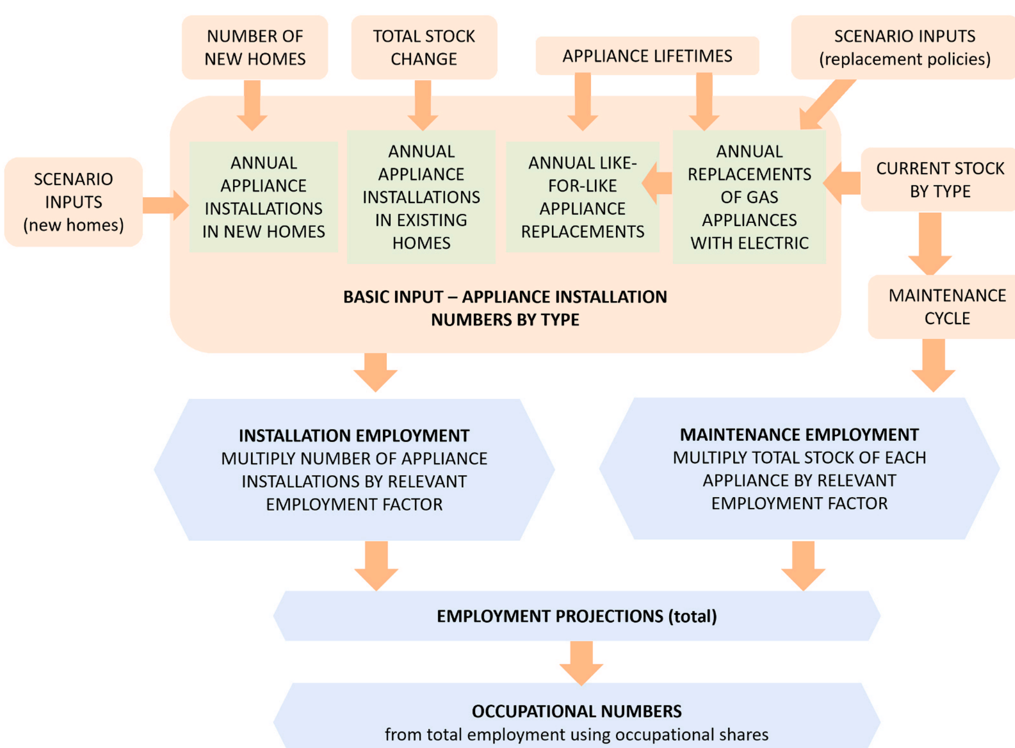

Fig. 1. Employment calculation for residential electrification.

appliance (Eqs. 1–4).

For maintenance, the employment factor is the number of hours for a maintenance visit divided by the assumed maintenance cycle for the relevant appliance, converted to full-time equivalent job-years in the same way that installation hours are converted (Eqs. 1–4). This derivation is shown in Eq. 10 (unit job-years):

$$\textit{Maintenance employment factor} = \frac{\textit{hours per visit}}{\textit{maintenance cycle}(\textit{years}) \quad \times \textit{working hours per year}} \tag{10}$$

One of the advantages of the method is it is simple and yet comprehensive. In a straightforward example, if one knows that it takes on average 2.44 h for an electrician to replace a gas cooktop with an electric cooktop, then the employment factor for this occupation in this situation is:

$$EF_{electrician.gas_{to_{electric_{cooktop_{replacement}}}}} = \frac{2.44}{1680} = 1.452 \quad \times 10^{-3} \quad \frac{job - years}{cooktop} \# \tag{11}$$

The employment factor (EF) is converted assuming 1680 h per year for one FTE (Eq. 5). Then, if the estimate is for 40,000 gas cooktops to be replaced with electric cooktops in 2040, there will be a demand for 58 FTE electricians in that year to undertake all the replacements.

Employment factors were calculated for four of the five situations:

- New home installations: including all appliances except individual gas heaters
- Replacement of appliances with same (like-for-like): this was for replacement of electric with electric, or gas with gas. Replacement was assumed to be at end of life. Employment factors were derived for all appliances except electric immersion heaters.
- Replacement of gas appliances with electric: this can be motivated either by electrification policies and incentives or consumer preferences, and is assumed to occur at end of life. Employment factors were derived for all appliances.
- Maintenance: according to a realistic maintenance cycle or gas safety mandatory maintenance (for tenanted properties). Employment factors were derived for all appliances.

It was not possible to calculate a separate employment factor for new installations in existing homes, such as the addition of ducted heating where only plug in appliances had been used previously. It was initially expected that these would be included as a subset of new homes installations with differentiated employment factors. It emerged that respondents made a bigger distinction between new build and existing homes because installations in new homes were significantly quicker, and did not report different times for installing a new heating system in an existing home compared to replacing a system. The employment factor for replacement was therefore used for these installations. Cooking and hot water appliances were never classed as new installations as it was assumed that all existing homes already have cooking and water heating appliances.

Occupational share was derived from surveys bottom-up based on the volumes of labour for each occupation. The occupational list encompasses 20 occupations within five different 1-digit categories of the Australian and New Zealand Standard Classification of Occupations (ANZSCO), with an overlap of approximately 20 % with occupations for EV charging infrastructure.

Copies of the surveys are available as additional information.

2.2. Determining appliance numbers for each scenario

The number of appliance installations and appliance maintenance visits for each type is calculated based on the current stock data, projections for annual stock changes, and the current penetration of gas and electric appliances in Victorian homes.

To determine the appliances of each specific type installed per year, the stock change for that appliance is needed. The share by group (electric/gas) is applied to the annual stock change per category (for example water heating or space conditioning), and the appliance share within that category and group is applied (Eq. 12).

$$\textit{Appliance stock change} = \textit{category stock change} \times \textit{group share of category} \times \textit{appliance share of group} \tag{12}$$

Overall stock change by category is taken directly from the Australian Residential Baseline Survey (RBS) (Australian Government, 2021), for all years and in all scenarios. The group share (gas or electric) for new home installations is derived from current penetrations in Victoria, and this largely determines the overall group share in the stock changes. The proportion of each specific appliance within category groups (for example, electric water heating) is then taken directly from RBS data.

Appliance numbers are derived for each of the five nominated situations for appliance scenarios.

2.2.1. Appliance scenarios

The baseline, or "business as usual", scenario is calculated from the current stock data and the RBS projection on overall stock changes, modified with information on the current share of gas and electric appliance installation. Two further scenarios were developed based on policies aimed at achieving electrification of home appliances:

- New Homes: this is a partial electrification scenario, in which all appliances installed in new homes are electric by 1 January 2028, and
- All Homes: this is a more extensive electrification scenario in which all gas replacements for heating, cooking or water heating appliances are disallowed from 1 January 2027.

In modelling terms, the change in installations in new homes was assumed to take effect gradually with full effect by 31 December 2027, reflecting the reality that homes granted planning permission prior to policy enactment would be exempt. The All Homes scenario type change for replacements was modelled as a sharp change, with like-for-like replacements assumed prior to 2027, and all replacements of gas appliances being with electric appliances from 1 January 2027 onwards.

2.2.2. Calculating installations in new homes

Information specific to new home installations is not available so in the employment calculations these need to be separately accounted for. This is because the time it takes to install in new build is markedly different from installations in existing homes. The RBS data does not distinguish between stock changes from new builds and those from existing homes. To address this, the stock change was independently calculated using projections of new home construction and assumptions about the share of gas and electric appliances in new buildings. The current proportions of Victorian homes with gas hot water (61 %), gas space heating (51 %) and gas cooktops (68 %) (Sustainability Victoria, 2023), and the penetration of electric space conditioning (80 %) (Australian Energy Market Operator., 2019) are used as proxies for the group shares in new homes.

Table 1 gives the share by appliance group in the RBS annual stock change, and the share used for new homes for each type of appliance in this analysis. In the case of space conditioning, homes frequently use both gas and electric, with the result that the sum of gas plus electric space conditioning systems is 131 % the number of homes. This results in 61 % of total appliance stock for space conditioning being electric. In the case of cooking, these shares are applied to cooktops and ovens combined, with each home assumed to have two cooking appliances. All new homes are expected to have an electric oven and 68 % of new homes to have a gas cooktop, resulting in the share of combined cooking

Table 1
Share of stock changes in new homes by appliance group (RBS data and baseline scenario).

	RBS share in annual stock change			Share used for new homes (baseline scenario)		
	2024	2028	2040	2024	2028	2040
Gas hot water	83 %	83 %	90 %	61 %	61 %	90 %
Electric hot water	17 %	17 %	10 %	39 %	39 %	10 %
Electric space conditioning	71 %	73 %	99 %	61 %	73 %	75 %
Gas space heating	29 %	27 %	1 %	39 %	27 %	25 %
Electric cooking	85 %	75 %	75 %	66 %	66 %	66 %
Gas cooking	15 %	25 %	25 %	34 %	34 %	34 %

appliances (ovens and cooktops) being 66 % electric and 34 % gas.

New home installations are straightforward to calculate, as the number of new homes is a model input. This is multiplied by the share of each appliance group using the percentage shares given in Table 1, with the distribution of individual appliances in that group taken as the RBS distribution of appliances for the stock change in that group (Eq. 13).

$$\text{New homes installations}_{app} = \text{Number of new homes} \times \text{category multiplier} \times \text{group share} \times \text{appliance\%} \tag{13}$$

The category multiplier is 1.31 for space conditioning, 2 for cooking appliances, and 1 for water heating.

A sample calculation for new homes installations is given in Table 2. As an example, in 2026 it is projected that 52,787 new homes will be built and assumed that each home will have one hot water heating system. The individual appliance numbers are calculated from the group split (that is, gas or electric) and the distribution within that group.

The use of current penetrations rather than the RBS projected shares makes a material difference to the percentage of gas and electric appliances, as shown in Table 3. The appliance groups most affected are electric hot water and gas cooking, although the overall numbers of appliances in each category remain the same. The percentage changes in group shares are not equivalent as the overall numbers of electric hot water heaters, for example, is far lower than the number of gas hot water heaters.

In the New Homes scenario all installations previously implemented as gas are switched to electric, effectively modifying the group shares in Table 1.

2.2.3. Calculating new installations in existing homes

New installations in existing homes are derived by starting with the difference between the RBS category stock change minus the new homes category installations. If new installations are greater than the stock change, it is assumed that there are zero new installations in existing homes. If the stock change is greater than new home installations, the individual appliance numbers are calculated by apportioning the difference according to the RBS distribution of individual appliances in the group stock change (Eq. 14).

$$\text{New installations existing homes}_{app} = [\text{Stock change}_{cat} - \text{Newhomes installinons}_{cat}] \times \frac{\text{baseline stock change}_{app}}{\sum \text{stock changes}_{cat}} \tag{14}$$

Table 3
Change to overall group share from using RBS stock change to current penetrations.

	2024	2030	2040
Electric hot water	8 %	17 %	22 %
Gas hot water	-2 %	-4 %	-5 %
Electric space conditioning	-1 %	-1 %	-3 %
Gas space heating	1 %	2 %	8 %
Electric cooking	-2 %	-4 %	-6 %
Gas cooking	5 %	9 %	13 %

Table 4 gives a sample calculation for existing homes. If the stock of the hot water heating category was 3080,622 in 2025, and 3137,440 in 2026, the stock change for 2026 is 56,818 new units. Thus 52,787 go to new homes, leaving 4,031 new units to go to existing homes. The distribution of appliances from the RBS category stock change is then applied, i.e. those with increased (or positive) change, as shown for electric immersion in Table 4).

2.2.4. Calculating replacement and maintenance numbers

Replacement and maintenance numbers are calculated from the current stock number for each appliance. Current stock uses the baseline stock number adjusted for the cumulative type changes relevant to the scenario. Type switches are specific to each scenario, as this is how the modelled policy is applied.

$$\text{Current stock}_{app} = \text{Baseline stock}_{app} + \sum[\text{New home installation type switch} + \text{Existing home installations type switch} + \text{replacement type switch}]_{all\ years} \# \tag{15}$$

Replacements are calculated by dividing the current stock for the given year, less the new homes installations for that year, by the lifetime of the appliances (Table 5). Type changes are applied to replacements in the All Homes scenario, and become part of the calculation of current stock.

$$\text{End of life replacements}_{app} = \frac{\text{Current stock} - \text{new installations}}{\text{Lifetime}_{app}} + \text{type switch}_{app} \# \tag{16}$$

Type switch for replacements is zero in the baseline and the New Homes scenario; in the All Homes scenario it is negative for gas and positive for electric appliances.

Maintenance numbers are calculated by dividing the total stock by the maintenance cycle.

$$\text{Maintenance}_{app} = \frac{\text{Current stock} - \text{new installations}}{\text{Maintenance cycle}_{app}} \# \tag{17}$$

2.3. Residential installer surveys

There were seventeen respondents in total to the residential installer survey (Table 6 gives the number for each technology). Respondent

Table 2
Sample calculation – new home water heater installations.

Technology	Group	Group %	Distribution with appliance group	New home % installation	New home installations 2026[1]
Electric immersion	Electric hot water	39 %	11 %	4.5 %	2367 units
Heat pump	Electric hot water	39 %	88.5 %	34.5 %	18,220 units
Solar electric boost	Electric hot water	39 %	0 %	0 %	0
Gas instantaneous	Gas hot water	61 %	87 %	52.9 %	27,925 units
Gas storage	Gas hot water	61 %	0 %	0 %	0
Solar gas boost	Gas hot water	61 %	13 %	8.1 %	4276 units

Note 1: based on input data of 52,787 new homes

Table 4
Sample calculation existing home water heating installations.

	Δ stock in RBS	Calculated Δ stock for existing homes
Electric immersion	2,337	$4,031 \times \frac{2,337}{2,337 + 22,182 + 40,846 + 5,691} = 133$
Heat pump	22,182	1258
Solar electric boost	-912	0
Gas instantaneous	40,846	2317
Gas storage	-13,326	0
Solar gas boost	5691	323
TOTAL	56,818	4031

Table 5
Appliance lifetimes and maintenance cycles.

	Lifetime in years[a]	Maintenance cycle in years[b]
Electric and gas hot water	13	5
Heat pump water heating	12	5
Solar electric/solar gas	15	5
AC ducted/non-ducted	15	5
Gas individual heaters	23	7.4
Gas ducted	23	5
Cooking (electric)	14	5
Cooking (gas)	14	7.4

[a]Lifetimes are from the RBS.
[b]The maintenance cycles for gas cooking and individual heaters are calculated with a maintenance cycle of 2 years for rented properties due to requirement for gas safety checks and no maintenance for owner occupiers, with 27 % of dwellings rented.

numbers for specific technologies and situations varied considerably, from only two for electric immersion installations to nine for heat pumps, gas instantaneous, and reverse cycle heating. Table 6 also gives the coverage for each technology in numbers and as a percentage of total annual installations. The percentage is calculated from the installations stated by respondents compared to the number of installations estimated by the model. Both respondent numbers and survey estimations include new installations in new homes, new installations in existing homes, like-for-like replacements, and replacements from gas to electric. While the percentage of annual installations covered for five technologies is low (1–2 %), actual numbers of installations by survey respondents are generally in the hundreds. The only exception is hydronic heating, with only 39 estimated annual installations. This technology is not included in the RBS, and no employment indicator is derived.

Survey respondent installations relative to modelled installations are high for solar electric boost water heating, and over 100 % for reverse cycle air-conditioning. The survey question was “Approximately how many installations of this technology would you expect to do in a year?” An explanation for the response rate over 100 % may be that the respondent undertakes installations outside Victoria, while the modelled installations are for Victoria alone, or that their response was an overestimate. In either case, it is likely that the respondent carried out a large number of installations relative to the total installations in the state.

2.4. Electric vehicle charging infrastructure

The overall method for modelling employment for EV charging infrastructure is similar to that used for residential electrification. Different charger types were taken as the basic technology unit. The employment calculations are given in Eqs. 18 – 20, all with units of job-years.

$$\textbf{\textit{Employment designing and installing}} = \textbf{\textit{chargers installed each year}} \times \textbf{\textit{EF}}_{\textbf{\textit{design\&installation}}} \quad \# \tag{18}$$

$$\textit{Employment operating and managing} = \textit{Cumulative chargers} \times EF_{operation\&management} \# \tag{19}$$

$$\textit{Employment maintaining} = \textit{Cumulative chargers} \times EF_{maintenance} \quad \# \tag{20}$$

Employment factors were derived for each type according to project phase and then scaled according to scenarios for numbers of chargers installed per year. The employment factors and the occupational shares were derived using installer surveys.

Five technologies were identified for employment modelling, corresponding to the different charger levels and situations (Table 7). In all cases these were assumed to be dedicated AC EV chargers. Installers

Table 7
Modelled technologies for EV charging infrastructure.

Charger category	Modelled technologies
Private	Level 2 chargers (AC) (residential)
	Level 2 chargers (AC) (commercial)
	Level 3 chargers (DC) (commercial) (25 kW to 350 kW)
Public/semi-public	Level 2 chargers (AC)
	Level 3 chargers (DC) (25 kW to 350 kW)

Table 6
Number of respondents and coverage compared to total residential installations.

Technology category	Modelled technologies	Total respondents	Respondent installations (units per year)	2023 total modelled installations	Proportion
Hot water heating	Electric immersion	2	200	37,091	0.5 %
	Heat pump	9	2280	11,542	20 %
	Solar electric boost	4	2000	2254	89 %
	Gas instantaneous	9	700	137,533	1 %
	Gas storage	6	500	62,011	1 %
	Solar gas boost	5	800	29,194	3 %
Space conditioning	Reverse cycle ducted	9	23,690	21,730	109 %
	Reverse cycle non-ducted	9	111,870	210,299	53 %
	Heat pump hydronic	2	39	0	n/a
	Gas ducted	8	8515	86,964	10 %
	Gas individual heater	7	0	18,875	0 %
Cooking products	Electric	5	3305	209,122	2 %
	Gas	5	800	112,283	1 %

surveys were undertaken to estimate gross employment per charger installation for each case. Three different project phases are considered: design and installation, operation and management, and maintenance. Level 1 chargers were not included as these utilise existing power points, supplying power to an EV using a specialised cable that is typically provided with the vehicle.

2.4.1. Deriving EV charger numbers

The primary input data for deriving charger numbers are the projected numbers of electric vehicles, from the Electric Vehicle Assumptions Book (Australian Energy Market Operator, 2023). The workbook gives projections for electric, hybrid, fuel cell, and internal combustion vehicles up to 2050 for five scenarios. Annual additions of chargers are derived from the yearly stock change of vehicles multiplied by the ratio of vehicles to chargers. Each charger type covers multiple vehicle types, and Table 8 gives the vehicle grouping used in the model. All vehicles apart from articulated trucks, rigid trucks, and buses were classed as light vehicles.

The number of chargers is calculated based on projected electric vehicle stocks, combined with assumptions for the capacity of each charger type and the percentage split between charger types (Eqs. 21 and 22). For private chargers, the number of vehicles per charger is used to determine the charger additions:

$$\text{Annual additions of private chargers} = \frac{\text{Stock change of vehicles}}{\text{vehicles per charger}} \# \tag{21}$$

For public chargers, the total capacity of charger per vehicle is used:

$$\text{Annual additions} = \frac{\text{Stock change of vehicle} \times \text{total capacity per vehicle} \times \text{split by charger type}}{\text{capacity for charger type}} \# \tag{22}$$

Only light vehicles were used to project public chargers for modelling purposes. Most available data on public charger penetration are confined to light vehicle charging, as these chargers dominate the installed and forecast fleet (International Energy Agency, 2023c). It is also assumed that truck and bus charging will be installed by fleet operators in an analogous manner to depot locations, with numbers tightly optimised, so that charger capacity for these vehicles overall is less affected by whether the charger is public or private.

Assumed penetration of chargers per vehicle category and the distribution between charger types are shown in Table 8 (a linear interpolation is used for intermediate years).

The number of vehicles per charger for trucks came directly from survey information, which advised there is one Level 2 charger per truck (22 kW), with two trucks per Level 3 fast charger (100 kW), corresponding to 0.67 vehicles per charger. The power levels of fast chargers are likely to increase over time as the technology of the vehicles and chargers evolve. Vehicles per fast charger are assumed to increase from two to three by 2040, with the slower chargers still one per vehicle, taking the overall ratio to 1.33 vehicles per charger. Buses were assumed to follow the same pattern.

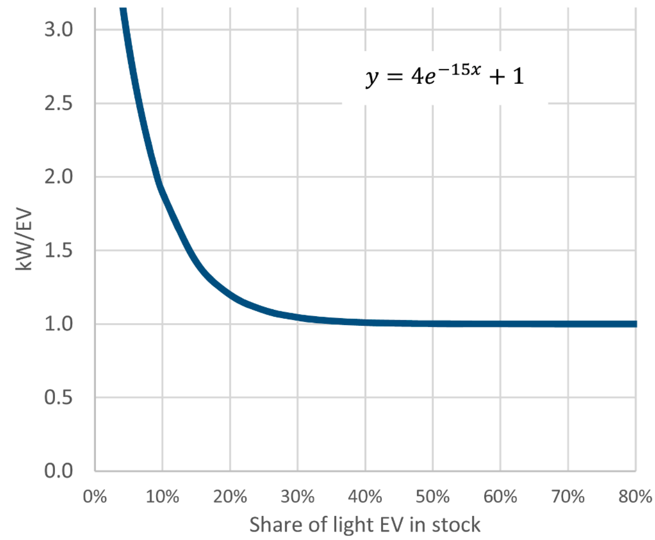

Fig. 2. Public charger capacity as a function of stock share (light duty vehicles only).

Adapted from Bernard et al. (2022).

For public chargers, the calculation is based on the observation that there is a common trend globally when comparing available public charger capacity per EV to the share of EVs in total vehicle stock, that tends towards 1 kW/vehicle (Bernard et al., 2022). This trend was used to calculate total public charger capacity for light vehicles for the Victorian case study, using the equation in Fig. 2. Table 9 gives the calculated capacity per EV for the three different scenarios, the assumptions for charger total capacity and the distribution between charger types. All three scenarios reach the endpoint of one kW capacity of public chargers per light EV by 2040. However, the trajectory varies, with the faster growth in EVs resulting in lower capacities per vehicle.

Eq. 23 is used to derive the number of chargers N:

$$N = \frac{EVs \times D \times Lv}{C} \# \tag{23}$$

where EVs is the number of electric vehicles of each type, D is the demand per vehicle in kW, Lv is the percentage split between Level 2 and Level 3 charger types, and C is the capacity of each charger. For light vehicles, it is an exponential function of the share of EVs over total vehicle stocks, that tends to 1 when the share is more than 50 %.

Table 10 gives an example of calculating the total number of (cumulative) chargers from vehicle stocks. The cumulative chargers are calculated from the vehicle stock for all years in the time series in order to calculate the annual increment. Design and construction employment is calculated from the annual increment, while operations and management, and maintenance employment are calculated from each year's cumulative total.

Table 8
Vehicle categories and number per charger.

Modelled category	AEMO vehicle type	Number of vehicles per charger in	2022	2040
Light vehicles (residential)	Small, medium, and large light commercial	Level 1 residential	2.0	2.0
		Level 2 residential	1.7	2.5
Light vehicles (commercial)	Small, medium, and large light commercial	Level 2 & 3 combined	1	2.0
		% of Level 2 commercial	80 %	25 %
		% of Level 3 commercial	20 %	75 %
Large trucks and buses	Articulated and rigid trucks, buses	Level 2 & 3 combined	0.67	1.33
		% of Level 2	67 %	67 %
		% of Level 3	33 %	33 %

Table 9
Assumed capacity and distribution by charger type, and calculated capacity by scenario.

	2022	2028	2030	2040
	Calculated public charger capacity per light duty EV			
Scenario 1: Progressive change	4.9	4.1	3.1	1.0
Scenario 2: Step Change	4.9	2.0	1.3	1.0
Scenario 3: Green Energy Exports	4.8	1.4	1.1	1.0
	Assumed capacity of each charger in kW			
Level 2 public charger (light vehicles)	22	22	22	22
Level 3 public charger (light vehicles)	50	69	75	100
	Assumed % split between charger types			
Level 2 public charger (light vehicles)	80 %	70 %	57 %	50 %
Level 3 public charger (light vehicles)	20 %	30 %	43 %	50 %

2.4.2. *Occupational shares*

The employment factor was derived bottom-up based on the volumes of labour for each occupation. The occupational list was developed from ANZSCO by the authors. There were some revisions to the list of occupations and titles based on interviews with industry association staff and two member companies. These companies were identified by the industry association as major installers and a good source to develop an occupational list reflecting industry practices.

2.5. *EV charging infrastructure installer surveys*

There were six respondents, with usable data from five. The following project phases were included: design and installation, operation, and maintenance. While the number of respondents is low, the coverage is high, with 1600 public chargers either maintained or operated by survey respondents (Table 11). It was estimated that there were 2570 public chargers in Australia at the end of 2022 (International Energy Agency, 2023c), so this is over 60 per cent of the total stock. Analogous to residential electrification, after deriving the employment factors and the number of chargers, the calculation of jobs is a simple multiplication.

To estimate workforce requirements for electric vehicle (EV) infrastructure deployment, we conducted structured expert surveys with key stakeholders in the Australian public EV charging market. Survey participants were drawn from eight major organisations identified as leading public charging infrastructure providers, selected using publicly available sources such as national charging network maps and industry directories. Of the eight organisations approached, five participated in the study although survey results from one participant was deemed unusable following analysis given major inconsistencies in the data they provided. Each survey was administered via online video conferencing software, with researchers present to guide participants through the questions and clarify content due to the complexity of the survey. Participants were recruited based on their direct involvement in EV infrastructure planning or operations, their role, and their recognised share of the market.

Several strategies were employed to mitigate potential bias and ensure robustness given the small number of respondents. Firstly, participants were selected based on market share, industry prominence and technical expertise. Second, the surveys were conducted in a structured, researcher-facilitated format to ensure consistency in interpretation and response. Thirdly, where feasible, responses were cross-validated with

Table 10
Sample calculation for cumulative chargers at 2030.

	Vehicle stocks	Level 2 chargers	Level 3 chargers
		CUMULATIVE PRIVATE CHARGERS	
Large trucks BEV	957	$\frac{(957+1,681)}{1} = 2,638$	$\frac{(957+1,681)}{2} = 1,319$
Large trucks PHEV	1681		
Buses BEV	100	$\frac{(100+0)}{1} = 100$	$\frac{(100+0)}{2} = 50$
Buses PHEV	0		
LIGHT VEHICLES			
BEV (residential)	170,975	$\frac{(170,975+324)}{2,25} = 76,133$	-
PHEV (residential)	324		
BEV (commercial)	31,509	$\frac{(31,509+2,444)}{7,16} = 4,739$	$\frac{(31,509+2,444)}{4,25} = 7,993$
PHEV (commercial)	2444		
		CUMULATIVE PUBLIC CHARGERS	
Total stock (light vehicles)	4737,711	$\frac{202,484 \times (4e^{-15\times4.3\%}+1)\times 0.57}{22} = 16,204$	$\frac{202,484 \times (4e^{-15\times4.3\%}+1)\times 0.43}{75} = 3,635$
Light vehicles EV	202,484		
Penetration of EVs	4.3 %		

Table 11
Number of respondents and coverage by EV charger type and project phase.

Site type	Charger type	Number of respondents				Numbers of chargers per year estimated by respondent	
		Design & installation	Operation	Maintenance	Total	Designed/ installed	Operated or maintained[a]
Private	Level 2 (residential)	2	2	2	2	7600	22,800
	Level 2 (commercial)	2	2	2	2	2119	6357
	Level 3	2	2	2	2	554	3988
Public/ semi-public	Level 2	3	3	3	3	2069	1068
	Level 3	4	4	3	4	654	530

[a]The total given is the maximum response for operation or maintenance.

Table 12
Initial survey results and variation (residential electrification).

	Modelled technologies	No of responses[a]	Installations covered by survey (units/ year)	Total person hours per installation			
				Weighted average	Average	Max	Min
			NEW INSTALLATIONS				
Water heating	Electric immersion	2	200	16.5	10.3	16.5	4
	Heat pump	7	2280	3.7	7.9	16.5	2
	Solar electric boost	2	2000	8	8	8	8
	Gas instantaneous	3	700	5.6	5	7	2
	Gas storage	2	500	7	6.5	7	6
	Solar gas boost	2	800	6.3	5.8	8	3.5
Space conditioning	Reverse cycle ducted	8	23,690	15.7	24.1	80	6
	Reverse cycle non-ducted	8	111,870	4.1	5.7	10	2.5
	Gas ducted	4	8515	7.1	14.1	25	7
Cooking	Electric	3	3305	1.0	3.75	8	1
	Gas	2	800	2.5	3.5	4	2.5
			REPLACEMENT LIKE-FOR-LIKE				
Water heating	Heat pump	3	6405	5.1	8.2	10	5
	Solar electric boost	2	700	9	6	9	3
	Gas instantaneous	2	400	11.5	6.8	11.5	2
	Gas storage	2	200	11.5	6.8	11.5	2
	Solar gas boost	2	100	9	6.5	9	4
Space conditioning	Reverse cycle ducted	10	40	7.4	11.7	20	4
	Reverse cycle non-ducted	8	27	8.9	6.5	9.5	3
	Gas ducted	2	5	10.00	7	10	4
	Gas individual heater	2	2600	3.5	3.8	4	3.5
			REPLACEMENT FROM GAS TO ELECTRIC				
Hot water	Electric immersion	2	100	17.5	10.25	17.5	3
	Heat pump	14	8214	10.1	10.1	24	4
	Solar electric boost	4	1100	10.0	12	24.5	5
Space conditioning	Reverse cycle ducted	11	118	15.8	16.2	40	3
	Reverse cycle non-ducted	12	631	7.1	7.1	11	3
Cooking	Electric Cooking	6	16	8.7	6.9	12	2

a. Some reported data have been modified to protect confidentiality; This does not impact the results.

publicly available infrastructure deployment data and internal documentation. While estimates varied considerably, this variability itself is indicative of meaningful differences in business models, technology configurations, and operational practices, which were preserved in the analysis to reflect the current complexity and immaturity of the sector. These steps collectively help to ensure that the findings are representative of current industry perspectives and provide a credible foundation for workforce estimation in this emerging field.

3. Results

The results presented are the employment factors for each technology and situation, and the corresponding occupational shares.

3.1. Residential electrification

The initial results from the surveys are the person hours required to do one installation of each type. Calculated results are shown in Table 12, along with the weighted average, the maximum, minimum,

Table 13
Average hours and employment factors for installations (residential electrification).

	Average hours			Employment factor[a]		
	New installation	Replace with same	Replacing gas	New installation	Replace with same	Replacing gas
		hours/ installation			Job-years/installation	
HOT WATER HEATING						
Electric immersion	16.5	-	17.5	0.0098	-	0.0104
Heat pump	3.7	5.1	10.1	0.0022	0.0030	0.0060
Solar electric boost	8.0	9.0	10.0	0.0048	0.0054	0.0059
Gas instantaneous	5.6	11.5	n/a	0.0033	0.0068	n/a
Gas storage	7.0	11.5	n/a	0.0042	0.0068	n/a
Solar gas boost	6.3	9.0	n/a	0.0038	0.0054	n/a
SPACE CONDITIONING						
Reverse cycle ducted	15.7	7.4	15.8	0.0094	0.0044	0.0094
Reverse cycle non-ducted	4.1	8.9	7.1	0.0024	0.0053	0.0042
Gas ducted heating	7.1	10.0	n/a	0.0042	0.0060	n/a
Gas individual heater	-	3.5	n/a	-	0.0021	n/a
COOKING						
Electric	1.0	-	8.8	0.0006		0.0052
Gas	2.5	-	n/a	0.0015		n/a

a. Converted to employment factor (EF) assuming 1680 h per year is equal to 1 FTE.

Table 14
Average hours and employment factors for maintenance (residential electrification).

	Hours per visit	Maintenance cycle used in model	Hours per year/ appliance	Job-years/ year
HOT WATER HEATING				
Electric immersion	1.0	5	0.20	0.00012
Heat pump	1.0	5	0.20	0.00012
Solar electric boost	1.0	5	0.20	0.00012
Gas instantaneous	1.8	5	0.36	0.00021
Gas storage	1.8	5	0.35	0.00021
Solar gas boost	1.8	5	0.35	0.00021
SPACE CONDITIONING				
Reverse cycle ducted	1.2	5	0.23	0.00014
Reverse cycle non-ducted	1.0	5	0.20	0.00012
Gas ducted heating	1.7	5	0.35	0.00021
Gas individual heater	1.5	7.4	0.20	0.00012
COOKING				
Electric	Set equal to gas	5	Set equal to gas	Set equal to gas
Gas	2.0	5	0.27	0.00016

Table 15
Occupational share new installations and replacement like-for-like (residential).

	HOT WATER HEATING						SPACE CONDITIONING				COOKING	
	Electric immersion	Heat pump	Solar electric	Gas instant	Gas storage	Solar gas	Reverse cycle ducted	Reverse cycle non-ducted	Gas ducted	Gas individual heater	Electric	Gas
NEW INSTALLATIONS												
Architectural draftsperson		1.8 %					0.4 %		1.0 %			
Project manager							0.4 %		1.0 %			
Project estimator		1.8 %										
Electrician	29.5 %	30.7 %	12.5 %	10.7 %	3.6 %	7.1 %	14.1 %	25.0 %	10.6 %		93.3 %	
Trade assistant (general)		5.7 %										
Refrigeration & AC technician							52.2 %	57.9 %	30.2 %			
HVAC apprentice							6.7 %					
Heating engineer[a]							7.1 %					
Gas fitter				33.3 %	25.0 %	28.6 %			43.2 %	50.0 %		65 %
Plumber	50.8 %	44.6 %	87.5 %	44.0 %	53.6 %	57.1 %	14.3 %	14.3 %	14.0 %	50.0 %		35 %
Administrative assistant	4.5 %	7.6 %		7.1 %	10.7 %	7.1 %	3.2 %	1.4 %			3.3 %	
Sales	3.0 %	4.3 %		4.8 %	7.1 %		1.6 %	1.4 %			3.3 %	
Concreter	12.1 %	3.5 %										
REPLACEMENT LIKE-FOR-LIKE												
Electrician	**15.0 %**	**31.1 %**	**5.6 %**			**5.6 %**	**13.7 %**	**25.1 %**	**10.0 %**		**93.3 %**	**15 %**
Refrigeration & AC technician							64.8 %	51.8 %				
Heating engineer										42.9 %		
Gas fitter	75.0 %	61.1 %	94.4 %	84.8 %	84.8 %	94.4 %	16.7 %	20.0 %	90.0 %	50.0 %		100 %
Plumber							2.8 %					
Plasterer	2.5 %	2.6 %		10.9 %	10.9 %		0.5 %	1.1 %		7.1 %	3.3 %	
Administrative assistant	7.5 %	5.3 %		4.3 %	4.3 %		1.6 %	2.1 %			3.3 %	

a. Heating engineer includes plumbing and electrical applications

and number of installations undertaken by respondents in each case.

There is considerable variation between the minimum and maximum hours for installations. The greatest variation was found in the new installations and replacement of gas with electric ducted heating systems, with a ratio of 13 between the highest and the lowest hours given. This may reflect the variation between situations where heating is installed.

Survey respondents for heating installations included both single homes and apartments. There was insufficient data to derive a separate indicator for single homes, so the data are merged, with a significantly greater representation for single homes.

Table 13 and Table 14 give the average hours and the employment factors derived for installations and maintenance respectively and can be used to calculate workforce requirements from appliance scenarios covering residential electrification. These are calculated from the survey data in Table 12. Hours for new installation are frequently lower than replacing like-for-like, perhaps reflecting the streamlined process, higher co-ordination of trades, and, in some cases, economies of scale often achieved in new home building.

Table 15 and Table 16 give the occupational shares developed from the survey responses. These percentages are applied to the total employment factors for the relevant appliance class and situation to provide the number of each occupation required for a given scenario.

The residential employment factors can be applied to scenarios for appliance penetration to calculate the overall workforce for new installations, maintenance, like-for-like replacements and electrification of hot water, space conditioning and cooking. Table 17 gives the average mix by occupation required between 2024 and 2040 for a scenario where all homes are electrified by a combination of mandating

Table 16
Occupational share replacement from gas to electric (residential electrification).

	WATER HEATING			SPACE CONDITIONING			COOKING
	Electric immersion	Heat pump	Solar electric	Reverse cycle ducted	Reverse cycle non-ducted	Heat pump hydronic	Electric
Architectural draftsperson		2.6 %	2.5 %	1.1 %	1.3 %		2.8 %
Project manager		5.6 %		4.4 %	5.2 %		11.1 %
Project estimator		2.6 %	2.5 %	1.1 %	1.3 %		2.8 %
Electrician	5.7 %	27.7 %	16.0 %	6.9 %	13.2 %		52.2 %
Electrician (apprentice)			3.1 %				
Trade assistant (general)		3.1 %					
Refrigeration & AC technician				57.2 %	47.2 %		
Heating engineer (plumbing and electrical)	5.7 %	1.2 %	2.0 %			100 %	
Gas fitter				1.0 %	4.1 %		12.5 %
Plumber	78.6 %	48.4 %	69.3 %	16.3 %	19.7 %		12.2 %
Plasterer			1.0 %	7.5 %	4.1 %		
Floor finisher		0.8 %					
Administrative assistant	7.1 %	3.4 %	2.6 %	0.5 %	2.7 %		3.1 %
Sales	2.9 %	3.4 %	1.0 %	0.8 %			3.3 %
Concreter		1.2 %		3.3 %	1.3 %		2.8 %

Table 17
Average occupation shares 2024–2040 for a residential electrification scenario.

	Hot water heating		Space conditioning		Cooking products		All services	Variation (top five occupations)
	Electric	Gas	Electric	Gas	Electric	Gas		
Total employment factor (FTE/10,000 units)	10.6	3.7	5.5	2.7	3.2	2.0	27.8	
Occupational split of jobs								
TRADES & TECHNICIANS	**87.4 %**	**86.6 %**	**79.2 %**	**99.1 %**	**91.1 %**	**99.1 %**	**85 %**	
Draftspersons	0.6 %	-	0.1 %	0.1 %	0.6 %	-	0.3 %	
Electricians	21.9 %	0.9 %	16.1 %	8.8 %	75.9 %	12.4 %	25 %	-37 % / + 14 %
Airconditioning and Refrigeration Mechanics	-	-	48.7 %	1.5 %	-	-	20 %	-44 % / + 19 %
Gas fitters	-	0.9 %	0.1 %	7.3 %	2.6 %	2.5 %	0.9 %	
Plumbers	64.8 %	84.8 %	13.5 %	81.4 %	12.0 %	84.2 %	40 %	-6 % / + 10 %
Plasterers	0.0 %	-	0.7 %	-	-	-	0.3 %	
Floor finishers	0.1 %	-	-	-	-	-	0.0 %	
PROFESSIONALS	**6.4 %**	**3.8 %**	**19.0 %**	**-**	**3.6 %**	**0.4 %**	**10 %**	
Quantity Surveyor	0.6 %	-	0.2 %	-	0.6 %	-	0.3 %	
Heating engineer (plumbing and electrical)	0.7 %	-	17.5 %	-	-	-	7.3 %	-99 % / + 60 %
Sales, Marketing and Public Relations Professionals	5.1 %	3.8 %	1.3 %	-	3.0 %	0.4 %	2.8 %	-25 % / + 9 %
ADMIN STAFF	**3.2 %**	**9.5 %**	**0.8 %**	**0.8 %**	**3.0 %**	**0.4 %**	**3 %**	
LABOURERS	**1.9 %**	**-**	**0.7 %**	**-**	**-**	**-**	**0.9 %**	
Electrical Trade Assistants	-	-	0.4 %	-	-	-	0.2 %	
General Labourers	0.7 %	-	-	-	-	-	0.2 %	
Heating and ventilation apprentices	-	-	0.1 %	-	-	-	0.1 %	
Concreters	1.1 %	-	0.2 %	-	-	-	0.0 %	
MANAGERS	**1.1 %**	**-**	**0.3 %**	**0.1 %**	**2.3 %**	**-**	**0.8 %**	

installation of electric-only services in new homes and requiring gas appliances to be replaced with electric appliances at end of life. This scenario would be different under alternative policies, for example an accelerated programme to replace gas appliances.

Individual occupations are likely to vary over the period. Table 17 gives the difference between the average requirement and the minimum and maximum for all occupations that contribute on average more than 1 % of the total. Plumbers are the least volatile, and heating engineers the most volatile.

The gross workforce required will depend on the mix of new installations, like-for-like replacements and electrification replacements, and the maintenance schedules for existing appliances. Section 2.2 provides a method to calculate appliance installations of each type in each year where a baseline stock projection is available.

Table 18
Design and Installation: survey coverage and outcomes (EV charging infrastructure).

Site type	Charger type	No of responses	Installations covered by survey (units per year)	Total person hours per year/ charger			
				Weighted average	Average	Max	Min
Private	Level 2 (residential)	2	7600	**5.3**	4.4	5.5	3.3
	Level 2 (commercial)	2	2119	**3.4**	2.7	3.7	1.7
	Level 3	2	554	**14.5**	12.0	20.3	3.8
Public / semi-public	Level 2	3	2069	**5.2**	14	34	2.0
	Level 3	4	654	**114.2**	151	417	5.8

Table 19
Operation and maintenance: survey coverage and results (EV charging infrastructure).

Site type	Charger type	No of responses	Chargers operated or maintained by respondents	Total person hours per year/ charger			
				Weighted average	Average	Max	Min
Private	Level 2 (residential)	2	22,800	**1.9**	1.5	2.0	1.0
	Level 2 (commercial)	2	6357	**2.1**	2.5	3.0	2.0
	Level 3	2	1068	**1.8**	1.3	2.0	0.5
Public / semi-public	Level 2	2	350	**1.3**	3.1	5.5	0.6
	Level 3	3	530	**11.4**	10.1	22.4	0.5

Table 17 gives the average overall employment per 10,000 appliance installations or maintenance visits, and the occupational share for the workforce. It should be stressed that this is an example, as the occupational shares and the total will depend on the appliance scenario in question.

3.2. EV charging infrastructure

The key result obtained from the EV installer surveys is the total person hours required to do one installation of each kind of charger, and the corresponding employment factor. The employment factor is different for each project phase.

Table 18 gives the values obtained from surveys for total hours for design and installation, and Table 19 for operation, management and maintenance. The variation between maximum and minimum is significant, reflecting that the industry is at an early stage of development. One response was excluded for maintenance, as it was an extreme outlier with other responses clustering in a narrow range (a factor of five greater than the closest maximum, and ten times greater than the weighted average response).

Table 20 gives the total hours for and the employment factors for both project phases. Table 21, Table 22 and Table 23 present the occupation share of these total hours for each situation.

3.2.1. Changes to employment factors over time

EV charging and the industry to support it is immature and evolving rapidly, and survey respondents were asked to quantify how employment hours would change as the industry matured. They did not, in general, consider that installations times would be reduced, and studies are inconclusive about whether installation costs are likely to go up or come down (Nelder and Rogers, 2019). However, the industry is at a very early stage, and the geographical and operational density of installations for both maintenance and operations is likely to increase. A learning rate is therefore applied to all but installation employment. Electric power infrastructure excluding coal and hydro generation, and battery EVs themselves, have demonstrated learning rates of between 11 % and 23 % (Rubin et al., 2015; Weiss et al., 2012). A learning rate of 12 % was used to derive a decline factor. Table 24 shows the decline factors derived for each scenario. As learning rates are applied with each doubling time the decline varies by scenario, resulting in decline rates of between 46 % and 55 % by 2040. The weighted average is slightly lower than the simple average as private light vehicles have a higher growth rate, and therefore a quicker doubling rate.

The derived decline factor for the relevant year is applied to the initial employment factor as shown in Eq. 24.

$$EF\ for\ year = base\ year\ EF \times\ decline\ factor \tag{24}$$

3.3. Limitations

There are many limitations to the data and employment factors presented here. However, the study provides data where little or none is currently available and so provides a starting point for employment assessment.

While the survey coverage is reasonable for the total numbers of appliances or chargers installed, the number of respondents per type of technology is low, so there is a risk that their responses may not be typical for the entire field. The EV charging infrastructure sector is at a very early stage of development, and it is likely that industry development will be highly uneven for some time to come. This is demonstrated in the considerable range between minimum and maximum times reported for both installation and maintenance. It would be beneficial to repeat the survey as the industry matures, both to secure a larger sample size and to determine whether the variability in responses reflects differences in charger characteristics which should be included in workforce modelling.

Application of the employment factors requires assumptions to be made on the likely variation of unit employment over time, per installation or maintenance visit for residential appliances, or per charger for EV infrastructure.

This work presents the employment factors themselves, and decline factors for EV charging infrastructure, management, operation, and maintenance. In the case of residential appliances, no decline factors are calculated, as this is a mature industry.

Bidirectional EV chargers were not included in the survey or the projections. This was not feasible to include in the collection of data on installation and maintenance times as these were not commercially available in Australia at the time of the research.

The calculation of residential appliance numbers required a set of assumptions on the current and future penetration of particular appliances in the baseline case, including assumptions on maintenance cycles, appliance lifetime, and penetration in new homes. The

Table 20
Average hours and derived employment factors (EV charging infrastructure).

	Average hours			Employment factor[a]		
	Design & Installation hours/ installation	Operation & management hours per year	Maintenance	Design & Installation Job-years/ installation	Operation & management Job-years/charger/year	Maintenance
PRIVATE						
Level 2 (residential)	3.3	1.9	2.0	0.0020	0.0011	0.0012
Level 2 (commercial)	3.1	2.1	2.0	0.0018	0.0013	0.0012
Level 3	11.6	1.3	7.1	0.0069	0.0011	0.0042
PUBLIC/SEMI-PUBLIC						
Level 2	3.9	1.8	3.8	0.0023	0.0008	0.0023
Level 3	84.3	11.4	7.7	0.0502	0.0068	0.0046

a Converted to employment factor (EF) assuming 1680 h per year is equal to 1 FTE

Table 21
Design and installation occupational share (EV charging infrastructure).

	PRIVATE			PUBLIC/ SEMI-PUBLIC	
	Level 2 (residential)	Level 2 (commercial)	Level 3	Level 2	Level 3
Business development	10.7 %	16.6 %	12.5 %	13.0 %	13.3 %
Construction/project manager	7.1 %	8.3 %	18.8 %	11.8 %	10.5 %
Procurement/logistics	10.7 %	6.5 %	4.8 %	4.9 %	5.2 %
Other managers				1.5 %	1.4 %
Architect & landscape architect					0.7 %
Environmental professionals					0.4 %
Surveyor					0.8 %
Civil engineer					4.0 %
Estimators/Quantity surveyor					0.7 %
Electrical engineer		6.5 %	13.5 %	4.9 %	20.2 %
Health & safety officer				1.0 %	
IT professional				1.0 %	
Telecommunications engineer			2.3 %	4.5 %	3.4 %
Other engineers		3.4 %	2.3 %	4.8 %	1.3 %
Site foreman		9.1 %	4.5 %	6.1 %	4.5 %
Civil engineering technician					2.8 %
Electrician	50.0 %	36.4 %	27.3 %	27.2 %	14.4 %
Administrative assistants	10.7 %	6.5 %	4.8 %	6.4 %	4.0 %
Customer service	10.7 %	6.5 %	4.8 %	3.9 %	2.3 %
Truck driver			4.5 %		2.3 %
Storepersons & packers					0.2 %
Construction labourer					2.9 %
Concreter					0.2 %
Electrical apprentice				3.0 %	1.0 %
Road traffic controller/road worker				3.0 %	2.4 %
Trade assistant				3.0 %	1.0 %

Table 22
Operation and management occupational share (EV charging infrastructure).

	PRIVATE			PUBLIC/SEMI-PUBLIC	
	Level 2 (residential)	Level 2 (commercial)	Level 3	Level 2	Level 3
Operations manager	-	33.3 %	45.8 %	37.9 %	80.8 %
Civil engineer	-	-	-	-	0.9 %
Electrical engineer	-	-	-	-	0.9 %
Health and safety officer	-	-	-	4.5 %	0.9 %
IT professional	-	-	12.5 %	4.5 %	0.9 %
Electrician	-	-	-	13.6 %	-
Telecommunications technician	25.0 %	25.0 %	12.5 %	4.5 %	0.9 %
Administrative assistants	-	-	-	9.1 %	1.8 %
Customer service	75.0 %	41.7 %	29.2 %	25.8 %	12.9 %

Table 23
Maintenance occupational share (EV charging infrastructure).

	PRIVATE			PUBLIC/SEMI-PUBLIC	
	Level 2 (residential)	Level 2 (commercial)	Level 3	Level 2	Level 3
Operations manager	-	-	-	-	11.5 %
Procurement/ logistics	-	-	-	-	2.1 %
Other engineers	-	-	-	-	3.1 %
Electrician	75.0 %	62.5 %	62.5 %	43.3 %	50.0 %
Telecommunications technician	-	-	9.4 %	12.5 %	6.3 %
Other trades and technicians	-	-	-	23.3 %	-
Administrative assistants	25.0 %	37.5 %	28.1 %	20.8 %	18.8 %
Customer service	-	-	-	-	8.3 %

Table 24
Decline factors applied to operations, management, and maintenance (EV charging infrastructure).

		2024	2030	2040
Progressive Change	**Weighted average**	**100 %**	**67 %**	**52 %**
	Simple average	100 %	66 %	55 %
Step Change	**Weighted average**	**100 %**	**58 %**	**46 %**
	Simple average	100 %	61 %	49 %
Green Energy Exports	**Weighted average**	**100 %**	**59 %**	**47 %**
	Simple average	100 %	60 %	48 %

uncertainties associated with consumer choices means that appliance penetration and maintenance visits may vary considerably from calculated numbers. This will inevitably impact employment scenarios, although it does not impact the employment factors themselves. The comparison between the baseline and alternative scenarios is more robust, as the different policy settings are easier to model. It would be beneficial to undertake further research on maintenance cycles and appliance lifetimes in particular. However, this limitation affects the employment outcomes rather than the employment factors, which are the key results in this work.

4. Discussion and conclusions

Residential electrification of cooking, space conditioning, and water heating across the housing stock is a major endeavour which will occur over many years. Deploying sufficient EV chargers to cater for the growing fleet of EVs represents a major infrastructure build-out encompassing both private and public locations. Both electrification tasks need to accelerate if net zero emission targets are to be delivered. Labour requirements are significant and not growing a skilled workforce is a major risk to delivery (Taylor et al., 2023; Brown et al., 2025). Policy makers, training providers and governments need information on the magnitude of the workforce required, and the requisite occupations and skills that are needed to develop appropriate training programs.

There are a number of implications from the study. Firstly, the work provides the first detailed inputs to enable calculation of workforce requirements for electrification scenarios for transport and residential services. EV adoption scenarios are commonly available as a key input to electricity planning (for example, Australian Energy Market Operator, 2023; National Energy System Operator, 2025) and may be used to make workforce projections including occupational shares using the method and employment factors provided. Appliance projections such as the Australian RBS are less commonly available in other jurisdictions. However, policy makers frequently make targets for elements of the residential electrification task, such as heat pump installations. Consequently, the employment factors in this study could be applied (with caution) to residential electrification or EV scenarios to estimate the numbers of tradespeople required.

Secondly, the methodology and framework can be applied by other researchers. The employment factors presented have limitations and further studies are required in other jurisdictions to test the employment indicators in different economic, climatic and built environment contexts. This study provides a methodology and framework which can be replicated elsewhere.

Thirdly, the study provides some information on the impacts of electrification on plumbers and gas fitters, which could be one of the areas of political contention that impacts on policy support for electrification. Concerns have been expressed in Australia regarding the impact of electrification on employment for plumbers and gas fitters, resulting in some opposition to the electrification policies, which may also occur in other jurisdictions. However, the data shows that the impact on plumbers is likely to be less dramatic than expected. There will be significant continuing employment for plumbers and gas fitters in the electrification of hot water systems, albeit somewhat less than in the baseline scenario, with plumbers continuing to account for 40 % on average of employment in the most ambitious electrification scenario. Over time, there may be interest in combining electrical and plumbing skillsets to reduce the numbers of personnel required. This was not modelled but could have a significant impact on workforce requirements.

Fourthly, there are key trades for residential electrification (electricians, plumbers, and refrigeration and air-conditioning technicians) which creates a vulnerability to skill shortages for rapid electrification. Each of these trades have been defined by Jobs Skills Australia (Jobs and Skills Australia, 2023) as being in persistent shortage. This is also highlighted by the International Energy Agency (IEA) (2024), which notes that markets across the globe are facing shortages of welders, plumbers, mechanics, electricians and other tradespeople. Whilst the IEA notes the existing workforce can be upskilled for residential electrification, there are structural factors underpinning skills shortages, such as ageing workforces. Consequently, this study further underlines the risk of skill shortages being a constraint on the speed of home electrification.

Fifthly, for EV charging infrastructure, the labour requirement overall is dominated by operation, management and maintenance, comprising more than 70 % of employment in all scenarios examined. For the installation of electric vehicle charging infrastructure, the major occupation is electricians supported by professionals (business development, project managers, electrical engineers), sales, and administrative staff. For maintenance, the labour requirement is again primarily for electricians, with some logistical and other trade support. The labour intensity for Level 3 public chargers was estimated to be eight times higher than Level 2 chargers, indicating the mix of chargers will have significant implications for employment requirements, which policymakers should be aware of in the rollout of charging infrastructure.

It would be valuable to see this work repeated in other jurisdictions to test the universality of the outcomes in different economic, climatic and built environment contexts, and to develop a more robust suite of indicators.

CRediT authorship contribution statement

Lara Helen: Writing – original draft, Methodology, Formal analysis, Data curation. **Jay Rutovitz:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization. **Scott Dwyer:** Writing – review & editing, Investigation, Conceptualization. **Chris Briggs:** Writing – review & editing, Investigation, Conceptualization. **Rusty Langdon:** Writing – review & editing, Investigation.

Declaration of Competing Interest

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

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.egyr.2025.11.035.

Data availability

Additional information used to derive employment indicators is provided including blank surveys and the relevant electric vehicle workbook.

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