World Energy Employment 2025

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Abstract

The *World Energy Employment* (*WEE*) report series provides comprehensive tracking and analysis of the global energy workforce, including estimates of its size and distribution across regions, sectors, and technologies. It also assesses how energy labour requirements evolve to 2035 across all IEA scenarios.

The *WEE 2025* – the fourth edition – examines how skilled labour needs and shortages have changed since the series first highlighted these issues in 2022, and explores their implications for education and training systems, wages, policy, and the global buildout of energy infrastructure. This year's report introduces, for the first time, detailed occupation-level estimates that offer new insights into the skills and education requirements shaping the energy workforce.

The analysis draws on the IEA's annual *Energy Employment Survey*, which gathered responses from more than 700 energy firms, trade unions and educators, providing fresh perspectives on labour dynamics, shortages, and evolving skill needs. The report also includes sectoral deep dives that offer granular analysis of trends across different parts of the energy sector.

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Executive summary

In 2024, global energy employment growth outpaced job gains in the wider economy for the third year in a row. Continued strong investment in energy infrastructure underpinned expanding energy employment, up by 2.2%, nearly double the economy-wide rate of 1.3%, bringing total energy sector jobs to 76 million. Since 2019, 5.4 million energy workers have been added – about 2.4% of all new jobs globally. In some countries, its contribution is far larger, reaching one in five new jobs in China and one in ten in the United States since 2022. The pace of the expansion in recent years marked a step change from pre-pandemic trends, when the energy sector added less than a third as many jobs annually than during the years between 2019 and 2024.

The electricity sector is now the largest energy employer, surpassing fuel supply for the first time, as the Age of Electricity gathers pace. Over the last five years, employment in the electricity sector – including generation, transmission, distribution, and storage – has risen by 3.9 million, representing nearly three-quarters of all energy job additions. Solar PV has been the principal driver of demand, accounting for half of the job additions in the electricity sector since 2019. Nuclear power, grids and storage accounted for another quarter of new power sector jobs seen since 2019, despite facing multiple headwinds such as increased component costs and shortages of skilled workers. Persistent challenges in the offshore power market have also slowed wind employment growth, with layoffs in turbine manufacturing, where jobs declined by 6% in 2024.

The shift to electrification is also changing the nature of employment in related sectors. Vehicle manufacturing employment continued to rise, driven by strong gains in jobs related to electric vehicles (EV), which rose by nearly 800 000 last year. In China, almost 40% of all jobs in vehicle manufacturing are now tied to EVs and their batteries. Employment in other energy end-uses rose by 2%, with electrification in buildings and industry contributing to a sizeable portion of the increase. In both vehicles and efficiency employment, part of this growth is met by workers in related segments retraining and shifting roles – such as heating technicians learning to install heat pumps or auto workers moving to EV assembly lines – but it also reflects the creation of new jobs in areas like manufacturing batteries and installing electric industrial equipment.

Demand for workers is increasing across all parts of the energy system, not just electricity, as the world remains thirsty for energy. Coal supply jobs have seen a resurgence in India, China and Indonesia in recent years, leading to global employment levels 8% higher in 2024 than in 2019, despite a 20% decline in advanced economies over that period. Oil and gas supply has recovered most of the jobs lost in 2020, as global production capacity continued to expand. However, it now appears that many firms are entering a new period of retrenchment in the face of lower oil prices and revenues, with a number of major oil companies announcing job cuts in 2025.

Emerging market and developing economies (EMDEs) led energy job growth in 2024, reflecting their status as rapidly rising centres of global energy demand. Overall, employment growth was strongest in emerging economies, led by India (5.8%), Indonesia (4.8%), and the Middle East (3.5%), compared with 2.2% in China and just 0.4% in advanced economies. Still, employment remains more concentrated in economies with well-established energy firms and energy-related supply chains. For instance, in the Middle East, Korea, and Canada, more than 4% of the workforce is employed in energy – nearly double the global average of 2%.

Employment demand is expected to continue rising across all IEA scenarios. Energy-sector job growth is on track to moderate to 1.3% in 2025, reflecting slower, though still positive growth in energy investment amid continued economic and energy market uncertainty. This moderated pace of growth is set to continue under today's policy settings, leading to energy employment growing by 3.4 to 4.6 million by 2035, depending on the pace of energy infrastructure build out. The power sector continues to be the main source of net job growth, however sectors like oil supply face divergent trajectories depending on the direction of future policy and market conditions, underscoring the importance of flexible approaches to workforce planning, hiring and retention. All scenarios ultimately depend on firms' ability to secure the skilled labour they need – a constraint that requires greater attention in a scenario aligned with net-zero emissions by 2050, where total energy workforce needs would increase by nearly 15 million by 2035.

Skilled worker shortages have emerged as a top concern for firms, particularly in applied technical roles. Over 700 energy firms, trade unions, and educators participated in IEA's annual Energy Employment Survey, and more than half reported critical hiring bottlenecks – a steady increase over previous years. These shortages are most acute in applied technical roles, which account for over half of the energy workforce – more than double their 25% share in the broader economy. Employment in these roles has grown by 2.5 million since 2019. Most of the top energy occupations facing constraints within energy are considered applied technical roles, including electricians, pipefitters, electrical power-line workers, and engineers, particularly in nuclear. Many of these broader categories are already in short supply across the wider economy.

An ageing energy workforce is deepening labour and skills shortages. The energy workforce is older than the economy-wide average, and too few qualified workers are entering the sector to replace retirees and meet rising demand. Certain subsectors face more severe challenges than others. In nuclear and grid roles, for every young worker entering, there are 1.7 and 1.4 workers approaching retirement, respectively, compared to an economy-wide average of 1.2. The pressure is greatest in advanced economies, where across the whole energy sector there are 2.4 workers nearing retirement for every worker under 25, compared with a ratio of about 1:1 in EMDEs. Imbalances are set to worsen – between today and 2035, two out of every three new hires will be needed just to replace retiring energy workers.

Building a pipeline of skilled workers is a strategic priority for energy security. The ability of countries to maintain energy security, expand grids, scale clean energy manufacturing, refurbish nuclear plants, or attract investment increasingly depends on having the right workforce in place. Today, shortages are already having tangible impacts: around 60% of companies reported labour shortages, putting timelines, system reliability, and cost control at risk.

Graduates with energy-relevant training are not keeping pace with rising needs for skilled workers. Economy-wide demand for applied technical workers grew 16% between 2015 and 2022, yet graduations from relevant vocational programmes increased by only 9%. This broader shortage is now directly affecting the energy sector, making it harder for firms to hire and retain the skilled workers they need. Nearly 50% of companies reported recruiting from neighbouring industries or increasing in-house training to fill gaps. To prevent the skills mismatch from worsening by 2030, the number of graduates entering energy would need to rise by around 40% globally, and even more in a pathway aligned with net-zero emissions by 2050. Expanding training capacity to this level would cost roughly USD 2.6 billion per year worldwide – less than 0.1% of global public education spending. Some regions have already made significant progress in drawing more young people into relevant vocational education. In China, Indonesia, and North Africa, the share of young people entering energy-relevant degrees grew by 25% over the past decade, while Europe already has one of the highest shares of youth pursuing these programmes.

Reskilling workers within the energy sector could help address skilled labour gaps. Previous IEA analysis has shown that over 40% of energy firms surveyed prefer to recruit internally to retain sector-specific know-how, while this year 50% of fossil fuel workers said they would prioritise staying within the energy sector if seeking alternative employment. Not all workers facing redundancy have a straightforward transfer pathway. With targeted retraining, around two-thirds of oil and gas supply workers have the base skills needed to move readily into other parts of energy, the same is true for about half of workers connected to fossil fuel power supply chains. By contrast, a smaller share of coal miners can be quickly reskilled, particularly those in markets with high levels of informality. Coal workers and communities therefore require more specialised support to ensure a just, people-centred transition.

Artificial intelligence (AI) is emerging as a powerful productivity tool in energy, but today's applications do little to ease the acute shortages in applied technical roles. Companies see the biggest long-term gains from AI in administrative efficiency and system performance, with early uses already streamlining permitting, improving safety, and enhancing training through virtual reality (VR). Yet energy firms lag other sectors in artificial intelligence capabilities, with concentrations of AI-skilled workers about 40% lower than in technology, finance, education, and media. And while investment in AI skills and capabilities is rising in the energy sector, current use cases do not significantly reduce demand for applied technical workers in construction, operations, and maintenance, which are mostly manual roles dominated by tasks that AI is not currently well suited to replace.

Policy makers have a range of tools to attract more workers into energy-related education and training. The *IEA Energy Employment Survey* identifies training costs, lost wages, and low awareness of programmes as the main barriers to entry. Policy responses that have been effective include targeted financial incentives, apprenticeships, and campaigns promoting vocational careers in energy. Targeted efforts to attract more women into technical and vocational fields – where they currently make up less than 5% of workers – are among the most impactful levers to increase overall female participation in the energy sector, currently around 20%. Firms are turning to direct engagement with educational institutions to help address skills gaps, by sponsoring students or providing training for hard-to-fill roles, particularly in vocational programmes and advanced degrees. Collaboration on curriculum development remains limited, with fewer than 25% of firms reporting involvement in such efforts, though many express interest in deeper engagement.

Attracting workers also depends on competitive wages and improved job quality. In the *IEA Energy Employment Survey*, workers and representatives cited pay, job security, and a safe working environment as the top factors in evaluating a role and these issues have been a frequent focus area of tripartite social dialogue and collective bargaining in the energy space. Energy-specialised roles generally pay more than comparable non-specialised roles, but wages vary widely across the sector. Oil, gas, and nuclear offer the highest pay, reflecting higher skill requirements and a stronger ability to compete for talent. In 2025, oil and gas saw the largest wage increases across most regions, averaging 3.7%, followed by nuclear at 3.2%, while coal and renewables grew 1.2% and 0.8%, respectively.

Energy employment is expected to remain a major source of job growth and an important foundation for public support of energy policies. As energy security moves higher on national agendas, a well-trained workforce is becoming essential for attracting supply chains, deploying new assets, and ensuring reliable operations. Co-ordinated action by governments, industry, and labour representatives can help prevent skilled-labour shortages from becoming a defining bottleneck, and instead enable the energy sector to deliver high-quality, well-paid jobs, strengthen competitiveness, and support countries in meeting their security and sustainability goals affordably.

Introduction

The *World Energy Employment 2025 (WEE 2025)* report provides a comprehensive overview of the current state of the global energy workforce, a forward view of employment demand to 2035, and an analysis of the opportunities and challenges that these trends pose for policy makers and other stakeholders in the energy sector.

The energy employment outcomes presented in this report are produced using a quantitative model, which estimates employment as a function of major demand drivers in the energy sector such as investment, capacity and production. Model calibration uses official labour statistics, industry reports and observed employment at the firm and project level to inform the model. Future projections of employment are aligned with scenario outcomes from the IEA's flagship *World Energy Outlook 2025* (*WEO 2025*) report.

As in previous years, these employment estimates are disaggregated by energy technology (e.g. nuclear power generation), as well as by economic activity (e.g. construction), region, and year. New model developments this year include an extension of the model results backward to 2015, and forward to 2035. For the first time, the *WEE 2025* report provides a breakdown of our employment estimates by occupation, based on international labour force statistics on occupational employment by sector.

The scope of the workforce covered by the model has also been expanded to include new workforce categories in end-use sectors, including in efficient lighting and renewable heating and cooling. This, along with other model refinements and updated data inputs, has resulted in an upward revision of 6.7 million to our estimate of the global energy workforce in 2024, compared to estimates published in *WEE 2024*. More details on these revisions, and the Methodology and definitions used for this model are provided in the Annexes.

This year's report also draws on a set of three dedicated surveys conducted by the IEA to gather new insights on workforce dynamics across the energy sector, each targeting a different set of stakeholders: the *IEA Industry Employment Survey*, the *IEA Labour Employment Survey*, and the *IEA Educators' Employment Survey*.

The *WEE 2025* report features an in-depth analysis on the Future of Energy Skills in Chapters 2 and 3. This analysis was supported by results from the aforementioned employment model and surveys, as well as insights generated from discussions with industry, labour, educational and policy representatives at the Workshop on the Future of Energy Skills, hosted at the IEA's headquarters in May 2025.

This year's report also includes new in-depth analysis of trends in occupational employment demand, and educational capacity, and more. These analyses build on deep bodies of work and data made available by organisations such as the ILO, OECD, and UNESCO. Please refer to the Annexes for more details on the formal definitions and the analytical approaches used.

Chapter 1. Overview

Global energy employment growth continues to outpace the rest of the economy

Energy employment growth was nearly double the economy-wide rate in 2024, rising by 2.2% to reach 76 million workers. The energy workforce, which includes jobs in the power sector, fuel and critical minerals supply, end-use efficiency and vehicle manufacturing, accounted for one in every fifty jobs globally. In all, the energy sector has created more than 5 million jobs since 2019, or 2.4% of the total jobs added across the global economy during the five-year period.

Concurrently, economy-wide employment growth slowed to just 1.3% on a global basis in 2024, compared with 2% a year ago and the recent high of 2.9% in 2021, as global employment levels normalised following the sharp post-pandemic rebound. This slower growth was partly a consequence of tight labour markets in many regions, as global unemployment rates remained at historically low averages of 5% in 2024, reducing employers' ability to draw on untapped labour capacity. Even as inflationary pressures and interest rates continued to subside, economic growth was more muted than expected, including in the People's Republic of China (hereafter, "China"), India and Europe, with the notable exception of the United States.

The post-pandemic boom in the energy workforce, driven by a sharp rise in investment, represents a step change from previous trends, with the energy sector adding less than a third as many jobs annually between 2015 and 2019 as between 2019 and 2024. The power sector has been the standout performer, as the energy sector entered the Age of Electricity. Power sector job growth accelerated in every year between 2015 and 2019, but since then it has surged to an annualised rate of 4%, driven mainly by the expansion of solar PV technology.

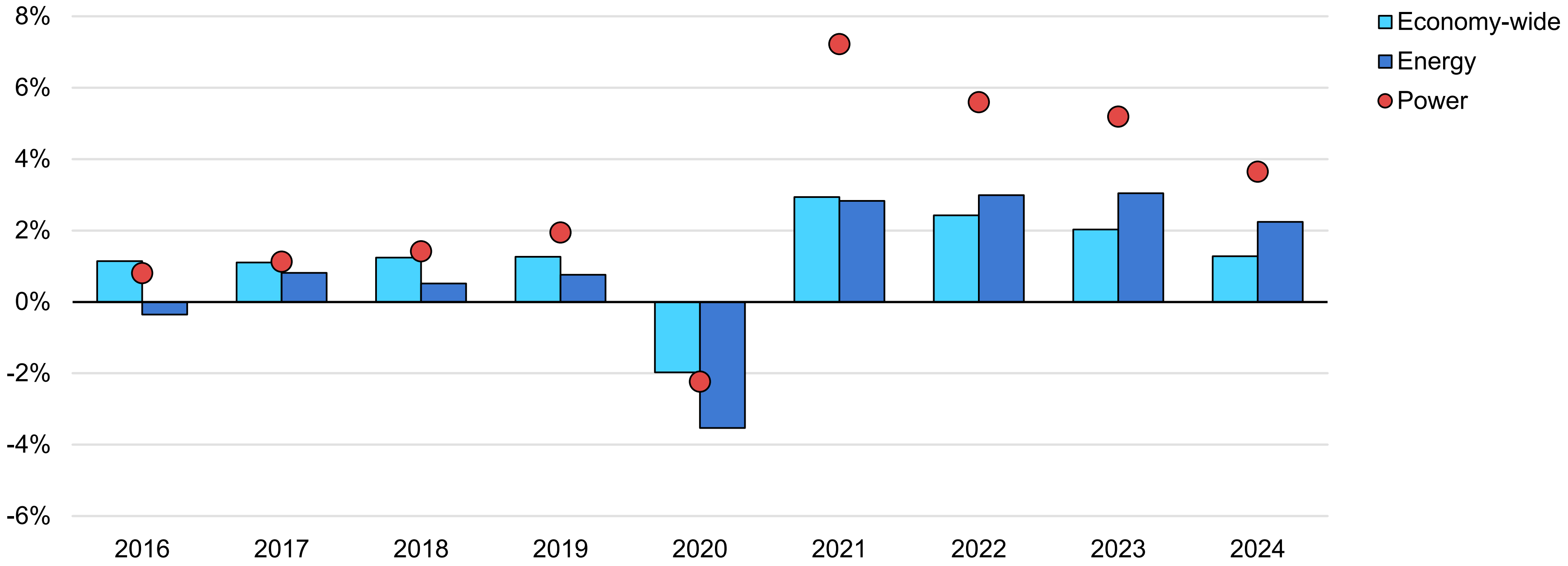
Other parts of the energy system also saw continued job growth in 2024. Fuel supply employment has recovered the steep job losses suffered in 2020, while jobs in energy end-uses such as EVs continued their steady growth. The majority of job additions across the energy sector were concentrated in construction, manufacturing and other roles tied to rising investments in the development of new energy infrastructure, where employment rose by 2.5% in 2024.

Policy developments in 2025 have significantly altered market expectations, however, with the economic outlook clouded by growing uncertainty over tariff regimes, their broader economic impacts, and elevated geopolitical instability that could directly affect parts of the global energy supply chain. As a result, IEA estimates show that growth in energy-related employment is expected to slow to 1.3% in 2025 – the lowest rate seen since the Covid-19 pandemic in 2020.

Exceptionally, the power sector is set to remain unaffected by this broader slowdown, with employment expected to maintain a 3.4% growth rate in 2025, barely dimming from 2024's pace. Growth is supported by a sustained surge in demand for electricians, line workers, engineers, and technicians needed to deliver and operate new projects.

The power sector has underpinned strong energy employment growth since 2020, as the energy sector entered the Age of Electricity

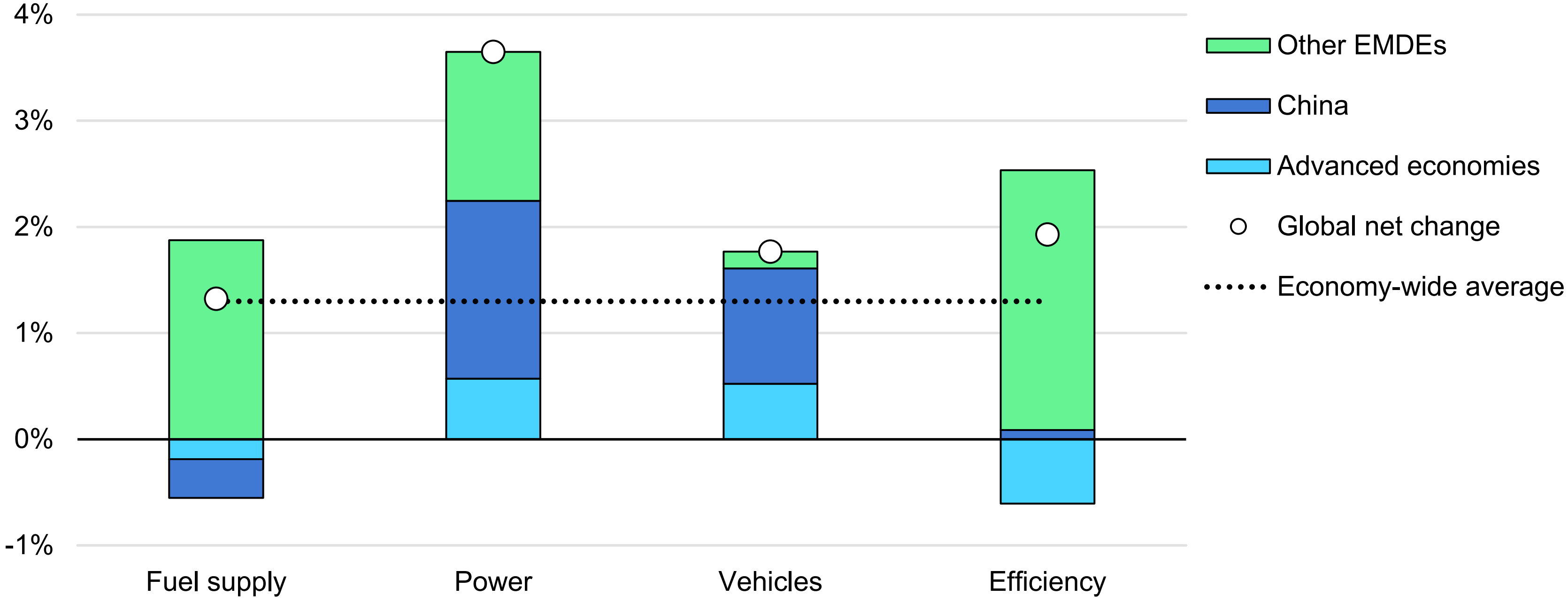
Annual global growth of economy-wide, energy, and power sector employment, 2016-2024



Note: Power includes employment in power generation and transmission, distribution and storage.
Source: IEA analysis of economy-wide employment based on data from the International Labour Organization (ILO).

Employment in almost all energy-related subsectors bested economy-wide growth in 2024

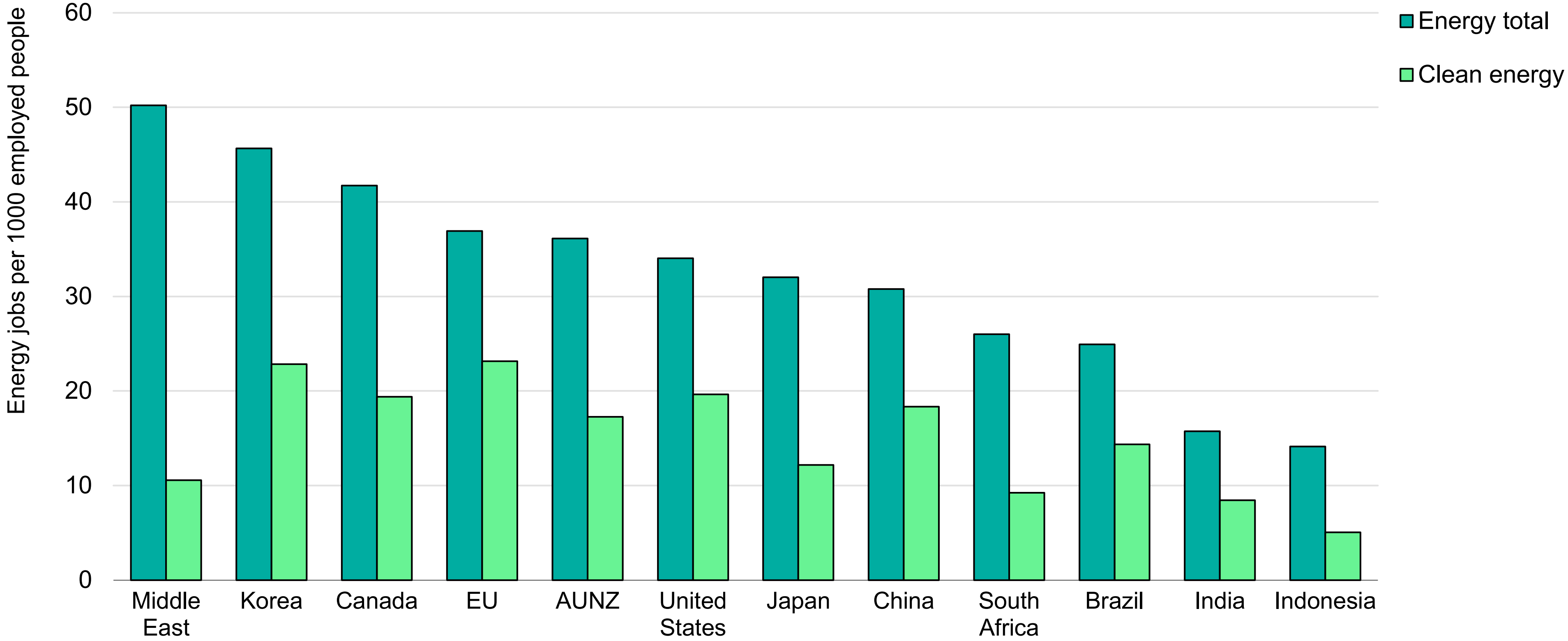
Growth in energy employment by technology and region, 2023-2024



Notes: Power includes power generation and transmission, distribution and storage. Fuel supply includes fossil fuels, bioenergy, nuclear fuels, hydrogen, and critical minerals. Vehicles includes the manufacture of internal combustion engine (ICE) vehicles, electric vehicles, and electric vehicle batteries. Efficiency includes industrial efficiency, building retrofits, heat pumps and other efficient heating, ventilation, and air conditioning (HVAC), efficient appliances, efficient lighting, and buildings renewables.

Globally, one in every fifty jobs economy-wide is in the energy sector

Energy jobs per thousand employed people by region, 2024



Note: EU = European Union; AUNZ = Australia and New Zealand.
Source: IEA analysis based on ILOSTAT data.

Employment rose across all energy subsectors in 2024, with power growing at almost double the pace of others

The power sector – including generation, transmission, distribution, and storage – has overtaken fuel supply segments to become the largest employer in the energy industry, reaching 22.6 million jobs in 2024. The construction of new power generation was the primary driver of growth. Since 2019, construction-related jobs in the sector have increased by 5.3% annually. In 2024, nearly a third of all generation jobs were linked to the construction of new infrastructure. Low-emissions technologies dominated new builds and now support nearly three times as many jobs as unabated coal, gas, and oil-based generation combined. Solar PV accounted for over 60% of new power generation capacity added in 2024, reaching a new record-high, adding 310 000 jobs – roughly half of the increase in total power generation employment. The revival of nuclear power also contributed, with around 70 000 jobs added in 2024, a 6% increase on the previous year.

Power transmission, distribution, and storage accounted for 8.5 million jobs globally in 2024, though growth in these segments was more modest, with employment rising just 2.6% y-o-y. While critically-needed investment in grid infrastructure has increased significantly in recent years, the sector has been straining against economic headwinds, as prices for both cables and transformers have nearly doubled since 2018. Labour shortages are compounding these challenges, with acute gaps in high-voltage electricians, skilled equipment manufacturing specialists, and experienced project engineers at original equipment manufacturers (OEMs).

Energy supply employment – coal, oil, gas, bioenergy, hydrogen, and nuclear fuels – continued to rebound steadily from the pandemic-era dip. Fossil fuel supply jobs grew by 220 000 in 2024, reaching 18.4 million, and are now above pre-pandemic levels but still below the peak seen between 2010 and 2015, when oil and gas exploration investment was at its highest. Coal supply posted an unexpected resurgence, driven by new mine openings in India and Indonesia, and strong demand in China. Approximately 470 000 jobs have been added to coal supply since 2019, to 6.1 million in 2024. Oil and gas employment also continued its post-pandemic rebound and has recovered most of the jobs lost in 2020, leaving the sector with around 12.4 million workers in 2024. Global oil production capacity continued to expand despite a tepid demand outlook, with much of the increase in capacity led by producers in the Americas, which have accounted for two-thirds of the increase in oil and gas employment since 2020. However, lower commodity market prices this year have led major international oil companies to increase layoffs, which contributes to an expected 0.8% decline in oil and gas employment in 2025. Low-emissions energy supply – including modern bioenergy, hydrogen and nuclear fuels – has steadily grown, with total employment rising by 3% annually since 2019, to 2.3 million in 2024.

Energy-related employment in end-use technologies, which include vehicles, heat pumps, and energy efficiency measures, added approximately 570 000 jobs in 2024. The vehicle manufacturing workforce stood at around 17.5 million globally, rising in tandem with higher vehicle sales. Many OEMs continued to transition their line-up to EVs, which reached 20% of global car sales in 2024, up from 4% in 2020. The shift has had a limited impact on the majority of vehicle manufacturing jobs, which are concentrated in general car parts such as seats and windows, however firms producing internal combustion engine (ICE) components are beginning to show structural shifts in their staffing decisions.

In buildings and industry, global energy efficiency job growth has slowed from recent highs of 2.6% to 1.9% in 2024, to around 14.3 million workers. Almost all of the increase was accounted for by emerging market and developing economies (EMDEs) as major economies rolled back some incentives for efficiency upgrades, contributing to a slowing of the global rate of energy efficiency improvement to just 1%.

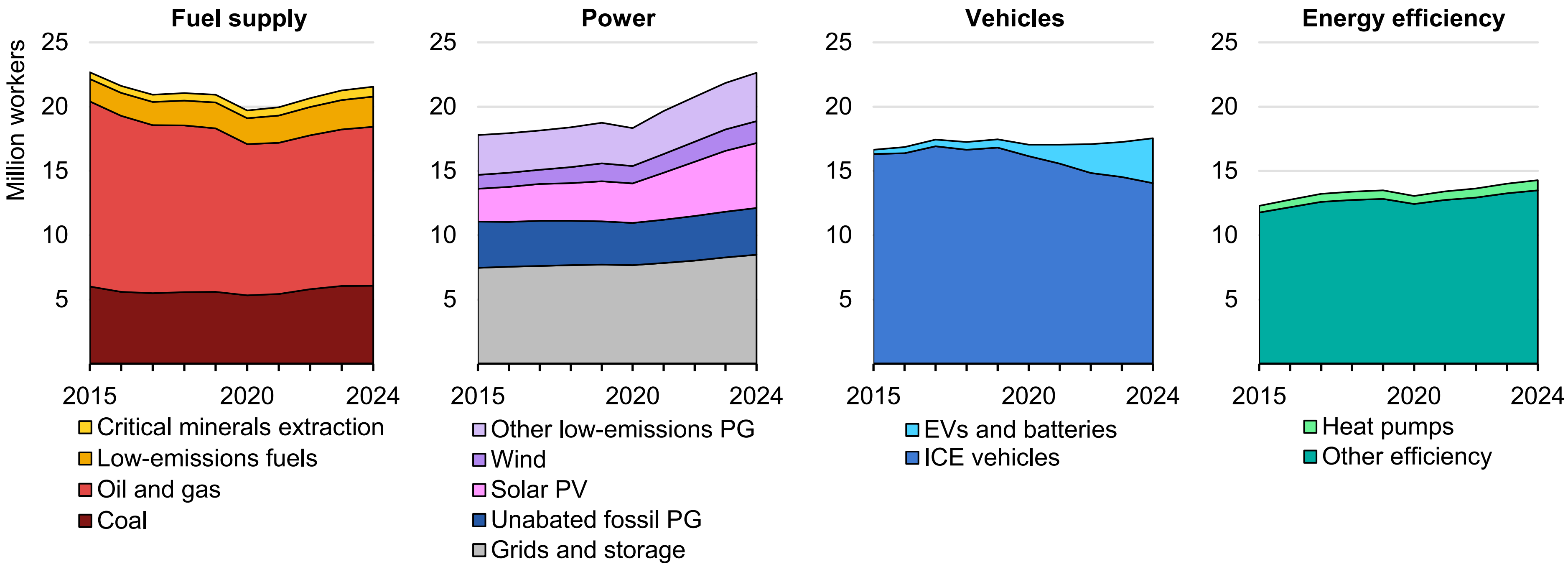
Energy employment trends in 2024 showed a marked divergence between advanced economies and developing economies. EMDEs added 1 million jobs in the fuel supply and power sectors combined – a 3% increase over 2023 – while advanced economies saw much slower growth of 1%, up by just 90 000 workers. A major driver of growth in EMDEs was China, whose gains in solar PV jobs more than offset a decline in coal sector employment in 2024. China also made continued progress in areas where other regions lagged, such as electricity grids and storage, with employment rising by 4% compared to just 2% elsewhere. It also strengthened its clear lead in clean energy manufacturing, accounting for nearly three-quarters of the job growth in that category in 2024. China now represents over half of global manufacturing employment in heat pumps, electrolysers and wind, two-thirds in EVs, 80% in solar PV, and more than 90% in batteries.

In advanced economies, 125 000 jobs were added in the power sector in 2024 (+2.4%), offsetting a loss of 50 000 in fossil fuel supply (-1.7%). Advanced economies also posted a solid increase of 1.2% in vehicle manufacturing employment, with EVs and EV batteries now accounting for 13% of jobs in the sector in these regions. The slowdown of energy efficiency improvement rates in advanced economies was also reflected in employment outcomes, as efficiency jobs fell by 1.5% in 2024.

Fossil fuel supply remained the main source of energy job growth in 2024 for many EMDEs outside of China, accounting for half or more of net job creation in the Middle East, Africa, and Central and South America. Low-emissions power added a smaller 210 000 jobs, primarily in construction, as many of these regions continued to face challenges in attracting investments to transition to clean energy manufacturing.

Energy employment has rebounded from the pandemic across all major energy subsectors

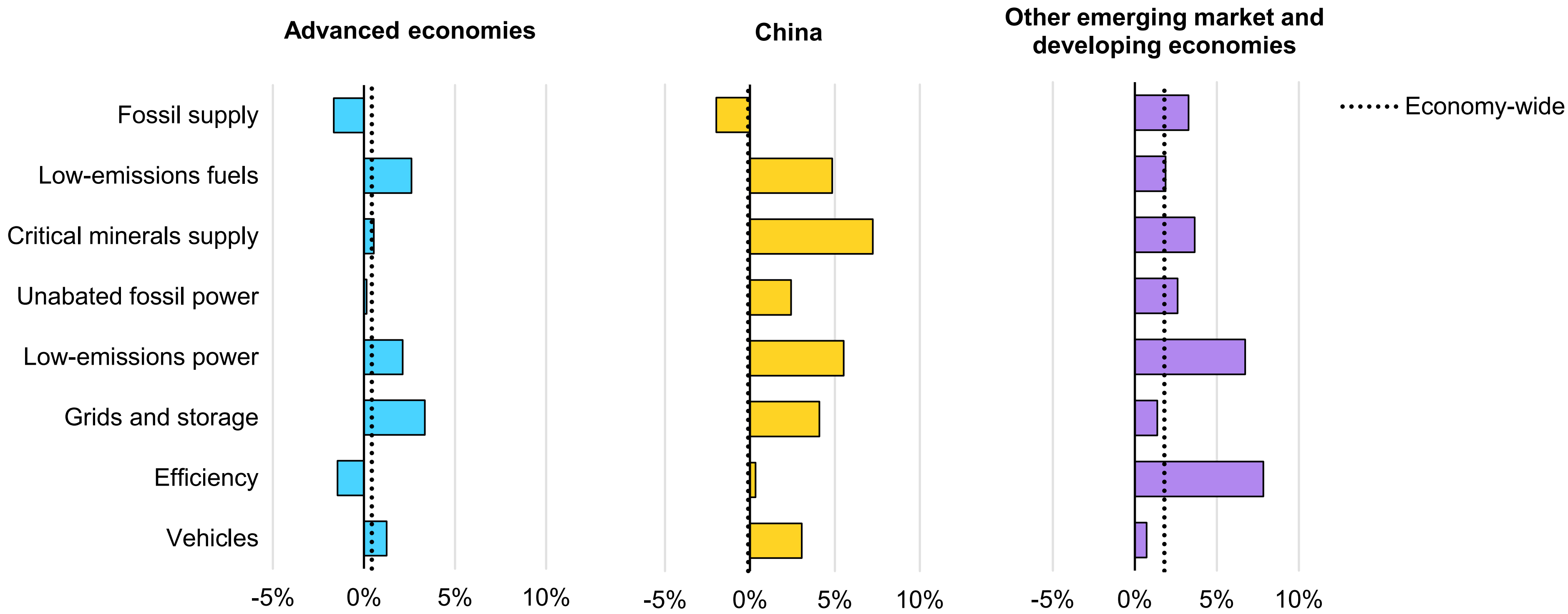
Global energy employment by technology, 2015-2024



Notes: PG = power generation; ICE vehicles = internal combustion engine vehicles; EVs = electric vehicles; and solar PV = solar photovoltaic. Grids and storage includes power transmission, distribution and storage. Low-emissions fuels include the supply of bioenergy, nuclear fuels, and hydrogen. Other efficiency includes building retrofits, efficient and renewable heating, ventilation and air conditioning (other than heat pumps), and efficient appliances and lighting.

China and other emerging market and developing economies saw job increases across almost all energy subsectors, while the picture for advanced economies was more mixed

Employment growth by technology and region, 2023-2024



Notes: Grids and storage includes transmission, distribution and storage. Low-emissions fuels include the supply of bioenergy, nuclear fuels, and hydrogen. Efficiency includes building retrofits, heat pumps and other renewable and efficient heating, ventilation and air conditioning, and efficient appliances and lighting.

Fuel supply, power and end-use sectors are key sources of employment in every region

Energy employment by region and sector, 2024 (thousand workers)

	North America	Central and South America	Europe	Africa	China	India	Other Asia Pacific	Middle East	Eurasia	**Global**
Supply: Coal	100	<50	100	200	2 800	1 500	1 000	<50	300	**6 100**
Supply: Oil and gas	1 700	1 100	600	1 500	1 400	800	1 200	2 800	1 300	**12 400**
Supply: Low-emissions fuels	200	500	300	400	200	400	300	<50	<50	**2 300**
Power: Generation	1 100	700	1 600	600	5 800	1 900	1 800	400	400	**14 200**
Power: T&D, storage	1 000	500	1 000	500	2 400	1 800	800	200	200	**8 500**
End uses: Vehicles	2 200	700	3 500	200	6 300	1 200	2 800	200	300	**17 500**
End uses: Efficiency	1 900	600	3 300	600	3 800	1 600	1 700	500	400	**14 300**
Critical minerals	<50	100	<50	400	<50	<50	100	<50	<50	**800**
All energy	**8 200**	**4 200**	**10 400**	**4 200**	**22 900**	**9 200**	**9 700**	**4 100**	**3 000**	**76 000**

Notes: Power T&D, storage = transmission, distribution and storage. Low-emissions fuels supply includes bioenergy, hydrogen and nuclear fuels. Vehicles include the manufacturing of all four-wheeled road vehicles (passenger cars, light-duty commercial vehicles, buses and trucks) and batteries for EVs. Efficiency refers to energy efficiency in industry and in buildings (covering retrofits, heat pumps, other efficient and renewable heating, ventilation and air conditioning, and efficient appliances and lighting). Values may not sum due to rounding. Global energy employment totals are higher than in previous editions of the *WEE* report due to the inclusion of new categories of energy employment and other modelling revisions. Please see the Methodology section in the Annex for further information.

The energy sector's high demand for applied technical roles leaves it exposed to broader-economy shortages for workers such as electricians and pipefitters

IEA analysis provides, for the first time, a breakdown of our employment estimates by occupation in order to quantify current and future skilled workforce requirements. The occupational definitions used for this analysis follow the International Labour Organization's (ILO) International Standard Classification of Occupations (ISCO-08), with each of these occupations associated with a skill level tied to their typical educational requirements.

Applied technical workers make up the largest share of the energy workforce, at 41 million. This group includes technicians, skilled trades and craft workers, plant and machine operators, and assemblers, which account for 54% of the energy workforce – more than double the share of these occupations in the broader economy. Skilled trades workers – such as electricians, welders, pipefitters and solar PV installers – make up the largest occupational subsector of applied technical workers and posted the highest year-on-year increase. This group added nearly 1.6 million since 2015, to reach 18.9 million workers in 2024. The surge is largely driven by the construction boom in new energy projects, particularly in the power sector. Demand for electricians, pipefitters, and plumbers is now straining existing labour pools – suggesting that rapid growth in energy construction may be intensifying the broader skilled trade shortages across the economy. Most of these workers require formal vocational training or advanced vocational qualifications, adding longer lead times to bring more skilled workers into the labour market.

Elementary and agricultural jobs – including elementary occupations and basic agricultural workers – accounted for the second largest growth in energy employment since 2015, adding over 1.3 million. Although elementary and agricultural workers generally play a smaller role in the energy sector than in the broader economy – representing 17% of the workforce compared to 37% overall – they can account for up to 28% of the workforce in construction-heavy sectors such as renewables and batteries. These occupations typically have more basic education requirements, however in energy they often require additional specialisation or on-the-job training to ensure safety and proper development of complicated projects.

Many companies are reporting difficulties hiring for technical roles, according to the annual *IEA Energy Employment Survey*, which received input from over 700 energy firms, trade unions and educators. Nearly half of the companies surveyed reported critical hiring bottlenecks, which has led to project delays, longer lead times, increased costs, and higher wages. Companies also reported a shortage of candidates with the desired skill levels, often resorting to hiring less qualified people or turning to on-the-job training. The rate of new graduates with energy-relevant degrees and certifications has been largely stable or falling in most economies, which is contributing to wider pipeline issues for skilled workers. Additional analysis on these trends and their impact is explored in Chapter 2.

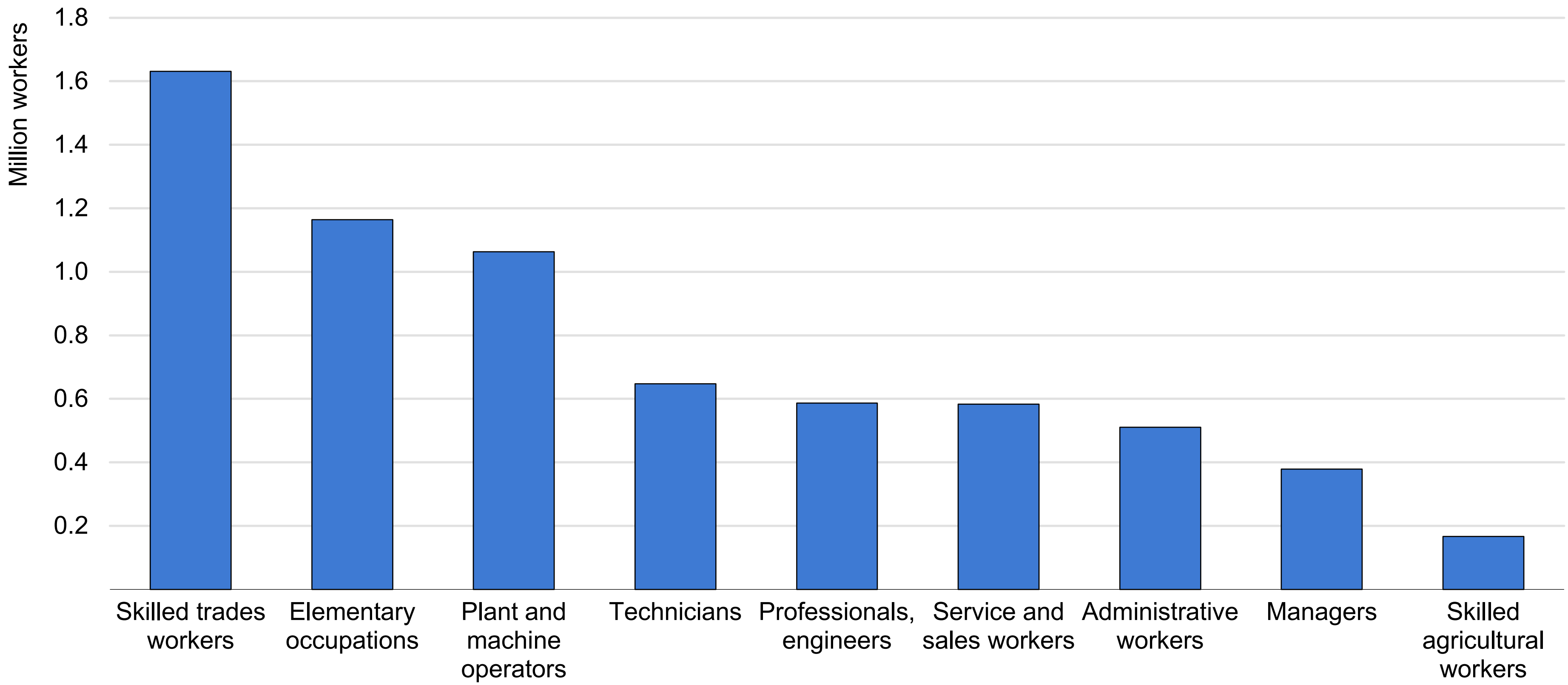
Applied technical workers make up 54% of the energy workforce, more than double the share in the broader economy

Global occupational employment shares, economy-wide and energy sector related, 2024

Notes: Applied technical workers include the ISCO-08 occupational groups craft and trades workers (e.g. electricians, welders, plumbers, pipefitters), technicians and associate professionals (e.g. electrical or substation technicians), and plant and machine operators (e.g. power plant operators, drilling rig operators, heavy machinery operators). Managers and professionals include the ISCO-08 occupational groups managers (e.g. project managers), professionals, engineers (e.g. nuclear engineers). Service and support workers include the ISCO-08 occupational groups administrative workers (e.g. administrative assistants), and service and sales workers (e.g. customer service representatives). Elementary and agricultural workers include the ISCO-08 occupational groups agricultural workers (e.g. crop producers for bioenergy), and elementary occupations (e.g. manual handlers).

The energy sector has added jobs for over 1.6 million skilled trade workers since 2015

Job additions by occupational group in the energy sector, 2015-2024



Notes: The occupational groups follow the ISCO-08 classifications and associated skill levels. Please see the Methodology section in the Annex for further information.

Overview of occupational categories and educational requirements

Occupational category	Number of energy workers	Education required	Skill level	Job function examples
Managers and professionals (16%)				
Managers	4 300 000 (6%)	Tertiary-level education, university degrees	High	*Project manager in utility-scale solar, exploration manager in oil and gas*
Professionals, engineers	7 800 000 (10%)		High	*Nuclear engineer, electrical engineer*
Applied technical workers (54%)				
Technicians	8 600 000 (11%)	Advanced vocational qualifications	High	*Battery technician, substation technician*
Skilled trades workers	18 900 000 (25%)	Upper secondary education and/or formal vocational education and training (VET)	Medium	*Electricians, welders, plumbers, pipefitters*
Plant and machine operators, and assemblers	13 900 000 (18%)		Medium	*Power plant operators, drilling rig operators*
Service and support workers (13%)				
Administrative workers	5 300 000 (7%)	Upper secondary education and/or formal vocational education and training (VET)	Medium	*Administrative assistant, inventory clerk*
Service and sales workers	4 400 000 (6%)		Medium	*Salesperson, customer service representative*
Elementary and agricultural workers (17%)				
Agricultural workers	800 000 (>1%)	Primary or lower secondary education	Low	*Forestry worker supplying feedstock for bioenergy*
Elementary occupations	12 100 000 (16%)		Low	*Support workers, manual handlers*

Notes: Values may not sum due to rounding. The occupational groups follow the ISCO classifications and associated skill levels. Please see the Methodology section in the Annex for further information.

Energy employers are under pressure to raise wages to attract and retain talent

Real wages have risen in most parts of the energy sector in 2025. In many cases, energy wages performed better than economy-wide real wage growth, which has been sluggish in the first half of this decade, held back by the post-pandemic surge in inflation, and declining productivity improvements. However, this is not consistent across all regions. Low-income countries in particular have struggled to register significant real wage growth for much of the past decade, and many advanced economies have struggled to raise historically low productivity growth seen since the 2008 financial crisis. Notable exceptions exist, especially in China and the United States, where wage growth has been strong in recent years, driven in part by high-tech and extractive sectors.

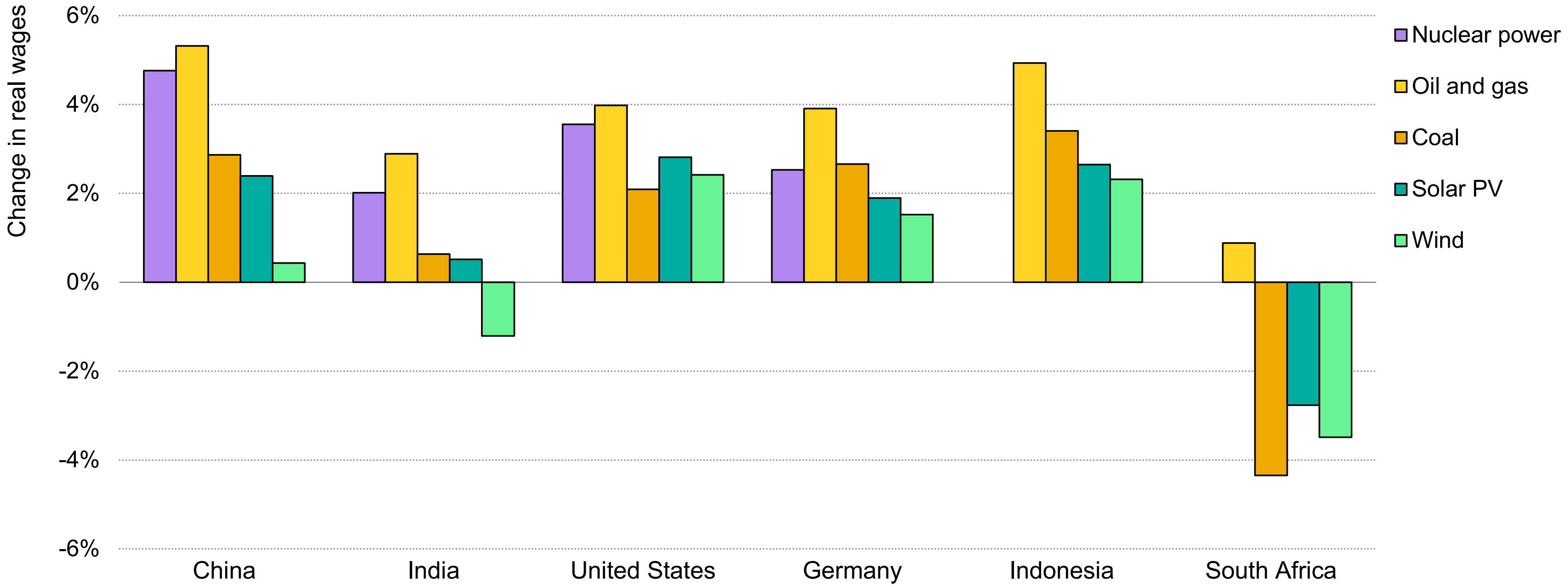
Wage growth varied across different energy subsectors, with the relative positioning of each remaining fairly consistent when looking across regions. Still, prevailing country wage trends tended to have a larger effect. Oil and gas witnessed the strongest wage growth, rising by around 3-5% across major economies, as the sector expands new liquified natural gas (LNG) import and export facilities, and is consistent with the industry's historical tendency to offer highly competitive wages to attract and retain top talent. Nuclear power posted eye-catching real wage growth rates, ranging from 2-5% in China, India and the United States. The post-pandemic rebound in the coal supply sector has seen its wage growth follow close behind at 2-4% in most regions. Average earnings in renewables mostly did not keep pace with these higher rates however, with solar energy seeing fewer constraints in recruiting skilled workers than nuclear power, and the wind sector facing significant economic headwinds in many regions.

In sectors with tight labour markets and shortages of skilled workers, energy firms are recognising need to raise wages to continue attracting and retaining talent. In the *IEA Industry Employment Survey,* 40% of industry respondents said they had raised salary offers to ease hiring challenges.

At the same time, many energy employers are facing price pressures that constrain their ability to raise wages. Among survey respondents who reported facing skilled labour shortages, one-quarter cited an inability to offer sufficiently competitive wages as a contributing factor to their shortages. Overcoming wage constraints may well play an important role for energy firms to enhance their competitiveness. Findings from the *IEA Labour Employment Survey* show salary is the top factor for workers choosing jobs. Yet, many of the most in-demand roles – craft and trades workers, operators and assemblers – still offer wages below the global economy-wide average. Firms must navigate these tensions carefully to sustain workforce pipelines and cost competitiveness.

Fossil fuel supply and nuclear power see strong increases in wages, while renewables are losing ground

Change in real wages by country and technology, 2024-2025



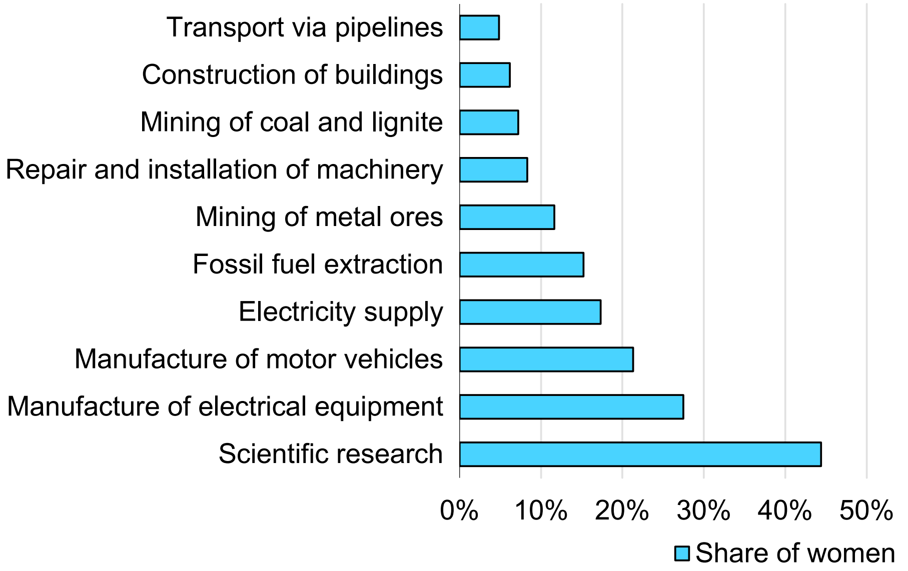
Source: IEA analysis based on data from the Economic Research Institute and the IMF.

Narrowing the gender gap depends on attracting more women into trades occupations

Women account for around one in five energy sector jobs, roughly half the share in the wider economy. This ratio has remained largely static in recent years, partly because the fastest job growth is in occupations where women traditionally make up less than 5% of workers, such as welders, electricians and line workers. Women's representation is much higher in certain roles, such as scientific research (45%) and manufacturing of electrical equipment (27%).

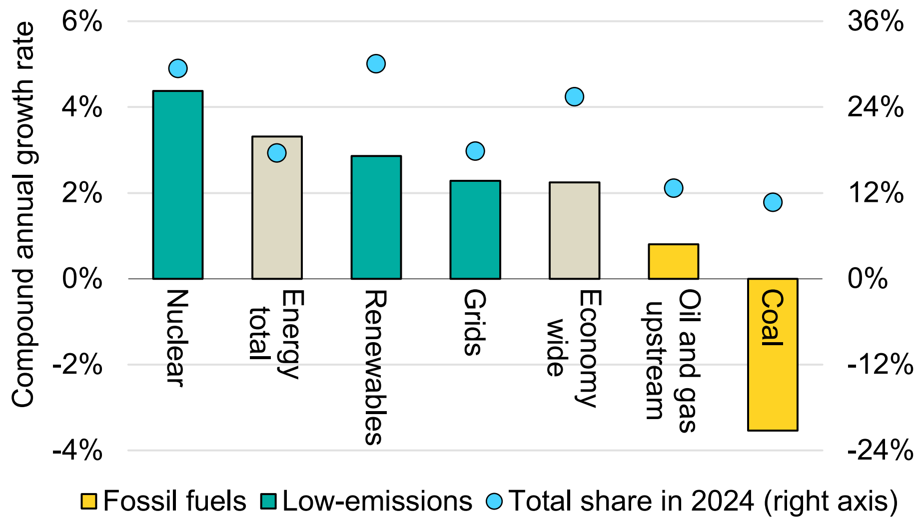
The share of women in senior leadership positions has shown promising trends, rising faster than the economy-wide average since 2015. Renewables and nuclear have seen particularly strong progress, while oil and gas supply showed only marginal gains, and coal witnessed declines. Women's share of leadership roles in the energy sector now stands at 18%, up from 13% in 2015, but it still sits below the economy-wide average of 25%.

Share of women in energy and energy-adjacent sectors, 2023



Note: Electricity supply refers to ISIC-35 Electricity, gas, steam and air conditioning supply.
Source: IEA analysis based on data from ILOSTAT.

Change in the share of women in senior leadership positions in the economy and by energy subsector, 2015-2024



Source: IEA analysis based on data from IEA (2025) Gender and Energy Data Explorer (Orbis, Moody's commercial database).

A range of drivers contribute to lower levels of participation of women in the energy sector. These include negative perceptions of women in certain occupations, workplace cultures, and limited exposure to vocational pathways. Several initiatives offer promising tools to address some of these issues. Programmes like Chicago Women in Trades in the United States, Build Together in Canada, and Australia's Women in Trades Roadmap have combined outreach, training, and policy reform to increase women's participation. These reforms include providing incentives to hire and train women, introducing gender targets in public projects, strengthening job-site safety and inclusion measures, and improving pathways from vocational programmes into apprenticeships.

Efforts in EMDEs, where women's participation in the energy workforce is lowest, are also being developed. For example, a recent World Bank report on Côte d'Ivoire highlighted a gender-sensitive vocational education and training (VET) programme that improves support for female students, including safer facilities, scholarships and mentorship. However, higher rates of informality, persistent financial barriers and limited job placement support continue to hinder broader progress in EMDEs. In many cases, even when women complete training, they face difficulties transitioning into formal employment, highlighting the need for more co-ordinated action to align training systems with labour market opportunities

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Energy jobs grow under all IEA scenarios, but workforce development plans must contend with a wide range of futures

Global energy-related employment is set to grow under all IEA scenarios – but the magnitude and pace of this growth varies across stages of transitions and policy settings. In the IEA's Stated Policies Scenario (STEPS), which assumes today's policy intentions will be implemented, global energy employment is expected to rise at a moderate pace to 2035. Under this scenario, the power sector continues to be the largest driver of growth, with the workforce climbing 14% to 26 million by 2035. Fossil fuel supply remains a significant source of employment, particularly in oil and gas, where jobs decline modestly to 93% of current levels. EV manufacturing jobs approach parity with those in ICE vehicles, and account for more than half of vehicle sales in key markets by 2035. Efficiency jobs grow by 1.2% per year, as the rate of energy efficiency improvements accelerates in the STEPS.

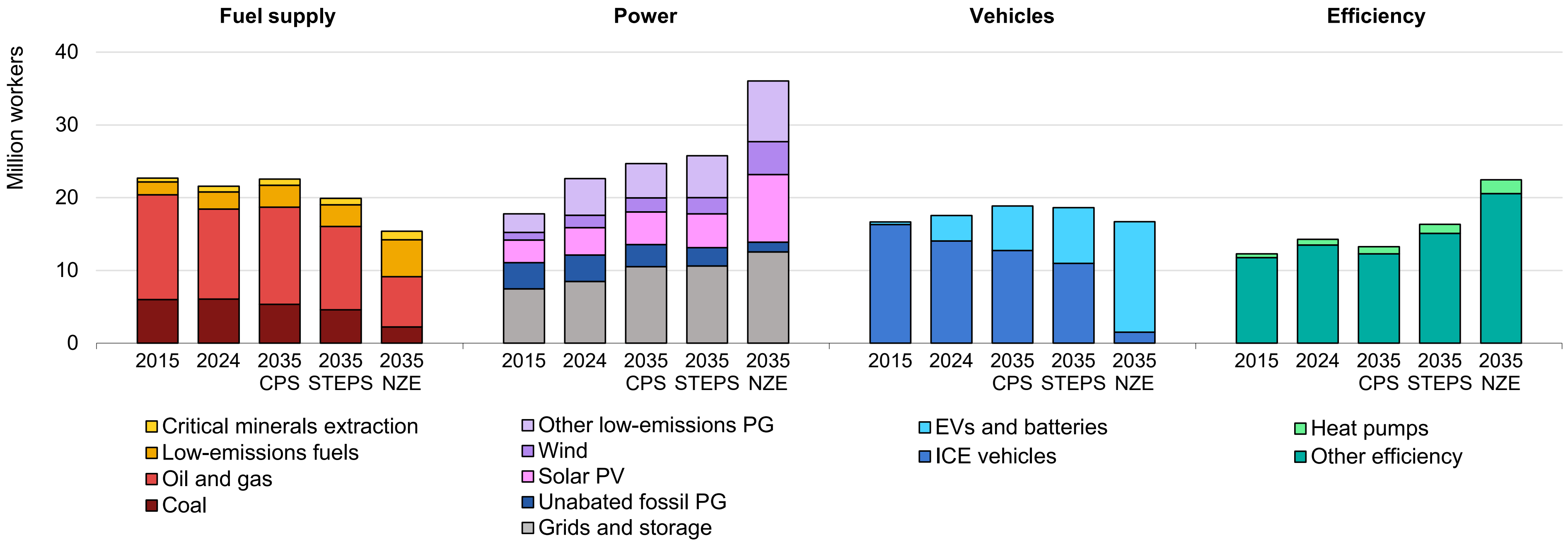
The Current Policies Scenario (CPS) considers only policies and regulations already in place and takes a generally cautious view on the speed at which new energy technologies are deployed. Employment growth by 2035 is accordingly more muted, especially in low-emissions energy segments. In total, the CPS has around 1.3 million fewer energy workers in 2035 than the STEPS. By contrast, fossil fuel supply sees a higher workforce than in the STEPS, as employment in oil and gas expands by 8% relative to current levels, although a decline of 12% is still observed in coal mining jobs. Employment in low-emissions power and electric vehicle manufacturing continues to rise, but efficiency jobs decline by 7% as rates of efficiency improvement remain slower than in the STEPS.

In the Net Zero Emissions by 2050 Scenario (NZE Scenario), the energy workforce expands significantly, as investment surges to support a faster transition. Power sector employment climbs 60% to reach 36 million by 2035, supported by major sustained investment across low-emissions technologies. The EV transition accelerates further, with EVs and their batteries representing over 90% of total vehicle manufacturing jobs by 2035. At the same time, fossil fuel supply employment sees further declines – particularly in coal supply, which falls by over 60%, followed by oil and gas supply with a 40% reduction – although some of these losses are offset by gains in low-emissions fuel supply.

Still, all three scenarios point to common structural shifts – rising employment in power and grids, a major transition in vehicle manufacturing, and sustained losses in coal. In these sectors, companies may have greater clarity in their workforce planning, where other subsectors see divergent trends under different scenarios, pushing firms to adopt a more dynamic approach to staffing requirements and matters of hiring and retention. Investing in versatile, multi-skilled teams, flexible training models, and reskilling pipelines will be critical to navigate changing technology mixes and policy landscapes.

The power sector grows in all scenarios, while the medium-term trend for other sectors may vary depending on policy settings

Global energy employment by technology and scenario, 2015, 2024 and 2035



Notes: PG = power generation; ICE vehicles = internal combustion engine vehicles; EVs = electric vehicles; solar PV = solar photovoltaic. CPS = Current Policies Scenario; STEPS = Stated Policies Scenario; NZE = Net Zero Emissions by 2050 Scenario. Low-emissions fuels include the supply of bioenergy, nuclear fuels, and hydrogen. Grids and storage includes transmission, distribution and storage. Other low-emissions PG includes power generation in renewables other than solar PV, wind, nuclear, and fossil-based carbon capture, utilisation and storage (CCUS). Other efficiency includes building retrofits, efficient and renewable heating, ventilation and air conditioning (other than heat pumps), and efficient appliances and lighting.

Chapter 2. The future of energy skills

Special focus: Building a skilled energy workforce for the future

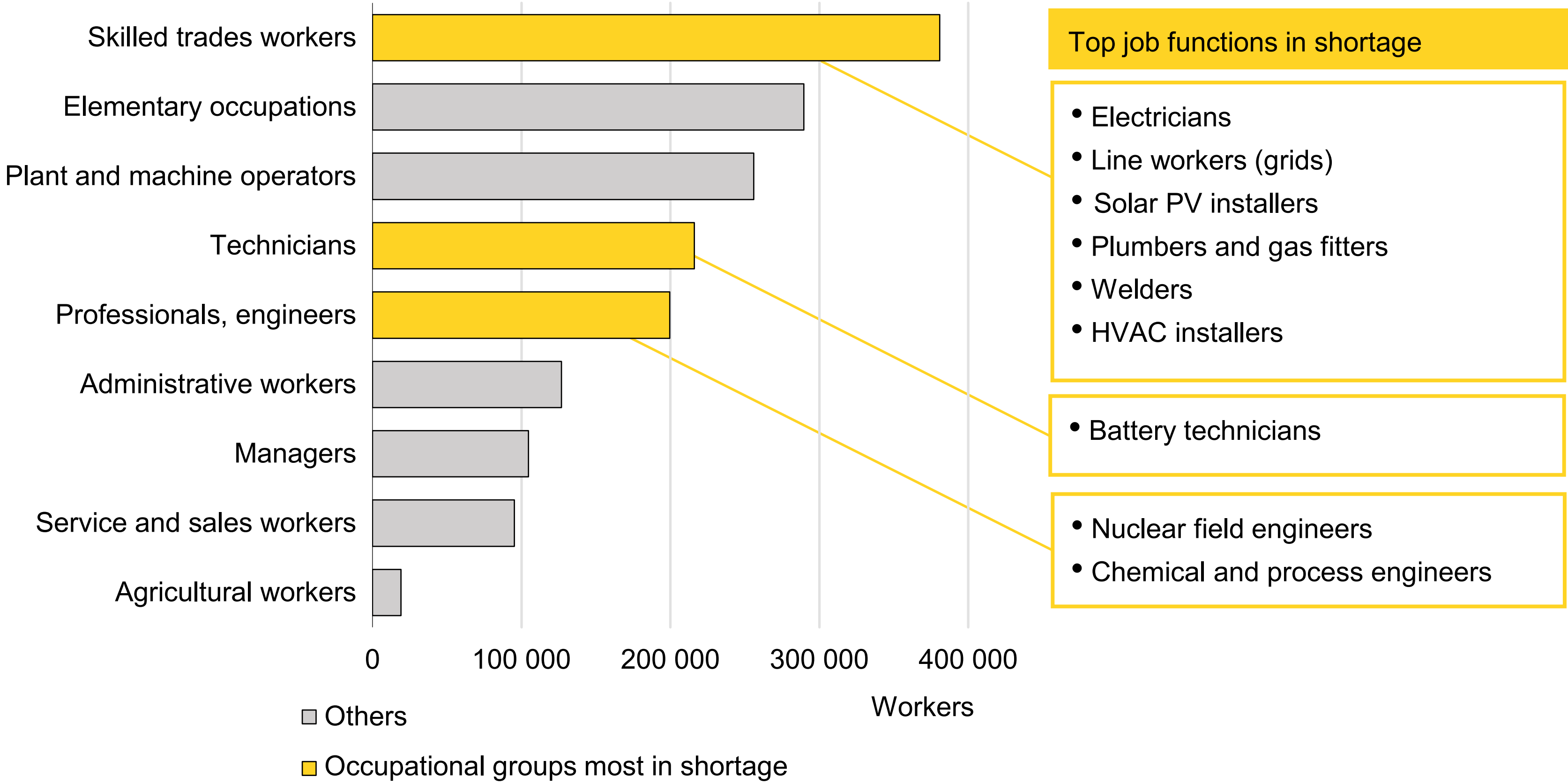
This year's special focus dives deeper into the growing skilled labour gap in the energy sector that the IEA has been signalling for the past two years. Fuelled by rising investment, the energy sector continued to outpace the broader economy in job creation for the third consecutive year in 2024 – a sharp shift from the pre-pandemic period. However, many parts of the energy industry continue to struggle to keep pace with employment needs, with intense competition for skilled workers in some occupations. Employers are increasingly making trade-offs on desired qualifications, raising wages to attract talent and relying more heavily on on-the-job (OTJ) training to compensate for the gap in required skills. These pressures have implications for competitiveness and carry potential risks for worker safety, project quality, and timely delivery.

The 2025 annual *IEA Industry Employment Survey* shows an increase in firms reporting hiring difficulties compared to previous years. Many are resorting to new measures to fill critical positions, reflecting a structural tightening of energy labour markets. At the same time, employers are seeking new skill sets as the nature of work in the energy sector continues to evolve. With the rapid expansion of clean energy and the growing integration of artificial intelligence (AI) and digital tools, the skills demanded of workers are changing. Traditional technical expertise remains essential, therefore balancing the retention of these core capabilities with the integration of new technologies and competencies is becoming an increasingly complex challenge for recruitment and workforce development.

This chapter examines the scale and nature of these workforce challenges – identifying the occupations most affected by shortages, assessing the alignment of education and training pathways, and exploring the implications for energy security and competitiveness. Chapter 3 builds on this analysis, outlining policy responses and strategies for governments, industry, and labour representatives to align skills development with the sector's long-term needs.

Skilled trades are the fastest-growing energy occupations, with six key roles in shortage

Global energy employment growth by occupation, 2023-2024



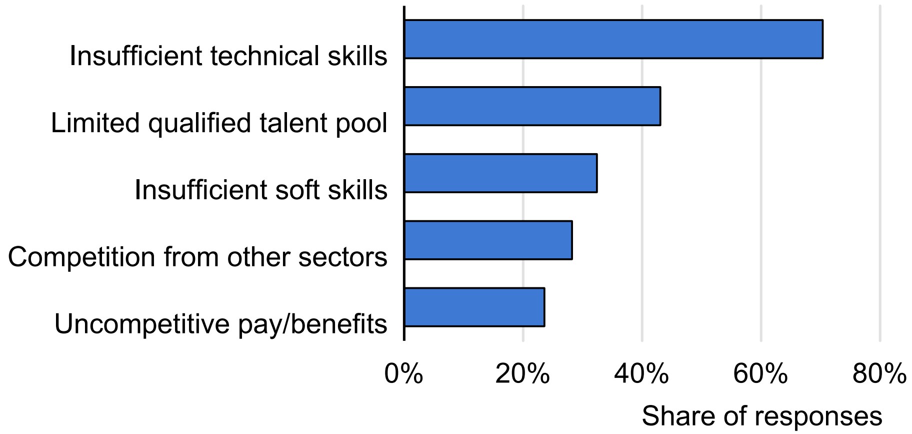
Notes: HVAC = heating, ventilation and air conditioning. IEA analysis based on Level 1 classification (major groups) of the International Standard Classification of Occupations (ISCO). The list of the top occupations in the energy sector was developed through IEA analysis of multiple data sources, including industry and government reports, official statistical products, industry surveys, and Lightcast job postings data. Occupations were identified and compared across regions, with those appearing most frequently and consistently across countries synthesised into the final list. The research encompassed a global scope and included the following countries: Bangladesh (2023), India (2022), Indonesia (2025), China (2022), Argentina (2025), Brazil (2024), Colombia (2025), Nigeria (2022), Kenya (2020), Canada (2024), the United States (2024) and the European Union (2024).

Energy employers face the greatest difficulty hiring applied technical workers

An increasing share of energy firms are reporting challenges in hiring applied technical workers. Of over 400 energy firms surveyed by the IEA in 2025, around 60% report hiring difficulties due to skills and labour shortages[1]. In the last year, around 50% of the employers surveyed adjusted hiring requirements due to a lack of qualified candidates, suggesting they may have lowered their prerequisites for employees' skills, broadened the scope of sought-out worker profiles or become more open to providing training opportunities themselves.

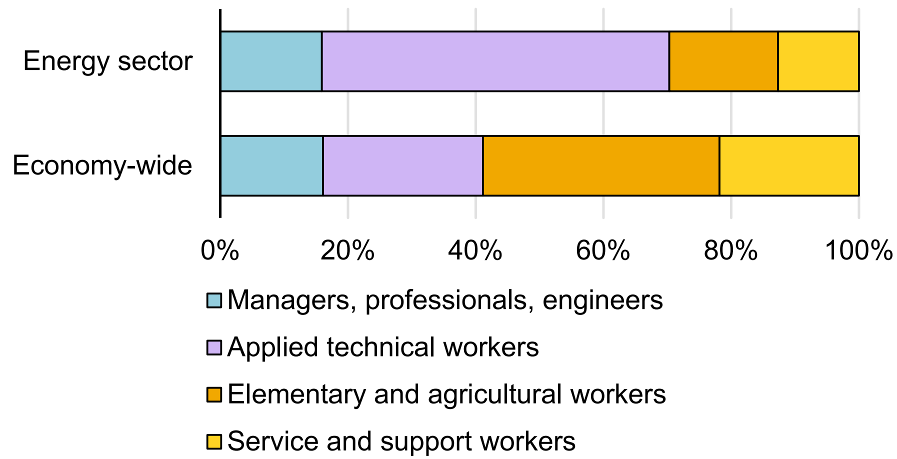
Skilled labour shortages are a persistent challenge across the wider economy, and the energy industry faces specific difficulties due to its heavy reliance on applied technical workers to build and maintain new energy infrastructure. This occupational category includes technicians (e.g. battery technician), skilled trades (e.g. electrician, welder, pipefitter), and plant and machine operator (e.g. power plant operator) roles, which together make up more than half of total energy employment – twice the share seen in the broader economy.

Main reasons for workforce shortages reported by energy employers



Source: *IEA Industry Employment Survey*, 2025.

Share of occupational groups in the energy sector compared to the overall economy, 2024



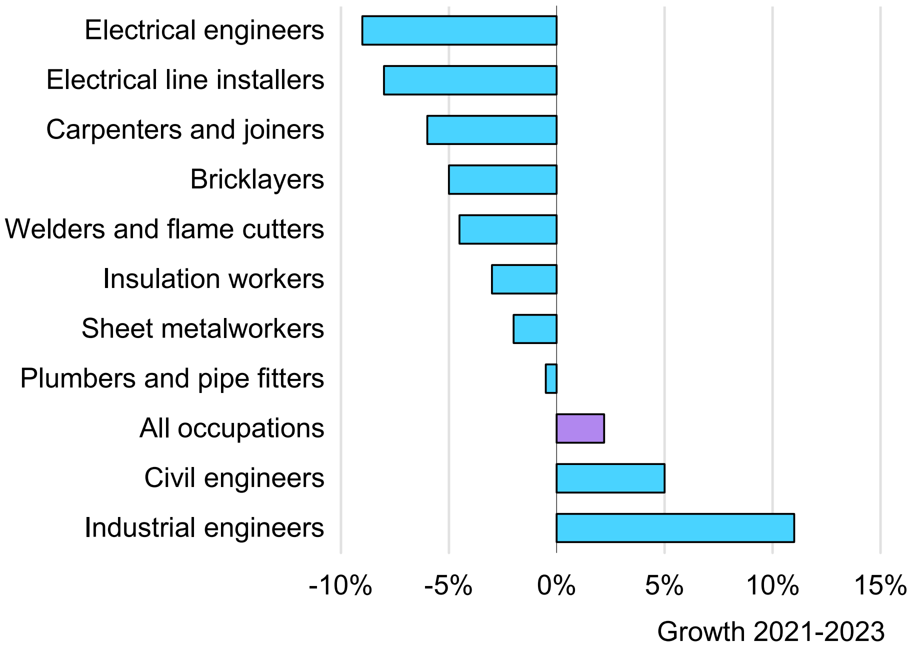
[1] While closely related, skills and labour shortages reflect distinct challenges. Skills shortages arise when too few workers possess the competencies employers require. Labour shortages occur when too few workers fill available roles, often because of weak local labour supply or factors that result in low worker interest in roles, such as unattractive wages or conditions. These effects can be compounded by mismatches in skills and high vacancy rates.

Skilled trade roles, the largest subset of applied technical workers, face the most acute shortages, represent around 25% of energy employment and accounted for over 20% of year-on-year growth in 2024. IEA analysis based on government reports, industry surveys, official statistics and job posting data suggests that six of the top energy occupations most in shortage are in skilled trades roles, namely electricians, grid line workers, solar PV installers, pipe and gas fitters, welders and heating, ventilation, and air conditioning (HVAC) installers.

Shortages of applied technical workers, and especially skilled trades roles, are most severe in parts of the energy sector with heavy construction demands. Because clean energy infrastructure is expanding so rapidly, these subsectors are currently far more dependent on construction-related occupations than other parts of the energy sector, employing around 50% more construction workers than the industry average.

Many construction and related skilled trades roles are in high demand across the broader economy, compounding the energy sectors challenges. Many energy companies scattered around the world are reporting persistent hiring difficulties for these positions, including in the United States where over a million trades jobs remain unfilled, and in the European Union where welders, electricians, plumbers, pipefitters, and metalworkers were among the top roles going unfilled in 2024.

Changes in employment by occupations in the EU27, 2021-2023

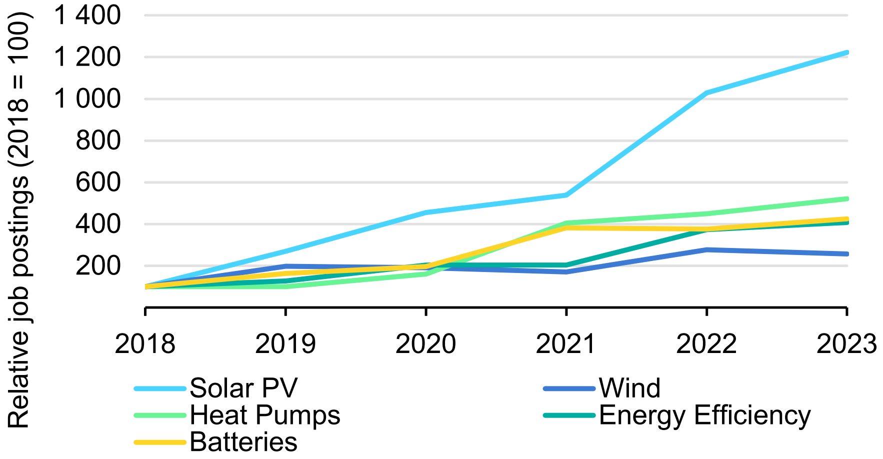


Note: EU = European Union.

Source: IEA analysis based on EURopean Employment Services' (EURES) (2024) Report on labour shortages and surpluses 2024.

Labour market indicators, such as job postings (a proxy measure for the rising and unmet demand of selected skills and occupations), show a sharp uptick in demand for skilled trades occupations within parts of the energy sector. Between 2018 and 2023, the number of job postings for skilled trades in key sectors, which includes wind, solar, heat pumps, energy efficiency and batteries, grew at an average annual rate of 40%, with solar marking the sharpest increase at a compound annual growth rate of 65%.

Job postings for technicians, trades workers and associated professionals by year and by sector, 2018-2023



Notes: Countries covered include Canada, Germany, Spain, Switzerland, the United Kingdom, the United States (2018-2023); Australia, Austria, Singapore (2019-2023); and Belgium, France, Italy (2021-2023).

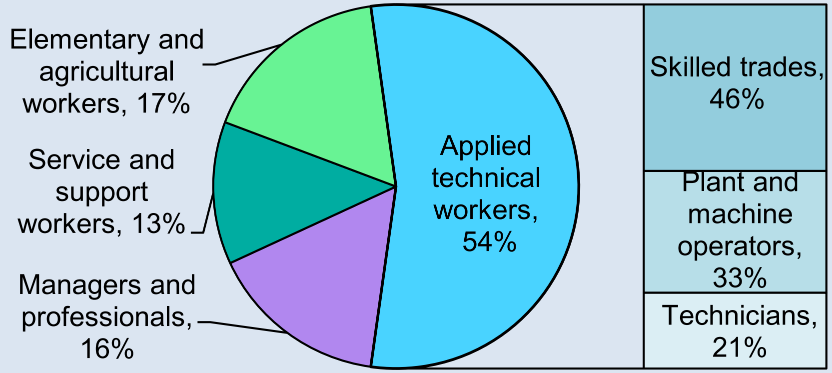
Source: IEA analysis based on data from Lightcast.

Due to persistent labour shortages, many energy companies are increasingly turning to contractors and subcontractors, especially for project development, construction, installation, and maintenance work. Close to 30% of the over 400 energy companies surveyed by the IEA plan to rely more heavily on contractors in the coming years, citing chronic challenges in recruiting qualified permanent employees as the main reason. However, this reliance adds complexity, as contractors operate across multiple sectors, placing the energy sector in direct competition with construction and infrastructure projects for the same limited talent pool. It may also slow efforts to train the energy workforce in a standardised manner.

Note on applied technical workers

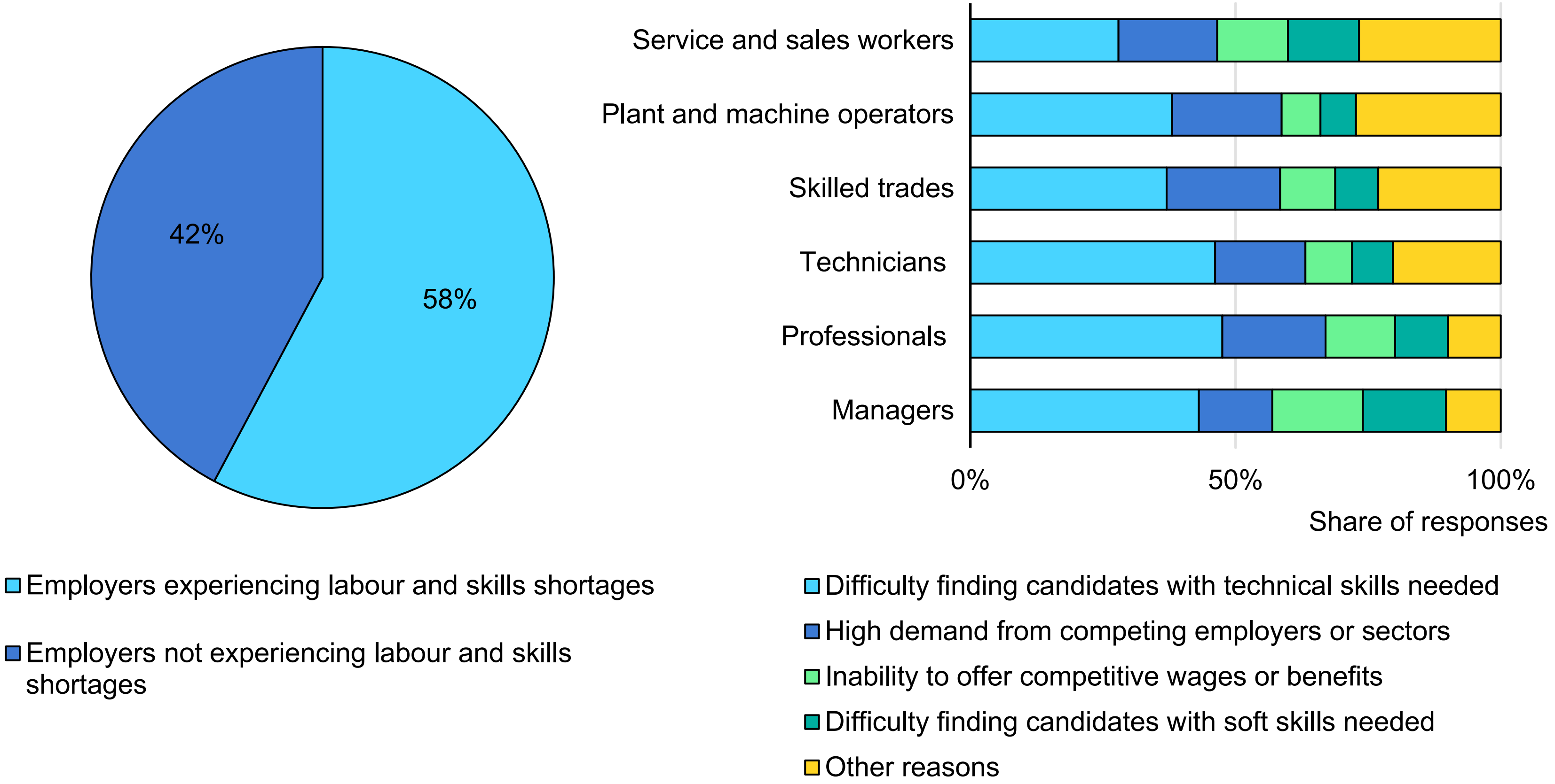
In this report, the energy workforce is broken down into several occupational groupings, which are based on the ILO's categorisation system (see Methodology, Definitions and classifications, in the Annex). Each occupational category is associated with different skill levels (low, medium, high) and corresponding educational attainment (e.g. vocational, advanced vocational and tertiary, which include bachelor's, master's and doctoral degrees). Currently, most shortages occur among high- to medium-skilled applied technical workers, making up more than 50% of the energy workforce. Technicians, skilled trades workers, and plant and machine operators are a subset of applied technical workers, with technicians classified as high skilled occupations, requiring advanced vocational qualifications, and the other two being medium-skilled roles requiring standard vocational education.

Applied technical workers classification by job function, 2024



Nearly 60% of energy employers report skilled labour shortages concentrated within applied technical roles

Share of employers surveyed by the IEA experiencing labour and skills shortages, and associated reasons for the reported difficulty in hiring for selected occupation groups



Notes: This analysis is based on a survey of over 400 energy employers. Other reasons reported for difficulty in hiring include long hiring timelines due to internal, security or regulatory processes, negative perceptions of working conditions in the industry, limited interest in energy sector careers, and geographic or relocation barriers.
Source: *IEA Industry Employment Survey*, 2025.

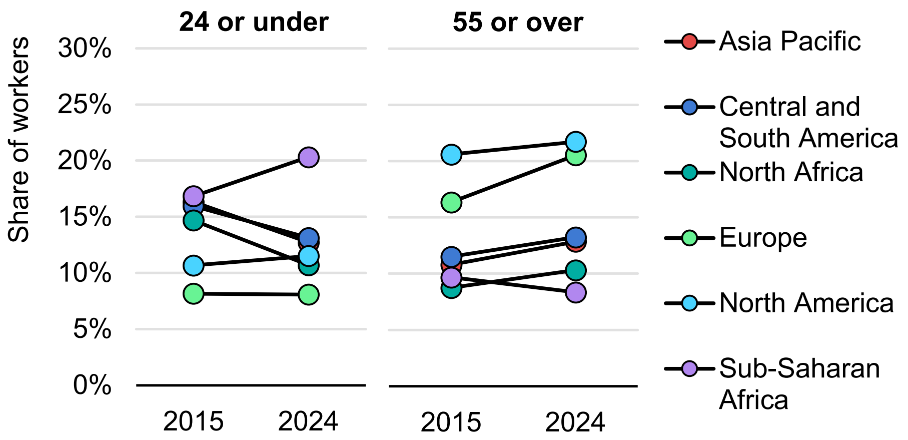
An ageing workforce and lower youth entry into the energy sector are contributing to skilled labour shortages

Shortages of skilled workers in the energy sector are being driven by two intersecting trends: the workforce is ageing faster than the economy-wide average, with many nearing retirement, while fewer young workers with relevant credentials are entering the field. These dynamics are evident across most regions, though their severity varies by location and subsector. Since 2015, the situation has worsened, with the share of energy workers over 55 years old rising across all major regions except sub-Saharan Africa. At the same time, the share of younger entrants has declined in Asia Pacific, Europe, Central and South America, and North Africa, while it increased in sub-Saharan Africa and North America.

The problem of rising retirement rates are more acute in advanced economies. In the next 15 years, 13 OECD countries are expected to see their population contract. Within the energy sector, the IEA finds that advanced economies have 2.4 workers within ten years of retirement for every worker under the age of 25, while in emerging market and developing economies (EMDEs) this figure is below one. In the United States, nearly 30% of union electricians are expected to retire within the decade. Over the same period, the United Kingdom foresees a shortfall of 1 million jobs as 20% of the engineering workforce retires. Similar problems have been prominently flagged, especially for skilled trades roles, in Canada, Japan and the European Union.

In some advanced economies growing shares of younger workers are entering the energy workforce. In the United States, there has been a resurgence of young people entering into skilled energy trades jobs, which is partly driven by the increasing cost of higher education and perceptions of better job security. However, the pace at which young people are entering the sector is still insufficient to match that of retirements.

Share of energy workers by age group in selected regions, 2015 and 2024



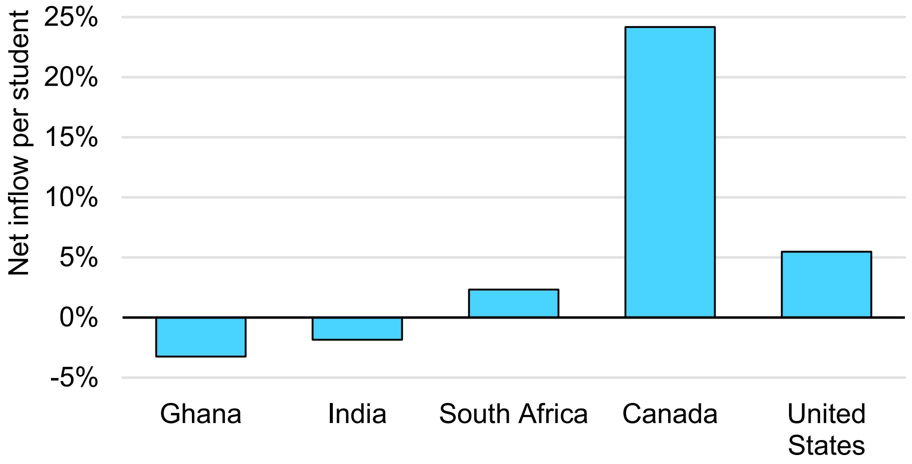
While most EMDEs have a younger pool of available workers, many are also facing challenges of an ageing workforce in the short term. India and Indonesia will see their working age population start to decline before 2040, while this shift has already started in countries such as China and Brazil. Even in sub-Saharan Africa where the population is getting younger, certain occupations relevant to energy are still facing challenges due to retirements. For instance, in South Africa, the average age of trades workers such as electricians, pipefitters, welders or plumbers is 55 years old.

Some parts of the energy sector are significantly older than others. In nuclear and electricity grids, the ratio of workers within ten years of retirement to new entrants under 25 years old is 1.7 and 1.4, respectively, well above the 1.2 economy-wide average. In these sectors, ageing has partially been driven by historic hiring booms that created large cohorts now nearing retirement, challenges in attracting younger workers due to shifting perceptions of these industries, and typically low turnover in such highly regulated and unionised sectors. Across the energy sector, skilled labour shortages have also been driven by concerns over job quality and wage competitiveness. In advanced economies, surveys show many workers are leaving – or choosing not to enter – trades sectors such as construction due to lower wages and less attractive working conditions.

In EMDEs, a lack of available training, especially in countries where clean energy industries are still in development, is pushing employers to source talent from other regions instead of training local workers. A lower base of formally trained workers means that skilled labour shortages often coexist with high levels of unemployment in EMDEs. In South Africa, the Department of Higher Education and Training regularly lists electricians and welders as scarce skilled occupations while the country faces one of the highest unemployment rates in the world.

Many developing countries face an additional complication with the outflow of skilled workers to higher-paying opportunities abroad, particularly from emerging economies, where graduates often migrate to advanced economies for better salaries, career progression, and access to technology. These patterns are visible from early career stages, as many students seek higher education in advanced economies where decades of investment have led to greater availability of educational offerings than in EMDEs.

Net flow ratio of internationally mobile students in selected countries, 2024



Note: The net flow of internationally mobile students is equal to the number of inbound students minus the number of outbound students, divided by total domestic student enrolment. Data covers students attending tertiary degree programmes only.
Source: IEA reproduction of data from UNESCO Institute for Statistics.

While migration can bring economic benefits through remittances, it reduces the domestic pool of professionals needed to plan, deploy, and maintain energy infrastructure. This combination of domestic training gaps and international migration intensifies difficulties in attracting and retaining the next generation of energy workers, an issue highlighted by several developing countries during the IEA's Workshop on the Future of Energy Skills.

Building a skilled energy workforce requires a sufficient number of energy graduates to come through formal education pipelines. In the European Union, a strong focus on vocational education in several member states keeps the concentration of young energy-relevant vocational graduates relatively high compared to other advanced economies, and these rates have increased by about 7% since 2015. In EMDEs, the number of young graduates still trails that of many advanced economies but is growing faster. For instance, in China, Indonesia and North Africa, the concentration of young energy-relevant vocational graduates grew by 25% or more since 2015.

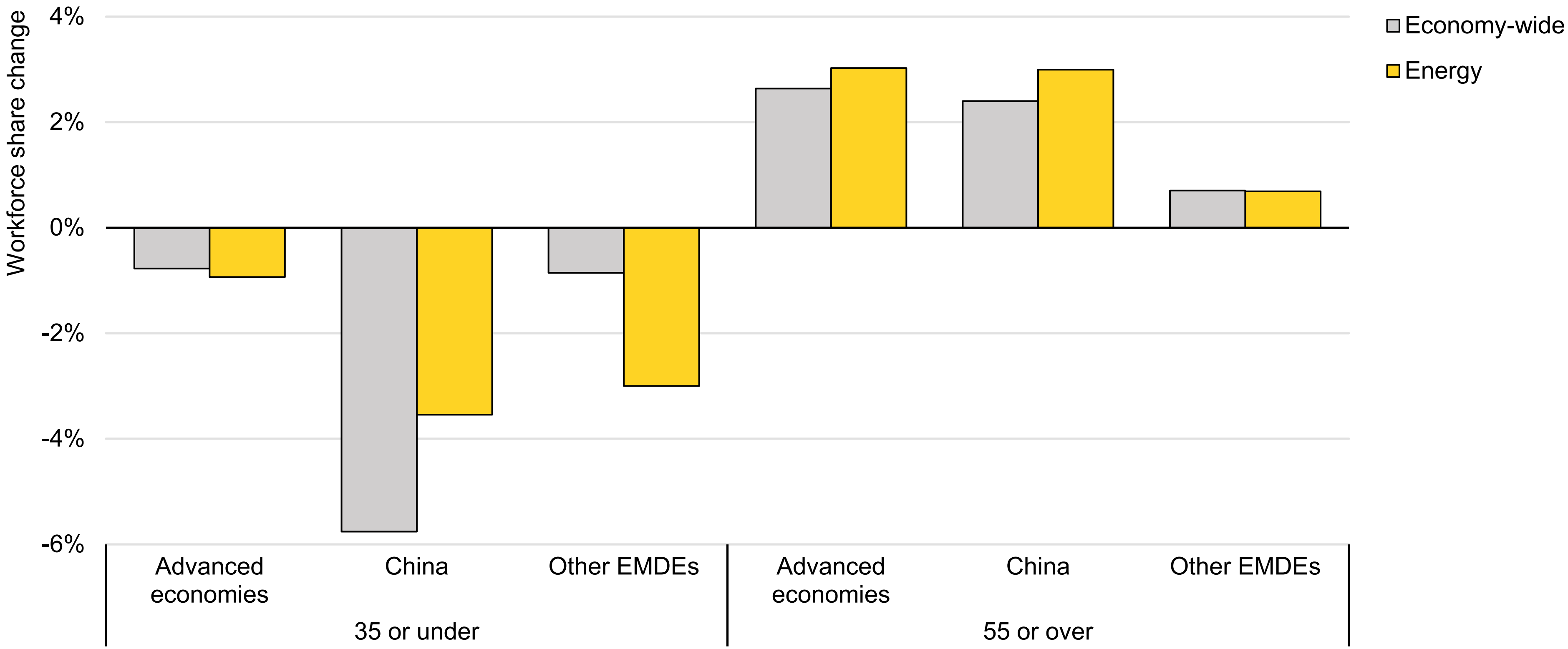
Many governments have implemented initiatives to improve the perception of vocational education and raise uptake. In China for example, the 2019 National Vocational Education Reform Implementation Plan has been focused on expanding the capacity of technical universities to deliver bachelor's and master's degrees in applied science fields. In Brazil, efforts to reform vocational education have led to a more flexible upper secondary education model whereby students can receive a dual high school degree that includes vocational qualifications. Many of these are explicitly linked to broader efforts to address youth unemployment that, despite declining at the global level, remains significantly higher than overall unemployment.

However, attracting more graduates into energy-related fields of study is not sufficient in itself. Many of those who graduate in energy-related fields may not go into the energy sector. For example, engineering graduates are often sought by other sectors. In 2023, of the 4.3 million engineering college graduates employed in the United States, only 1.7 million were employed in an engineering position, with over 600 000 working instead in IT and software roles, and over 1 million working in non-science and non-engineering jobs. In the United Kingdom, only 44% of newly employed engineering graduates entered one of the core industrial sectors relevant to the energy sector (mining, manufacturing, construction or utilities). These traditional industrial sectors typically struggle to compete with salaries on offer in rival sectors, particularly in software.

As the energy sector works to attract and retain talent over the next decade, the energy workforce will have to address a three-pronged challenge: resolving ongoing skilled labour shortages, replacing the accelerating outflow of retiring workers and meeting growing employment needs for qualified workers as energy demand continues to expand. Investing in younger workers will be particularly important to provide them with economic opportunities, especially in regions such as Africa, where three to four additional young people enter the labour market for every job created annually.

The energy workforce is ageing faster than the wider economy in many regions

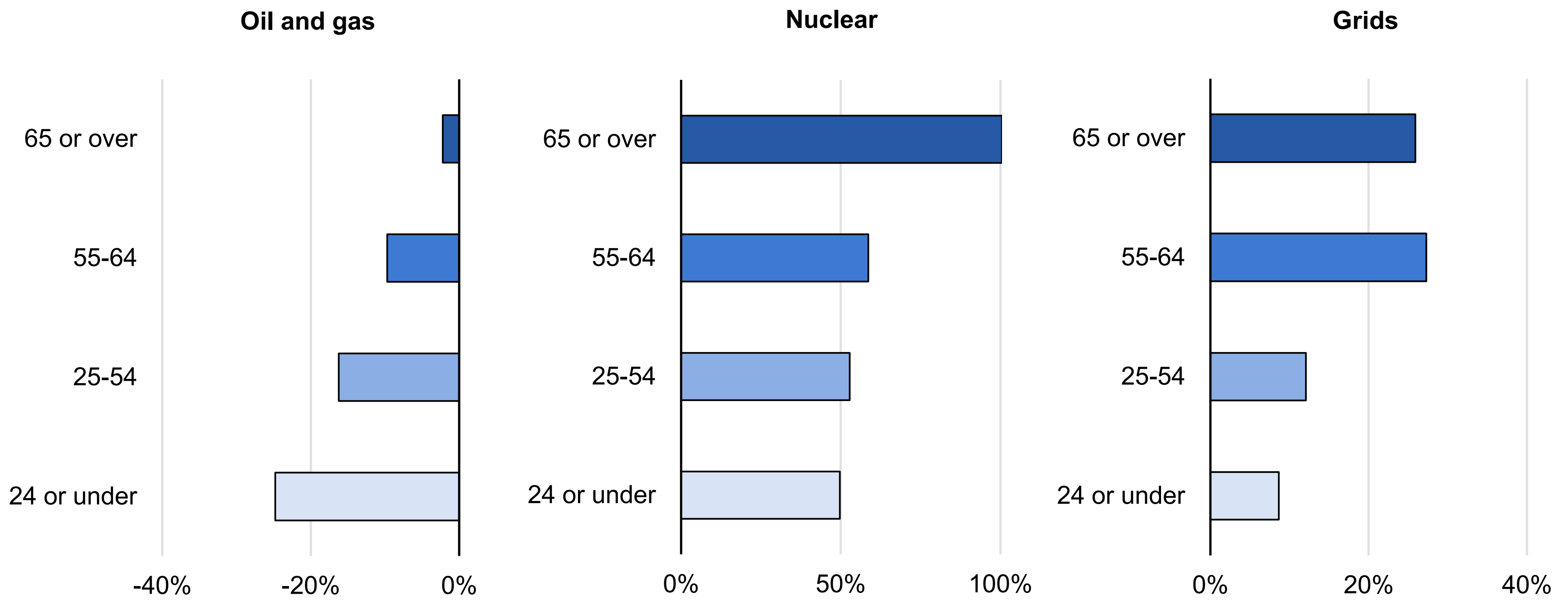
Change in energy employment by age group and region, 2015-2023



Notes: EMDEs = emerging market and developing economies. The percentage change is calculated as the difference between the 2023 workforce and the 2015 workforce within each age group.
Source: IEA analysis based on ILOSTAT data.

An ageing workforce poses increasing risks for the installation and maintenance of critical energy infrastructure

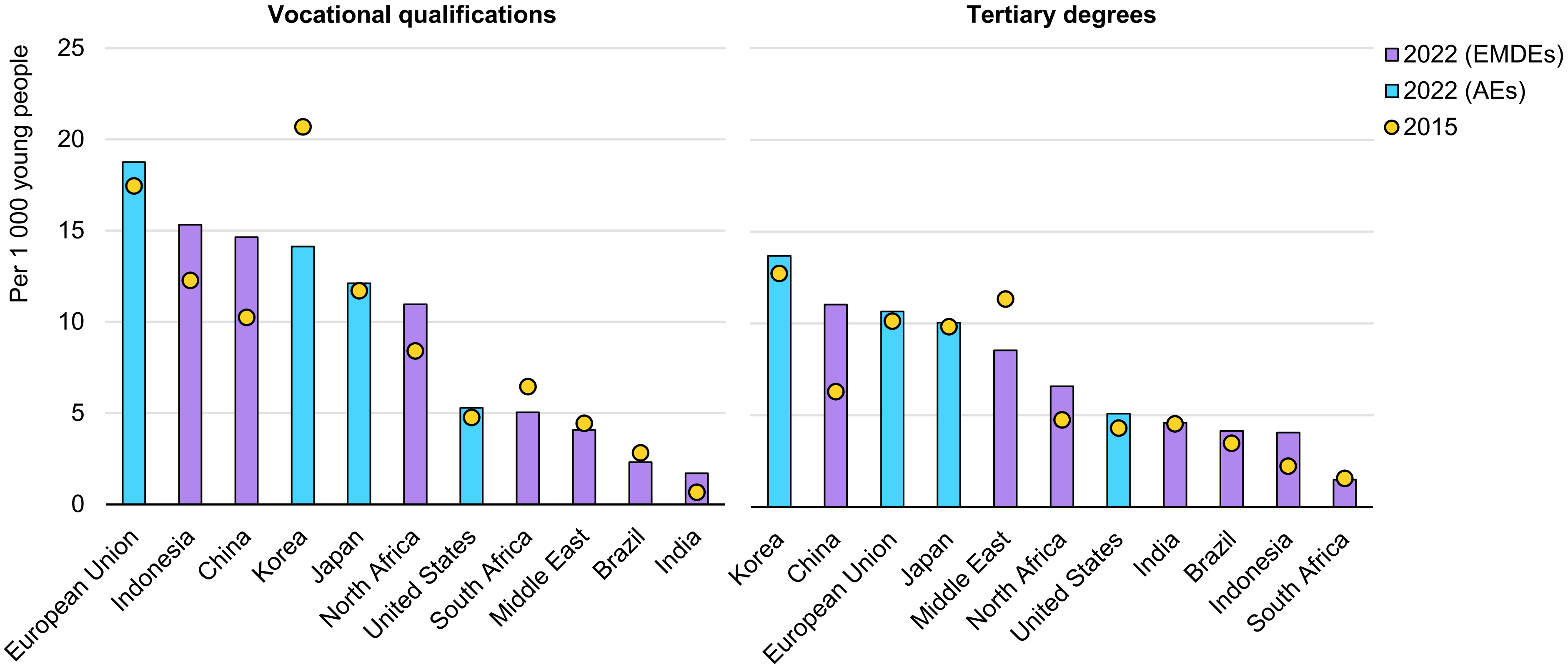
Change in employment by age group in selected energy subsectors, 2015-2024



Source: IEA analysis based on data from ILOSTAT.

Vocational education levels are highest in advanced economies, but growing faster in emerging market and developing economies

Vocational and tertiary graduates from energy-relevant degrees per thousand young people (2015-2022)



Notes: EMDEs = emerging market and developing economies. 'Energy-relevant' fields correspond to ISCED-F field code 07 – Engineering, manufacturing and construction. Tertiary degrees include bachelor's, master's and doctoral degrees (ISCED levels 06-08), while vocational qualifications are vocational degrees attained from lower-secondary to short-cycle tertiary level (ISCED levels 02-05).Young person refers to the population between 20-29 years of age.

Source: IEA analysis based on data from the Chinese Ministry of Education, India Ministry of Statistics and Programme Implementation, OECD Education at a Glance, UNESCO Institute for Statistics, and UN Demographic Statistics Database.

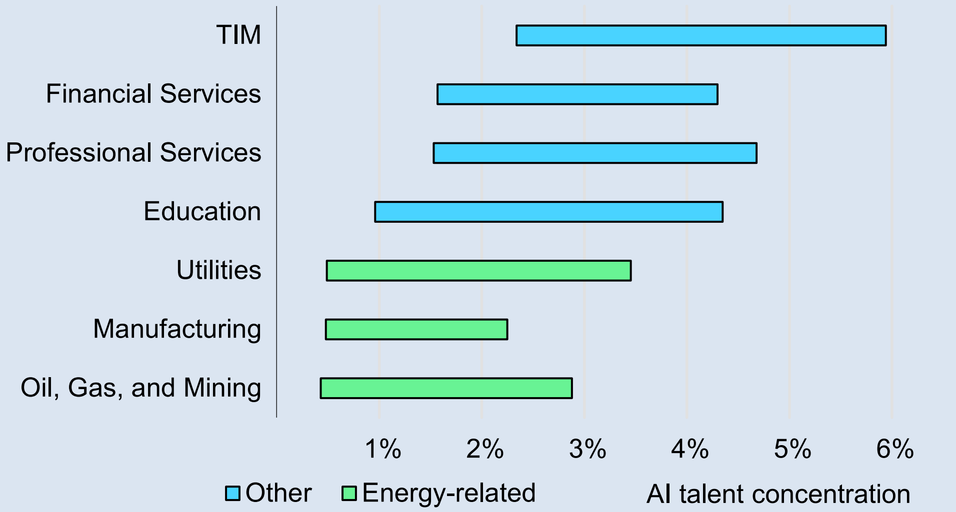
Unclear business use cases and high costs are creating barriers to developing AI literacy

Emerging technologies – particularly AI – are increasingly being looked at as an important new tool within the energy sector. In a survey conducted by the IEA with 400 energy companies, the top two long-term benefits anticipated from AI adoption were "improved administrative efficiency" (such as speeding up permitting processes) and "improved quality output" (such as real-time monitoring of power grid performance).

AI is already being applied across the energy sector, especially related to administrative efficiency, improved worker safety, and improved fault detection. In extreme operating environments, such as oil refineries or nuclear plants, AI-driven systems can help predict equipment failures, reducing the likelihood of accidents and manual interventions. Virtual Reality training modules are reducing the time and costs of doing onsite trainings, especially in high-risk areas such as offshore oil, gas and wind. AI has been applied to streamline administrative tasks related to permitting and compliance through automated document analysis and information gap detection.

As the business case for AI becomes clearer, the demand for digital skills is growing across the industry. However, the energy sector is falling behind other industries in building this digital capacity. Between 2018 and 2024, the concentration of AI talent in utilities, oil, gas, and mining was on average 40% lower than in sectors such as education, financial services, technology, information and media. While other industries have moved quickly to attract and integrate AI expertise, energy-adjacent sectors have struggled to keep pace.

AI talent concentration by sector, 2024



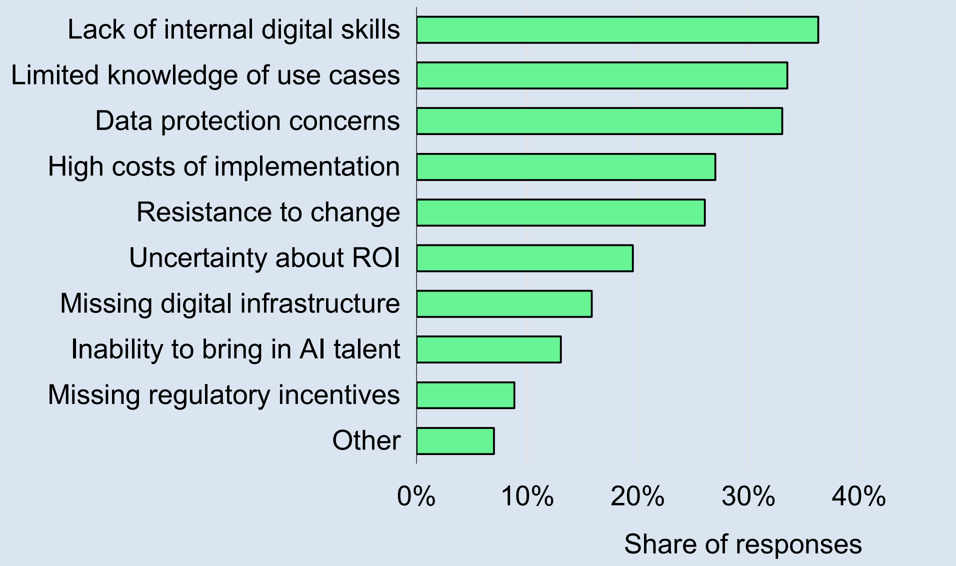
Notes: TIM = Technology, information and media. A LinkedIn member is considered "AI talent" if they have explicitly added at least two AI skills to their profile and/or they have been employed in an AI job. AI skills include, among others, machine learning, artificial intelligence, image processing, neural networks, natural language processing, predictive modelling and deep learning. AI talent concentration' is calculated by dividing the counts of AI talent in a country by the counts of LinkedIn members in that respective country (LinkedIn, 2025). Countries covered in this analysis include the United States, Canada, Germany, France, India, Brazil, Saudi Arabia, South Africa and the United Kingdom.

Source: IEA analysis based on LinkedIn data (2025).

Several barriers are slowing progress in developing the needed digital literacy. First, energy companies often struggle to compete with tech and finance firms on salary and benefits, making it difficult to attract top digital talent. IEA analysis on four key occupations – software engineer, data scientist, machine learning, and hardware engineer – in the United States and Canada revealed that entry-level salaries are on average 30% higher in the technology sector than in energy companies. Second, many organisations lack clearly defined AI strategies or use cases, which makes it harder to justify investments in new roles or capabilities. Third, there may be limited opportunities for training existing staff with the needed AI-related skills.

AI's overall impact on the workforce has yet to be seen. While automation may reduce labour required for specific tasks and costs of certain functions, most companies cite increased productivity and improved quality as the primary benefits of AI. Using these tools does shift the nature of work in some occupations, requiring individuals and organisations to rethink job roles. Some successful models are emerging with companies partnering with universities or technology providers to deliver targeted training programmes, while others are investing in internal platforms to build digital capabilities across their workforce.

What is the greatest barrier in adopting AI and digital technologies in your day-to-day operations?



Note: ROI = return on investment.
Source: *IEA Industry Employment Survey*, 2025.

The adoption of AI tools faces steeper challenges in EMDEs, where limited digital infrastructure and connectivity risks and lower levels of digital literacy may create uneven uptake of AI tools more broadly. That said, there are emerging applications of AI tools to address energy data and capacity gaps in these economies such as leveraging satellite imagery, remote sensing and local sensor data to map underserved regions and refine demand projections. More examples and case studies can be explored at the IEA's Energy and AI Observatory.

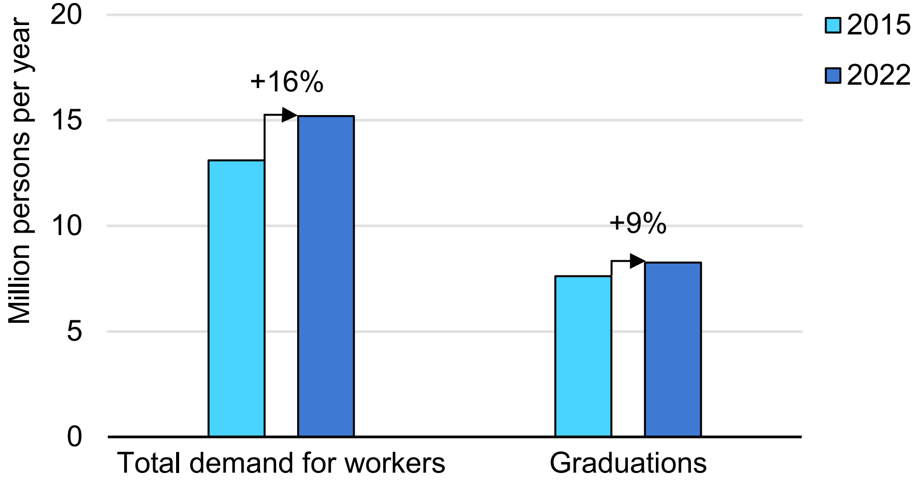
The past decade saw shortfalls in new graduates with degrees relevant to energy

Recruiters for most energy occupations typically require or prefer candidates to have completed some form of formal education, whether vocational or tertiary. High-skilled roles – such as engineers and managers – generally call for tertiary education. Applied technical roles, which include technicians, trades workers and plant or machine operators, often require some form of vocational education and training (VET) qualifications, which typically combine classroom instruction with hands-on practical learning.

Over the past decade, vocational education in fields relevant to energy has stagnated in many countries, even as energy sector demand for these qualifications rises. The number of graduates with technical skills relevant to energy, which has been captured by certifications in engineering, manufacturing and construction fields (ISCED-F field code 07 and includes qualifications in trades such as electricians and welders, hereafter "energy-relevant" degrees), has gradually fallen on a per-capita basis in advanced economies. EMDEs outside of China produce fewer graduates from energy-relevant degrees per capita than the rest of the world, and current trends suggest they are not on pace to catch up.

IEA analysis indicates that growth in the supply of these qualifications is not keeping pace with industry demand for applied technical roles. Annual demand for applied technical workers in industrial sectors commonly demanding a high share of these workers (including mining, manufacturing, utilities and construction) rose by 16% between 2015 and 2022, driven both by expansion in the labour force and replacement of retiring workers, compared with only a 9% increase in relevant graduations.

Annual demand for applied technical workers from industrial sectors, and graduations from energy-relevant vocational degrees, 2015-2022



Note: Total demand for workers represents annual demand for new applied technical workers (technicians, skilled trades workers and plant and machine operators) from industrial sectors (mining, manufacturing, utilities and construction). Graduations represent annual graduations from energy-relevant vocational qualifications (i.e. engineering, manufacturing and construction).
Source: IEA analysis based on data from ILOSTAT, Chinese Ministry of Education, India Ministry of Statistics and Programme Implementation, OECD Education at a Glance, and UNESCO Institute for Statistics.

The gap is set to widen further under current trends, particularly for energy-sector roles. IEA analysis suggests that in the Stated Policies Scenario (STEPS), in which current policy intentions are implemented, current flows of vocational graduates into the energy sector would need to rise by 43% by 2030 to match projected demand, with even higher requirements under a scenario aligned with net zero emissions in the energy sector by 2050.

That said, the energy sector currently accounts for only 5% of total industrial demand for these graduates. Meeting projected needs under today's trends would therefore require an increase of roughly 2% in overall graduations in energy-relevant degrees by 2030. The sector could alternatively attract a larger share of existing graduates, but this is constrained by widespread shortages of applied technical workers across the economy, and strong wage competition from other industries.

Where energy firms are either unable to fill open positions with desired qualifications, many make up for this shortfall by hiring less qualified candidates and increasing on-the-job training. Many workers across the global economy do not necessarily have the formal training typically desired for their roles, but have acquired these skills over time, often informally, and have not had these skills certified. This is often the case in EMDEs, where an estimated two in three young adult workers lack formal qualifications that match their jobs.

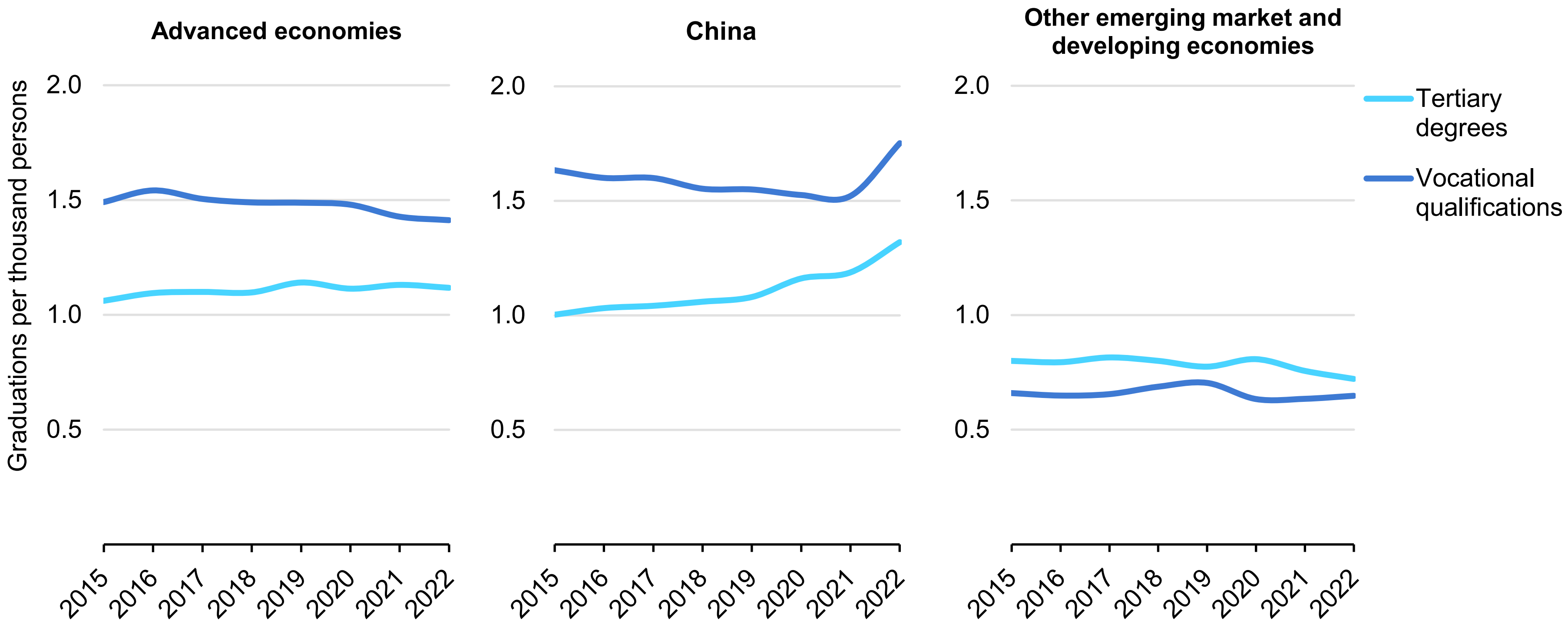
Survey responses from industry representatives across energy sectors indicate that more than half of skills for entry-level positions are acquired through on-the-job (OJT) learning and training. This significant share stresses the importance of improving alignment between industry needs and educational curricula, to ensure that formal education helps graduates be readily equipped with the skills required by employers. While on-the-job training remains a cornerstone of workforce development, its importance varies by field depending on specialisation, safety standards, and the need for a flexible labour pool. For example, electricians and HVAC technicians must meet strict certification requirements to ensure safety and quality when working independently across multiple sites.

As new technologies emerge across the energy sector, companies are often the first to provide training by developing in-house programmes or certified supplier networks to address immediate skills gaps. This firm-led approach reduces the burden on workers to seek training independently but can also fragment training systems, increase costs for emerging industries, limit labour mobility, and constrain market competition by creating closed pools of qualified workers.

Policy makers need not view every emerging technology as requiring a new certification. Creating separate credentials for each new field risks shifting costs onto workers or public budgets. Instead, many new competencies – such as those related to solar PV, battery systems, or EV infrastructure – can be integrated into existing standards. Partnerships between employers, educators, and governments can help achieve this balance through co-developed curricula, apprenticeships, and industry-supported training facilities that align workforce development with evolving sector needs.

Engineering and trades qualifications are stagnant or falling on a per capita basis worldwide

Annual graduations from energy-relevant qualifications (tertiary and vocational) per thousand population, 2015-2022

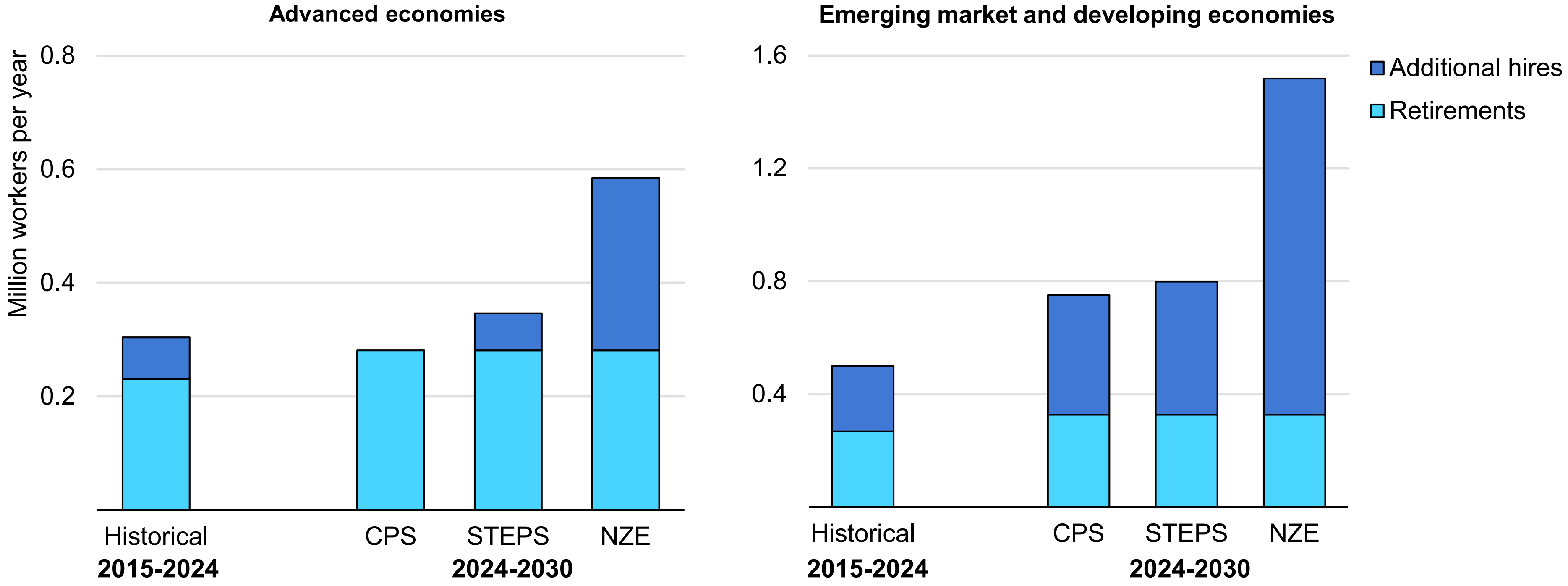


Notes: Engineering, manufacturing and construction degrees correspond to ISCED-F field code 07. For vocational qualifications, this category includes qualifications in trades such as electricians and plumbers. Tertiary degrees include short-cycle tertiary, bachelor's, master's and doctoral degrees (ISCED levels 5-8), while vocational qualifications are vocational degrees attained from lower-secondary to short-cycle tertiary level (ISCED levels 2-5).

Source: IEA analysis based on data from the Chinese Ministry of Education, India Ministry of Statistics and Programme Implementation, OECD Education at a Glance, UNESCO Institute for Statistics, and UN Demographic Statistics Database.

Demand for applied technical workers is set to increase across scenarios, especially in emerging market and developing economies

Annual demand for applied technical workers in the energy sector, 2015-2024, and 2024-2030 by scenario



Notes: CPS = Current Policies Scenario; STEPS = Stated Policies Scenario; NZE = Net Zero Emissions by 2050 Scenario. Retirements and additional hires represent sources of demand from the energy sector for new workers in applied technical roles, including technicians, skilled trades workers, and plant and machine operators.

Source: IEA analysis based on data from ILO, UNESCO, OECD, the Chinese Ministry of Education, and the Indian Ministry of Statistics and Programme Implementation.

Building a skilled energy workforce requires significant investments to expand vocational education and training

Energy-related education and training – including vocational training, technical qualifications and any relevant certifications – make up a small proportion of total economy-wide education and training expenditures. IEA analysis shows that from 2015 to 2024, an estimated USD 12 billion was spent annually on vocational education and training (VET) for energy workers worldwide, equivalent to around 0.2% of global public spending on education.

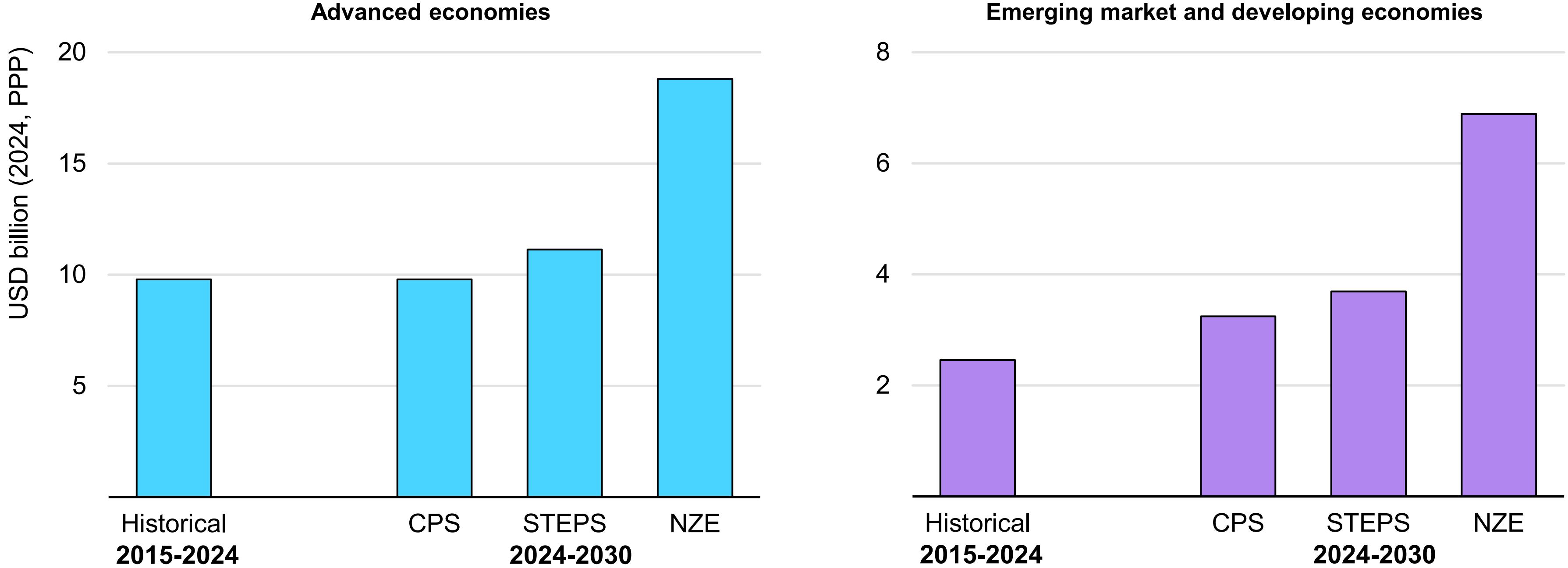
The largest growth in demand for energy-related jobs over the next decade will be for VET-trained workers, whose education and training are more likely to be self-funded rather than by public financing or employer funded in many advanced economies. VET programmes also typically cost more than general (non-vocational) education, due to requirements for specialised equipment and the focus on in-the-field training for developing technical skills. In OECD countries, vocational programmes cost on average 16% more than general education schemes. In EMDEs, the cost to the individual is also likely to be much higher due to more limited public funding, with nearly one-third of total education financing met by households.

To equip the workforce with the skills necessary to meet rising demand for energy-related professions, spending on technical training will need to be increased substantially. According to IEA analysis, growing demand for workers over the coming years means expenditure on these programmes would need to rise by 21% in the STEPS, in which current policy intentions are implemented. In advanced economies, this represents an increase of around 14% on current levels, whilst for EMDEs investments would need to increase by 50% relative to current levels, bringing global expenditure on energy-relevant vocational programmes to nearly USD 15 billion by 2030. In the CPS, which considers only policies that are already in place, global expenditure would rise to USD 13 billion, a 6% increase on current levels. Expenditure needs could rise significantly as climate ambition increases, up to as much as USD 26 billion globally in a scenario consistent with a 1.5°C global temperature increase.

Meeting these needs will require substantial public and private investment into skills development. In EMDEs, support through official development assistance (ODA) and other international public finance will be key, as budgets become increasingly constrained under rising debt burdens and funding is prioritised for early-stage education and skills development. While support for all forms of education in EMDEs through ODA reached a record high of nearly USD 17 billion in 2022, the education share of total ODA has fallen in recent years. In 2022, less than 10% of ODA from G7 countries was directly targeted toward green skills and employment. Despite the G7 commitment made in 2022 to increase this share, total funding is likely to fall in line with the estimated 18-22% decline in ODA to education from 2023 to 2025 due to the impact of ODA cuts by key donors, including France, Germany, the United Kingdom, and the United States.

Meeting future needs for skilled labour will require an expansion of investment into energy-related vocational training provisions

Annual cost of providing vocational qualifications for the energy sector, 2015 to 2024, and by scenario, 2024 to 2030



Notes: PPP = purchasing power parity; CPS = Current Policies Scenario; STEPS = Stated Policies Scenario; NZE = Net Zero Emissions by 2050 Scenario.
Source: IEA analysis based on data from the ILO, UNESCO, OECD, the Chinese Ministry of Education, and the Indian Ministry of Statistics and Programme Implementation.

The lack of globally standardised energy qualifications poses challenges to workforce planning

A key challenge in workforce development is the limited standardisation of energy-related skills and qualifications across sectors and jurisdictions, and even within the territories themselves. No globally harmonised system exists for mutual recognition of energy trades. While some regional frameworks (such as the European Qualifications Framework (EQF)) and industry-led training standards (such as Global Wind Organisation (GWO) certifications) facilitate cross-border mobility, most licensed occupations, including electrical work, remain subject to national and regional codes, and inspection requirements. As a result, workers often need to pass jurisdiction-specific licensing exams, even when they hold relevant prior qualifications. These exams can represent a high barrier to entry, given their costs, limited availability of testing slots or locations, and uneven access to preparation resources. A lack of data associated with certifications, OJT and apprenticeships, and more broadly gaps in energy-specific workforce statistics also hinders the ability to understand how skills are gained and where shortages exist, and was a key future work area identified at the 2025 IEA Workshop on the Future of Energy Skills.

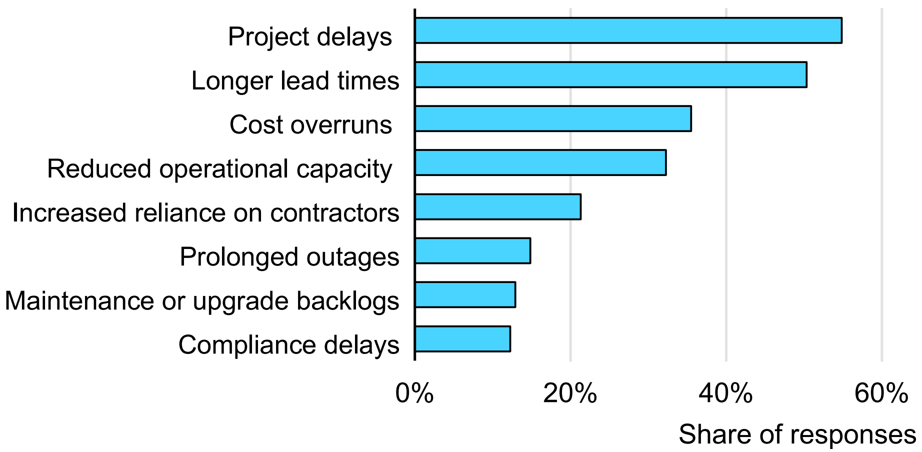
Many energy professions require certifications that demonstrate job holders have the technical capacity to carry out specific tasks safely and in compliance with local regulations. These certifications are particularly important in energy subsectors where many small and medium-sized enterprises are involved and where the workforce is highly distributed, as is the case for building efficiency and solar PV installation. These qualifications are highly heterogeneous: ranging from mandatory licences (such as for electricians), to certifications which are de facto industry standards but fall short of being a legal requirement, to voluntary credentials that are not required but may signal technical capability. The absence of harmonised frameworks for defining and categorising certifications further limits international comparison. Such heterogeneity is likely to be present within countries as well, with overlapping or inconsistent credential systems creating potential challenges for workers and employers as skills needs evolve in the energy transition.

Pathways into energy sector jobs vary significantly depending on workers' prior experience and skill levels. While many roles require formal training through academic, vocational, or apprenticeship programmes, more flexible routes are available for entry-level positions and for workers transitioning from related sectors. In such cases, short-term certification courses, micro-credentials, or OJT training can provide accessible entry points. For highly specialised roles, even experienced professionals may require modular upskilling or targeted OJT training to gain technology-specific competencies (see Chapter 3 for more detail).

A shortage of skilled workers poses risks to energy firm's competitiveness and the secure operation and expansion of energy systems

The shortfall of available skilled energy professionals is already having significant impacts on slowing recovery times from project delivery delays, increasing overall costs and creating compliance challenges. Over 40% of energy employers surveyed by the IEA reported that hiring difficulties have led to operational bottlenecks, resulting in project delays, cost overruns and reduced operational capacity, among other issues. The hardest to fill positions are applied technical workers, especially skilled trades roles, and engineers who are also among the top occupations most in shortage.

Operational bottlenecks experienced by surveyed energy companies due to hiring difficulties



Source: *IEA Industry Employment Survey*, 2025.

The dearth of skilled workers has correspondingly contributed to higher project costs and eventually higher energy prices, in part due to employers raising wages to attract more workers. In the US solar and battery sector, skill shortages contributed to a 43% rise in labour costs between 2021 and 2023. In 2024, a combination of labour shortages and long lead times for equipment procurement led to the delay of around 53 GW of solar projects in the United States. In India, similar delays and cost increases are affecting solar panel and storage battery manufacturers as employers struggle to hire enough skilled workers to meet planned capacity expansions.

The lack of skilled of workers also threatens the quality of technology deployment. In Europe, the Regulatory Assistance Project estimates that poorly installed heat pumps can only operate at half their expected efficiency, reducing long-term energy and bill savings for households. Poor-quality installations can frustrate users and undermine public confidence in new energy technologies.

Beyond deployment, workforce gaps affect maintenance of critical infrastructure. In 2022, the French nuclear sector faced extended maintenance outages due to worker shortages, contributing to electricity production levels hitting a 30-year low and raising concerns about reliability. To address workforce needs, some operators are rehiring skilled retirees and implementing targeted recruitment strategies.

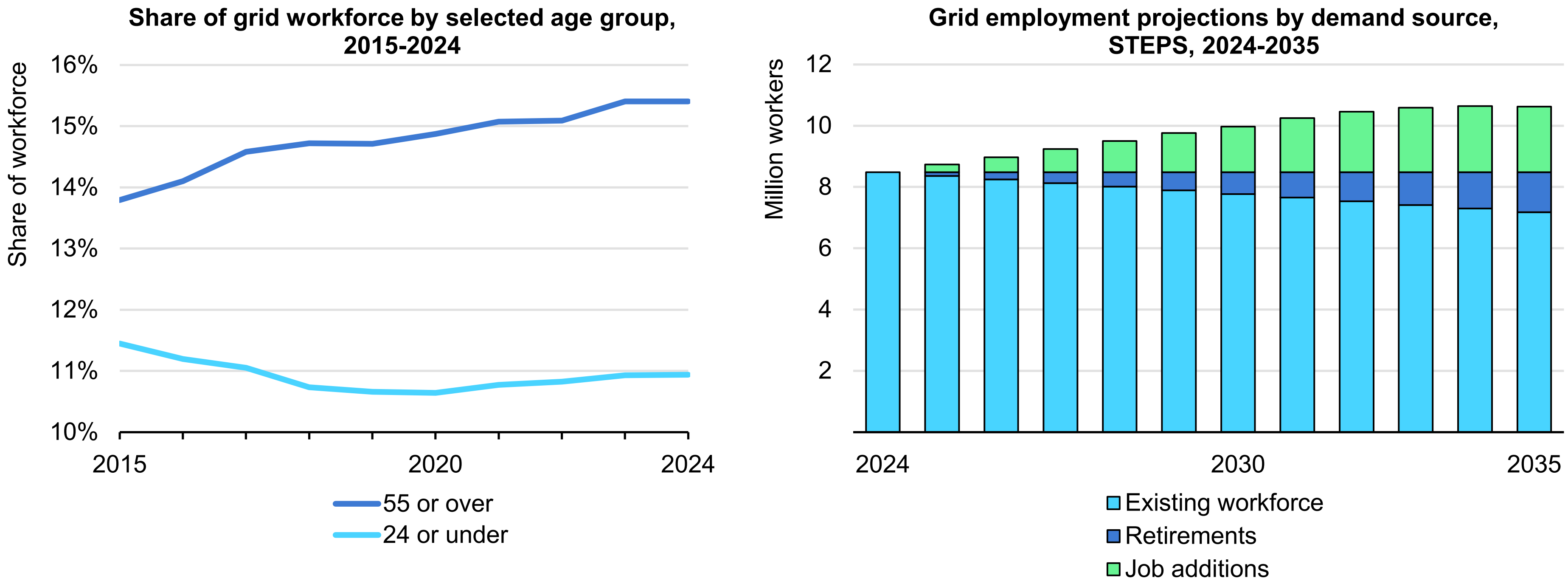
While power systems will drive energy job growth in the next decade, the workforce needed to roll out new grid infrastructure, and maintain and modernise the existing one has the potential to be a major pain point. Globally, the grid labour force has experienced significant demographic shifts over the past decade, with the share of grid workers reaching retirement age growing more than twice as fast as that of workers aged 25 to 54. This trend risks accelerating in the future, with nearly one grid worker retiring for every two jobs created by 2035.

In response, a growing number of governments are investing in new programmes aimed at attracting more workers into applied technical fields and related education as a part of their wider efforts to improve competitiveness. For example, the European Union foresees an investment of EUR 65 billion into skilling its workers, with a significant focus on the energy sector. In China, a new Vocational Skills Training Initiative for 2025-2027 is meant to address declines in vocational education, enhance labour productivity and reduce workforce mismatches in sectors, including advanced electric vehicle manufacturing. In India, the government has recently approved a national scheme to boost innovation, productivity and economic growth by revamping vocational education in close collaboration with industry. The programme will direct significant investments to upgrading, maintenance and capacity expansion of training facilities as well as provide training to 50 000 additional trainers and develop courses for skilled trades roles experiencing high demand growth.

There has also been an increased focus on drawing more students into energy-related tertiary degrees, especially master's and doctoral degrees, as a means to spur innovation. Countries with a high output of science, technology, engineering, and mathematics (STEM) graduates also see increased levels of innovation activity in the energy sector, such as patent applications and scientific publications. For instance, Korea, where the share of STEM graduates and per capita energy-related patent filings is among the highest globally, has seen its battery manufacturing workforce nearly triple since 2019 and increased the export value of its battery sector by 30% between 2020 and 2023. Advanced economies and China enjoy the highest concentration of young energy-relevant tertiary graduates today, nearly 10 graduates per 1 000 young people, while EMDEs see around one half of the same conferral rate.

The shortfall of skilled workers could jeopardise crucial grid and electricity generation expansion plans through 2035

Grid workforce historical share by age group, 2015-2024, and future projections in the Stated Policies Scenario, 2024-2035



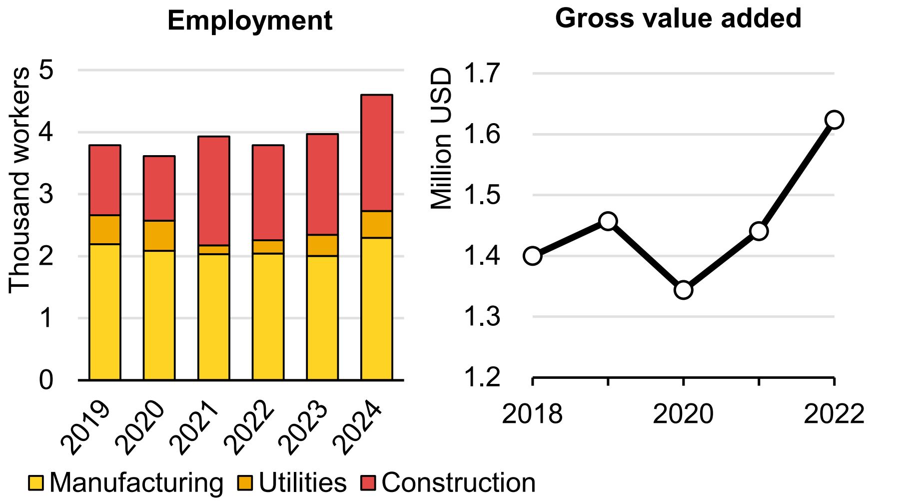
Notes: STEPS = Stated Policies Scenario. The retiring workforce projections are based on the assumption that employees retire at 65 years old.
Source: IEA analysis based on ILOSTAT data.

In local communities, upskilling and reskilling the workforce can help generate additional revenues and secure sustainable local economies

At the local level, investing in a skilled workforce to install, operate and maintain energy systems can unlock job opportunities that provide new revenue streams for workers and communities. These investments are especially relevant in communities transitioning away from fossil fuel industries, which are exposed to risks of socio-economic decline as a result of job and revenue losses stemming from the closure of long-standing industries. In these communities, policies and programmes that both invest in providing workers with upskilling and reskilling opportunities as well as support local industrial diversification are key to ensure the transformation of energy systems leads to better outcomes.

In Spain, the long-term Just Transition Strategy, launched in 2019 to offset the impacts of coal's decline in the region, has delivered tangible results. In the former coal province of Teruel, targeted tenders and investment incentives were offered to attract new renewable energy projects and upstream manufacturing industries that provide employment opportunities for former coal workers, create jobs in the industrial sector and deliver vocational training to unemployed people. A more than EUR 1.5 billion investment is expected to develop renewable energy locally, including seven wind farms and seven solar power plants. By 2024, energy-related employment, especially in efficiency and renewables, increased by nearly 21%. The gross value added (GVA) generated by the energy sector also rose 11% between 2019 to 2022. In the wider Just Transition area of Aragon, where Teruel is located, 5 500 new wind-sector jobs have replaced lost coal employment, driving economic diversification and growth.

Impact of Spain's Just Transition Strategy on Teruel's low-emission energy-related employment, 2019-2024, and gross value added from energy-related sectors, 2018-2022



Notes: Clean energy-related occupational data refers to the Clasificación Nacional de Ocupaciones (CNO) codes from INE (Spanish National Statistical Institute), based on their relevance to energy efficiency and renewable energy. This includes, but are not limited to, engineers, electricians, mechanics, technicians, and installers. Energy-related sectors for both figures include manufacturing, construction, utilities (gross value added also includes mining).

Source: IEA analysis based on data from Gobierno de Aragón Open Data (2025) and Observatorio de la Formación Profesional (2025).

Targeted policymaking can extend beyond regions affected by the energy transition, serving as a tool to create jobs in areas that have historically struggled to sustain local industry, and support broader energy resilience efforts. In Canada, the Clean Energy for Rural and Remote Communities programme provides financial support for renewable energy and capacity building projects that reduce the use of fossil fuels for heating and electricity in Indigenous, rural, and remote communities. Most projects incorporate training and apprenticeships that equip workers with technical skills in areas such as solar panel installation, wind turbine maintenance, and biomass supply chain management. This approach enables communities to own, operate and manage clean energy assets, helping to retain local economic and employment benefits and enhance energy resilience.

In EMDEs, the deployment of decentralised energy technologies can help both achieve energy access and employment outcomes. Equipping workers across sectors to operate and maintain clean energy technologies can also help generate new income and local economic value, and multiply the creation of economic opportunities beyond the energy sector. In Malawi, the deployment of 1.7 MW of solar power is set to help improve energy access while increasing 6 000 farmers' income and supporting the creation of 1 500 seasonal jobs each year. In Ghana and Senegal, the Alliance for Rural Electrification estimates that up to 40 000 direct jobs could be created by 2030 from the development of decentralised energy systems, including long-term employment in the operation and maintenance of electricity networks. Improving energy access in turn increases households' ability to power essential infrastructure that lead to better health and education outcomes, among others. An important part of many of these projects is capacity building so local communities are able to manage and maintain these systems rather than becoming dependent on external assistance to maintain and operate them.

Chapter 3. Policy responses to address labour shortages

Special focus: Finding solutions to address skilled labour shortages

Policy makers have a range of tools to address skilled labour shortages in the energy sector, working with industry, educators, and labour representatives to develop a workforce that can meet emerging energy-system needs. This chapter reviews effective policy options for reskilling and upskilling, lowering barriers to training, and attracting new entrants into energy careers.

It highlights approaches such as strengthening industry engagement and work-based learning, modernising curricula, expanding flexible training, improving perceptions of technical careers, conducting skills mapping, and promoting decent work as means to attract more workers to energy-relevant fields. These strategies are illustrated through real-world case studies and highlight where they have been successfully applied.

This chapter also examines how the energy skills agenda fits within broader education and labour priorities in both advanced and emerging economies. It considers how best to structure policy efforts, emphasising ways to keep training initiatives aligned with real labour-market needs, and ensures co-ordination between firms, policy makers, educators, and labour representatives. Effective approaches must be tailored to national and local contexts, taking into account existing skill levels, labour-market tightness, wider education objectives, and a balanced distribution of responsibility among employers, governments, and workers – while avoiding the risk of shifting training costs disproportionately onto individuals.

Finally, the chapter situates these efforts within wider education and labour-policy trends. The analysis draws on IEA assessments of energy, education, and labour policies; in-depth interviews with key stakeholders; inputs from the IEA's two-day Workshop on the Future of Energy Skills; and new surveys added to the annual *IEA Energy Industry Employment Survey* to capture perspectives from educators, workers, and their representatives.

Policies options to attract and train more workers

Area	Potential policy measures	Examples
Encouraging early interest in technical and trade careers	• Offer technical secondary school pathways as an alternative to academic tracks leading to university. • Expand dual-enrolment and pre-apprenticeship programmes that allow high school students to earn credits toward certifications.	• Technical training options in Germany
Financial incentives	• Offer free or heavily funded training programmes for highly demanded trades/occupations. • Provide wage compensation to cover participants lost wages during upskill/reskill energy courses. • Provide tuition tax credits or training grants for apprentices and for employers who invest in training and/or sponsor trainees.	• Canada's Sustainable Jobs Training Fund • EU's Skills Academies • South Africa's Just Energy Transition Skilling for Employment Programme • Denmark's wage compensation scheme
Industry engagement and work-based learning	• Expand apprenticeship programmes through co-funding models between government and industry. • Create industry advisory councils to guide national curriculum updates and ensure alignment with market needs. • Collaborate with emerging industries to define qualifications for new fields (e.g. battery installation). • Encourage colleges, technical schools and universities to adopt periodic curriculum review processes informed by industry needs.	• Combined classroom/practical training in Canada • Germany's dual vocational training system • Europe's Skills for Solar task force • Viet Nam's Industry Advisory Board for Renewable Energy
Changing public perceptions of technical career paths	• Launch regional and national marketing campaigns to highlight the value, innovation, and good working conditions associated with skilled trades and engineering careers. • Support gender equity and inclusion initiatives such as mentorship programmes and outreach campaigns encouraging women and underrepresented groups to enter technical fields.	• Schneider Electric's Youth Education & Entrepreneurship Program in 60 countries • Pakistan's efforts to create inclusive working environments for women • Female targeted training in Colombia

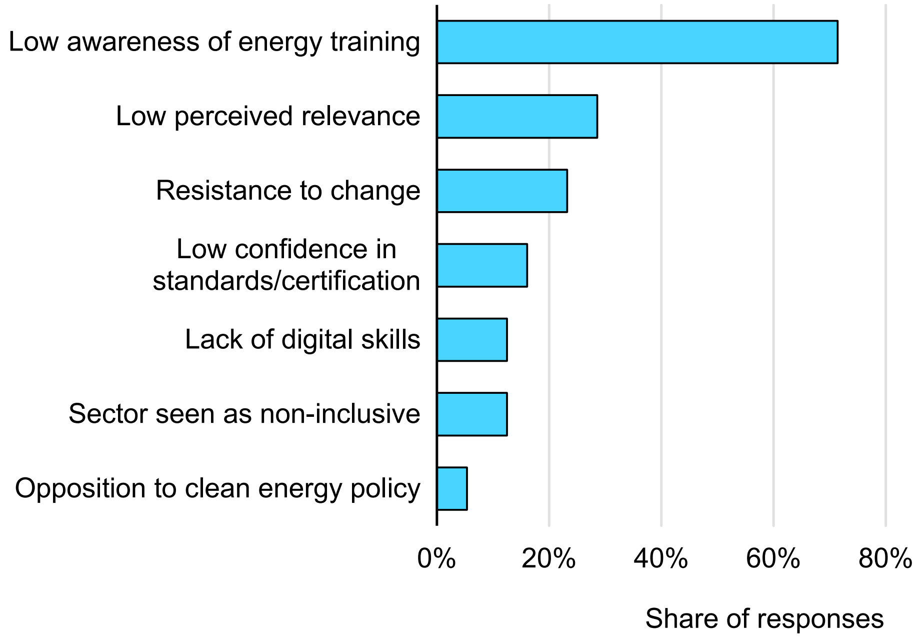
Area	Potential policy measures	Examples
Curriculum and credential modernisation	• Introduce modular, stackable certifications that allow learners to progress from short-term credentials to full degrees. • Integrate emerging technologies (e.g. AI) into training and certification frameworks. • Ensure training alignment with international standards, establish mutual recognition agreements to enhance worker mobility.	• Specialised short postgraduate courses in Nigeria • Short-cycle accredited courses in South Africa
Accessible training options	• Offer flexible training options including online modules to increase accessibility. • Provide locally based education and training programmes outside cities to increase accessibility.	• Village-based education and training courses for Indigenous people in Malaysia • Flexible training pathways targeted at women in Uganda
Labour market monitoring and skills mapping	• Enhance national statistical tracking of energy and technical employment using supplementary surveys. • Strengthen labour market forecasting systems to identify and publicise priority skills and certification shortages. • Convene regular forums among industry, labour unions, and ministries of energy, education, and labour to share observations and inform co-ordinated employment and skills roadmaps. • Improve monitoring of wage trends in occupations facing persistent shortages.	• South African Energy Skills Roadmap • EU Renewable Energy Skills Partnership • US Energy & Employment Report (USEER)
Promoting decent work to attract workers	• Take measures to address informal work while increasing formal training and certification. • Ensure respect of ILO conventions and decent work principles. • Engage in tripartite social dialogue with energy employers' and workers' representatives. • Promote and facilitate multi-stakeholder groups and initiatives to create and new decent clean energy job opportunities.	• Project Surya in India • Tripartite social dialogue in Chile • Canada's Sustainable Jobs Partnership Council

Well-designed policy and supportive measures can draw more people into energy-related education and training

Drawing more people into energy education and energy related careers is top of mind for many in government and industry, as demand for workers across energy sectors continues to grow. In the *IEA Educators' Employment Survey*, low awareness of energy-related training opportunities was identified as the primary non-financial barrier by training providers. Clear communication of training pathways, career outcomes, and available support mechanisms could help attract more learners. More than 90% of those surveyed emphasised the need for greater involvement by governments and industry in disseminating information and promoting training opportunities.

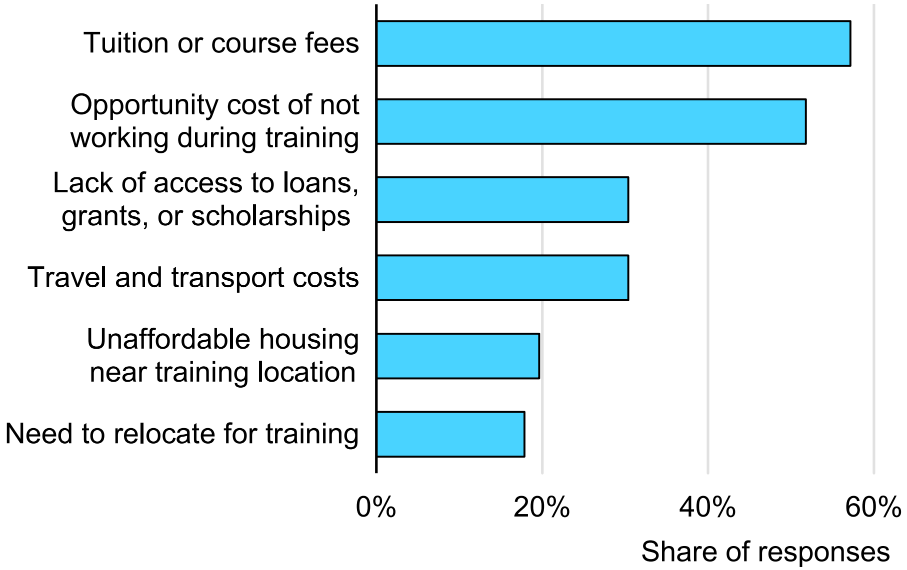
Given a shortfall of potential workers undertaking training to meet projected future needs in both advanced economies and emerging markets and developing countries (EMDEs), understanding the barriers to training programmes and addressing them is critical. According to the *IEA Educators' Employment Survey*, tuition and course fees, lost wages during training, limited access to financial support and additional costs related to transport and housing are key barriers. Reducing these financial barriers through targeted funding schemes, stipends, or in-kind support and offering training in rural areas can significantly improve access and participation in training.

Share of energy training and education providers reporting on non-financial barriers for training uptake, 2025



Source: *IEA Educators' Employment Survey*, 2025.

Share of energy training and education providers reporting on financial barriers for training uptake, 2025

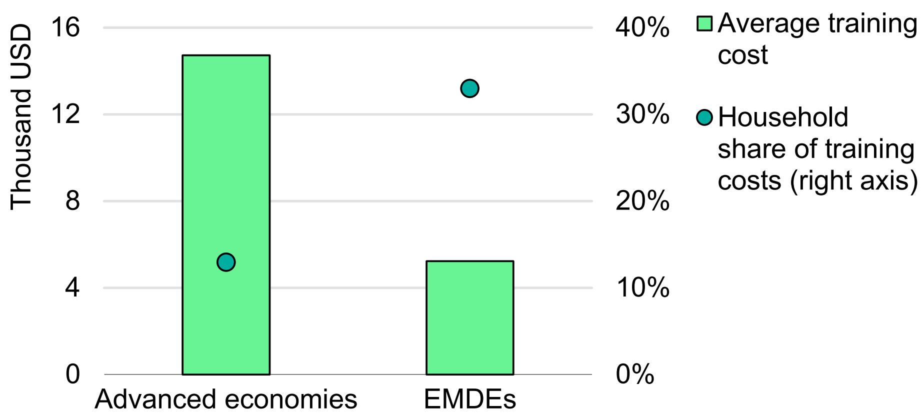


Source: *IEA Educators' Employment Survey*, 2025.

Funding support plays a critical role in enabling broader participation in energy skills development, particularly in emerging and developing economies. In advanced economies, on average 15% of overall training costs for vocational training across sectors is paid for by individuals, but this more than doubles to 33% in EMDEs.

For some training routes, the cost may be fully borne by the individual. With public funding being more constrained in most EMDEs, support from international partners can help ensure that training for skilled workers is sufficiently affordable. With Official Development Assistance (ODA) funding to education falling, it is also likely that financial support will need to be more reliant on co-funding programmes with the private sector, especially the energy industry.

Vocational training costs by region and share of cost borne by households, 2024



Note: EMDEs = emerging market and developing economies.
Source: IEA analysis based on data from the OECD (2024) and World Bank (2024).

A number of countries have launched targeted funding initiatives to expand energy training and build a skilled workforce capable of supporting their energy transition targets. In Canada, the Sustainable Jobs Training Fund, launched in 2024, allocates USD 70 million from 2024 to 2028 to training projects that help workers upgrade or gain new skills for jobs in low-carbon energy, including green buildings. Over 10 000 workers will receive training at no cost or at subsidised rates.

In the United Kingdom, the National Skills Fund has allocated over USD 260 million to fund training courses in skills such as heat pumps, solar panel installation, and EV maintenance, with over 40 000 people trained in these Skills Bootcamps in the 2022/23 period. The European Union has announced plans to review and implement targeted EU Skills Academies linked to the green and digital transition, with grids and wind identified as strategic sectors.

In South Africa, the Just Energy Transition Skills for Employment Programme aims to significantly lower training costs for energy transition jobs, with the goal of equipping over 10 000 workers annually over the next 25 years with competencies for low-emissions technologies. The broader Just Energy Transition Investment Plan allocates USD 89 million to establish pilot training centres, supported by both public and private finance. The programme is explicitly designed to subsidise sector-specific training, such as solar PV, wind, and grid infrastructure, by pooling private-sector contributions, donor climate funding, and government resources.

Typical education and training pathways for low-emissions energy occupations

Training pathways by occupation based on selected OECD countries

	Basic training options						Additional training options	
Occupation	Academic training		VET		Apprenticeship training		Skills-based certification	On-the-job training
Solar panel installer	N/A*		6–24 months	OR	24–36 months	AND	< 1 month** Industry standard	< 6 months**
Wind turbine technician	24-48 months	OR	12–24 months	OR	24–36 months	AND	< 1 month Industry standard	6–12 months
High-voltage line workers	N/A*		12–36 months	OR	36–48 months	AND	3–6 months Industry standard	N/A
Electrician	24-48 months	OR	24–48 months	OR	36–60 months	AND	< 1 month** Technology specific	6–12 months Technology specific
Welder	N/A*		6–24 months	OR	36–48 months	AND	1–6 months Industry standard	3–6 months Technology specific

Notes: VET = Vocational Education and Training. *Possible pathway but rarely pursued or very limited offer; ** Voluntary training.
OECD countries included in the sample were Canada, Germany, New Zealand, the United Kingdom, and the United States.

Policy options to expand vocational education and training in EMDEs

The share of people completing cross-sectoral vocational education and training (VET) programmes is significantly lower in EMDEs than in advanced economies. This is a contributing factor to the shortage of both skilled and formally trained workers in EMDEs, exacerbated by enduring underinvestment in vocational education and training institutions, and limited industry and education collaboration. The repercussions are felt across these economies, including in the energy sector.

To address economy-wide worker informality and low-levels of skilling, EMDEs are increasingly adopting so-called "multi-channel strategies" that combine formal education with modular short-term training, upskilling initiatives, and industry partnerships. Several programmes also formally certify informally acquired skills. These approaches aim to deliver job-ready skills to diverse learner profiles, including youth, informal workers, and professionals transitioning from adjacent sectors.

In the Stated Policies Scenario (STEPS), it is estimated that there will be 4.7 million new jobs in the energy sector by 2035 in EMDEs, the majority of which will be medium- and high-skilled roles. These workers typically require vocational education and training, or tertiary education such as university degrees. Meeting this demand will require a significant scale-up in training and education systems to expand the pipeline of formally trained workers. Many EMDEs have launched specialised programmes to ramp up the technically skilled energy workforce. Nigeria, for example, has introduced postgraduate courses specifically for the renewable energy sector and set up vocational education training programmes with solar modules embedded in electrical engineering curriculums and specialised short courses. The South African Renewable Energy Technology Centre provides formal short-cycle courses to accredit wind turbine and solar PV technicians. So far, over 700 technicians have been trained and seven further vocational colleges are now able to also provide the courses in South Africa.

In India several initiatives exist to address this challenge, including the national Skills Council for Green Jobs. The Council has implemented national training programmes to expand renewable energy training and has already trained more than 100 000 students and workers, most of them in solar energy occupations. In Viet Nam, the RENEW Skills Development Programme launched new curricula and practical trainings focused on wind energy technology operations, maintenance and grid integration, with the aim of reaching over 4 000 students and current technical workers before the end of 2027.

Reskilling, upskilling, and specialised training strategies to retain and improve the skilled energy workforce

With many countries in the process of changing their energy mix towards cleaner fuels, reskilling and upskilling workers in impacted sectors provides an important tool to help address skilled labour shortages while also providing quality job transitions.

Many jobs in the fossil fuel energy sector, such as oil and gas, tend to have higher wages. Trade unions have stressed that ensuring new clean energy jobs are decent helps ensure social acceptance from workers and communities and have advocated for impacted workers to be reskilled into new local jobs with guarantees in place for fair wages and good employment contracts.

The *IEA Labour Employment Survey* found that staying employed in the energy sector was one of the top three priorities for fossil fuel workers when considering transitioning to a job in clean energy, alongside fair pay and a safe working environment. Both the fossil fuel and clean energy sectors require a large proportion of applied technical workers, providing the possibility of transferring workers from occupations in fossil fuel to clean energy with some upskilling and reskilling. With targeted retraining, around two-thirds of oil and gas supply workers have the base skills needed to move into other parts of energy, the same is true for about half of workers connected to fossil fuel power supply chains. Detailed recent analysis in the United Kingdom found that some sectors have particularly similar skills requirements, with estimations that around 90% of UK oil and gas workers have skills transferable to the offshore renewables sector. Analysis on skills transferability using data from online job postings and international skills and occupational classifications can help identify overlaps, improve the transferability or workers and increase the speed of filling vacancies.

However, while occupations may have similar skill sets, some of these workers will be more impacted than others in energy transitions. For example, a smaller share of coal miners can be quickly reskilled, particularly those in markets with high levels of informality. Coal workers and communities therefore require specialized support to ensure a just, people-centred transition. More detailed analysis of skilled labour needs in the short, medium and long term at occupational and skill level would be helpful to understand whether additional reskilling is needed as opposed to only upskilling.

There are also "top up" trainings to reskill or upskill workers. These can be short-cycle sessions to meet energy or technology-specific needs and regulatory requirements. They are typically delivered through short certification courses or on-the-job training, leading to specific licences or qualifications. For example, these approaches are used for an electrician to work as a solar technician or a welder to become specialised in subsea welding. Modular training, micro-credentials and employer-provided instruction can also play a role in equipping workers with product or brand-specific knowledge needed to install, maintain, service, or repair specific equipment.

Early intervention and initiatives that assist workers to retrain in a timely manner could prevent job displacement and wage losses. Offering impacted workers options in advance of plant closures, as happened in Portugal, allows for workers to prepare to move internally, upskill or reskill to new roles or take early retirement. Providing funding for job transfers and reskilling options can also increase reskilling uptake. In Sweden, the Education Support for Transition Agreement provides the right to training leave with financial support for impacted workers.

Online platforms can provide accessible information on job transition opportunities and reskilling and upskilling options. For example, the United Kingdom launched its Energy Skills Passport, an online platform which aims to help oil and gas workers transition to the renewables sector. The platform provides skills mapping analysis to help users understand which similar roles they could apply for in other energy sectors and provides certification validation and career development through tailored guidance on upskilling or additional certifications. Tailored skills programmes are also available through the Oil and Gas Transition Training Fund.

Multi-stakeholder engagement also plays a pivotal role in transitioning fossil fuel workers into other energy sectors. In Chile, ex-coal workers are being reskilled to build transmission lines, with around 2 000 line workers needed linked to the energy transition. The initiative is supported by the Ministry of Energy, the National Commission for Skills and Certification, technical training centres and the German Corporation for International Cooperation (GIZ), which is involved in projects related to the energy transition in 60 countries.

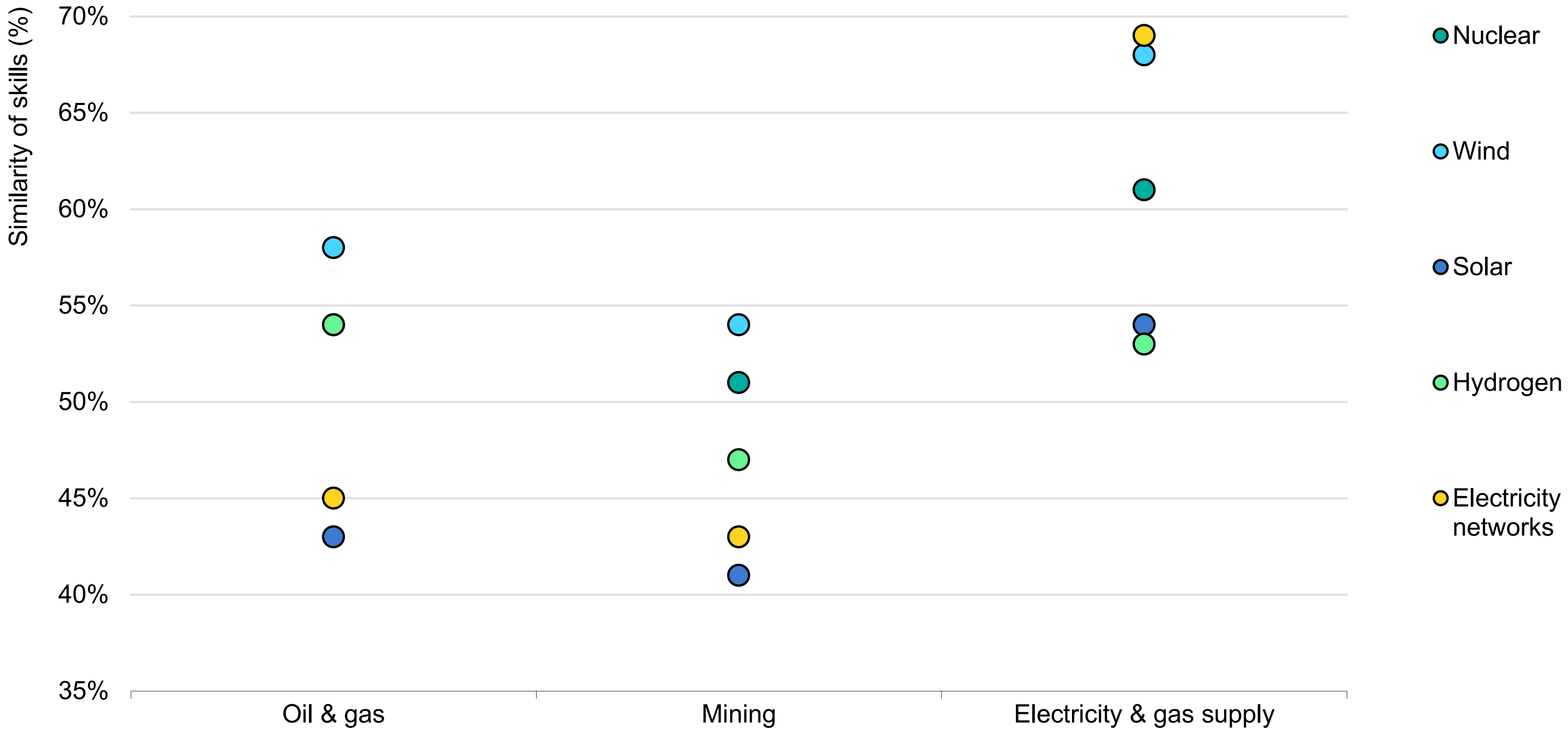
Workers impacted by the coal phase out in Alberta, Canada are supported by the provincial Coal Workforce Transition Program, with financial assistance for re-employment and education provided through a Coal and Electricity Transition Tuition (CETT) Voucher. Onsite transition to employment services are available with access to short-term skills courses. Labour adjustment committees, made up of employers, workers and trade unions, ensures that stakeholders are included in developing transition plans for their worksites and organise specialised training, job fairs and regional job matching.

Committing to reskilling and support for impacted workers was an important first step in Spain's Just Transition Strategy. A tripartite agreement between the government, employers and trade unions provides provisions for vocational training and the creation of new jobs to support workers.

The participation of workers in broader stakeholder engagement on energy transitions can also be beneficial. Employee representatives are on national boards working on just transitions, including the Scottish Just Transition Commission, South Africa's Presidential Climate Commission, and Australia's Net Zero Economy Authority.

Skill transferability between energy sectors could reduce reskilling and retraining requirements

Skill similarity across fossil fuel and low-emission energy sectors in the United Kingdom, 2024



Source: IEA reproduction of findings from the United Kingdom Department for Energy Security and Net Zero.

Australia: Reskilling workers to address skills shortages and ensure a just transition

In Australia, reskilling impacted workers and providing new decent jobs has been central to gaining social acceptance for the energy transition, supported by stakeholder engagement at both the local and national level.

Understanding skills transferability is an important first step in reskilling workers. The Australian Industry Energy Transitions Initiative found that around 47% of fossil fuel workers may be able to transition to the renewable energy sector while maintaining the same occupation type with minimal reskilling. Another 12% of these fossil fuel workers were estimated to be able to transition to industries related to renewable energy such as mineral mining.

Some occupations will be easier to transition than others. Notably, there are significant differences in transferring skills from fossil fuels to low-emission energy, including a dramatic decrease in the demand for drillers, miners and shotfirers (blasters) to 700 in renewable energy generation compared to 17 200 workers currently working in carbon intensive industries. These workers will require either complete retraining to move into another occupation in the low-emissions energy sector or other support to transition to a similar role in a non-energy sector.

Impacted workers may be able to transition to the wider low-emissions energy supply chain or to clean energy manufacturing to keep the same occupation, skill level, and wage. Multi-stakeholder engagement and policy collaboration on energy, industrial, education and labour market issues can help workers and communities secure new jobs with support for reskilling.

In Collie, Western Australia, around 20% of the local population are employed in the coal industry and related supply chains. Just transition plans have been developed with stakeholders in response to the shutdown of its state-owned coal-fired power plants by 2029, with measures for reskilling and the creation of new jobs through the Collie Transition Package and the Collie Industrial Transition Fund (AUD 700 million [Australian dollars]).

To aid reskilling efforts, new specific government support is available for impacted workers and employers, including the Energy Industry Jobs Plan that provides access to retraining and help for impacted workers to find new jobs. The possibility to adopt Regional Workforce Development Plans offers broader support and are developed with key stakeholders, including employers, trade unions and community representatives.

Attracting youth, and underrepresented groups with affordable and specialised training can significantly increase the energy labour force

The energy workforce can benefit from dedicated efforts to attract workers from demographics that are currently underrepresented. Targeted efforts can help draw more young workers, women and other underrepresented groups into training pathways that are accessible.

Skilled young people are central to ensuring future energy security in every part of the world, but the level of VET graduates differs from region to region. Each year, around 7% of the youth population (aged 20-29 years) graduates from vocational education in the European Union, about 5% in Japan and Korea, and an estimated 2.5% in EMDEs overall. China stands out among emerging economies, at roughly 5%. Some sectors require urgent attention such as the European electricity market, with over one-third of workers aged 50-74 years. The European Youth Energy Network is in the process of launching the Energy Transition Careers Compass to help young people understand the different energy education and career options. Youth for Energy Southeast Asia also advocates for policy makers to invest in education and skills for tomorrow's workforce.

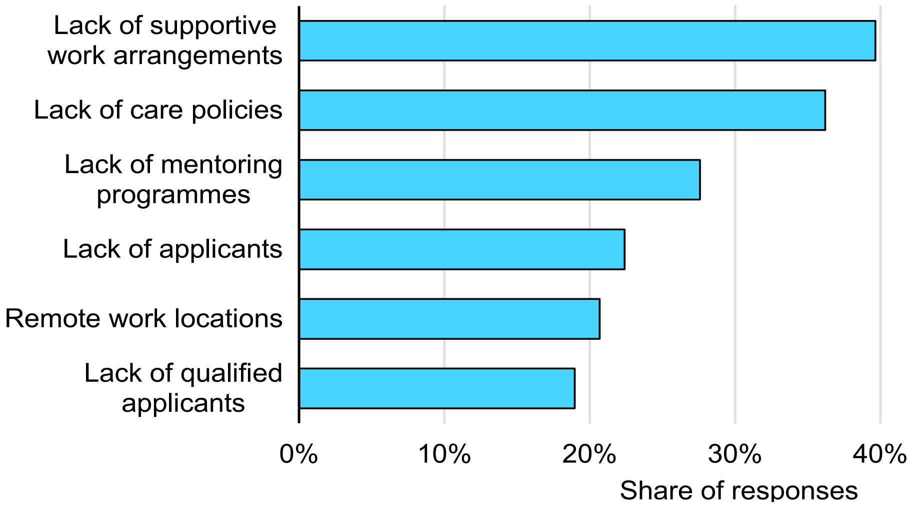
Specific outreach programmes are helping to encourage young people to join the energy workforce. In Ethiopia, Kenya and Uganda, training in solar PV design, installation, and maintenance coupled with mentorship programmes is helping guide young people through their energy careers. In Myanmar, over 500 young people were trained in 2024 and 2025 in solar PV design, installation, maintenance, as well as employment readiness soft skills, leading to 68% of graduates being hired in the industry within three months of graduation.

Schneider Electric's Youth Education & Entrepreneurship Program has reached over 763 000 young people, 10 000 trainers and entrepreneurs in 60 countries with the aim to engage young people in energy management. In addition, its New Skills for the Future initiative provides mentoring programmes, with a special focus on vulnerable young people included for those who are displaced or not in employment, education or training (NEET). Canada's Green Jobs for Youth offers training and paid internships to Canadian citizens, permanent residents and refugees.

Disadvantaged youth who have been displaced due to war and conflict have also benefited from targeted training initiatives. This is especially important as many of these young people will have had their education disrupted. The International Organization for Migration's (IOM) Resettlement Project trained 30 young people (15 male and 15 female) after they returned to South Sudan. The students were trained in solar installation, repair and maintenance and undertook paid internships. In Lebanon, the ILO with the Safadi Foundation is providing paid on-the-job solar training. Over 80 young people have completed the training, including Lebanese and Syrian refugees.

Gender-related barriers continue to limit women's participation in energy training programmes. As the *IEA Educators' Employment Survey* indicates, the most frequently cited challenges are the lack of flexible working-time arrangements, insufficient childcare policies, and limited access to mentoring programmes. These structural barriers outweigh the issue of applicant numbers, suggesting that many qualified women are deterred from entering the energy workforce due to insufficient support systems. Addressing these constraints through supportive services, policy cohesion and targeted outreach is critical to tap into underrepresented talent.

Reasons for underrepresentation of women reported by training and education providers, 2025



Source: *IEA Educators' Employment Survey*, 2025.

The World Bank's Energy Sector Management Assistance Program (ESMAP) provides a Women's Employment in Energy Sector Utilities Toolkit initiative that offers advice and resources on how to bolster women's employment, including addressing barriers.

In Pakistan, the Water and Power Development Authority has made significant efforts to create inclusive working environments for women. The establishment of on-site childcare facilities, offering safe transport services for female workers and their children, and paid maternal leave has led to an increase of female representation from 8.1% in 2010 to 15.8% in 2023, with exceptionally high retention rates.

In Uganda, a pilot programme led by GIZ in collaboration with the Directorate of Industrial Training (DIT) expands women's access to energy sector employment through flexible certification pathways. The programme supports the recognition of previously informally acquired skills, making it easier for women to access jobs in the energy sector.

Targeted policies can provide decent job opportunities for local communities, including Indigenous Peoples

Indigenous Peoples are largely unrepresented in the energy sector. A number of new energy projects will be built on Indigenous land, with important discussions taking place on land use and economic benefits, including local jobs. Training Indigenous workers will enable them to play a larger role in these developments.

In Australia, around 50% of envisaged low-emissions energy infrastructure will be on First Nations land which will create thousands of jobs. The participation of First Nations people in the energy sector has grown in the last 15 years, which offers higher rates of full-time employment and better wages compared to other sectors. The First Nations Clean Energy Network recently published the Powering First Nations Jobs in Clean Energy report, a 12-point strategy plan that includes initiatives such as co-ordinated apprenticeship schemes for wind farm technicians, training and employment targets for large-scale renewable energy projects, and integrating training into programmes such as First Nations housing retrofits.

The importance of recognising Indigenous rights in the energy transition, including benefit sharing, have been raised in Malaysia. CREATE Borneo, with support from international funders including National Geographic, is working with Indigenous Peoples in developing community-owned micro-hydro and solar mini-grids.

As part of this project, village-based education and training is also provided to enable local people to manufacture, operate and maintain the energy systems.

In Canada, around 6% of the energy workforce identify as Indigenous, comparable with the wider industrial sector. In 2022, around 15 800 Indigenous Peoples were directly employed in the energy sector, with approximately 10 800 working in the oil and gas industry. As a result, the move to low-emissions energy is expected to disproportionately affect Indigenous workers. Canada's Sustainable Jobs Act aims to accelerate support for workers and communities impacted by the energy transition and highlights the need to address specific barriers and create employment opportunities for Indigenous Peoples. Additional initiatives such as the Canada Greener Homes Grant provides opportunities to train and recruit Indigenous energy advisors and increase their participation in the energy workforce.

Workforce mapping and long-term planning to ensure a skilled workforce for the future

Workforce mapping is a critical first stage for understanding current and projected future skilled energy labour shortages. A multi-stakeholder planning process to address education and training requirements helps align workforce development with evolving demand for skilled energy workers. Successful holistic planning approaches often involve participants from across government, education, industry and labour, which collectively enables better outcomes through co-developed curricula, certification programmes, apprenticeships, industry-supported training and educational facilities, among other shared initiatives outlined in this chapter.

Developing consistent reliable data on the existing workforce and educational trends underpins the planning process. At a recent IEA workshop on the future of energy skills, experts highlighted that a major challenge of workforce planning is the lack of disaggregated data on specific skills and occupations and the variations in quality of data among energy sectors. Involving a robust set of stakeholders to provide more comprehensive granular data would make workforce planning more accurate.

Government investment in gathering data and maintaining databases would help significantly improve workforce mapping. For example, input and collaboration with key stakeholders in the United States has led to more accurate information on regional and national energy jobs. The US Energy & Employment Report (USEER) benefits from additional information collection through surveys to provide detailed data on workers' demographics and occupations.

Multi-stakeholder approaches provide a broad framework for training initiatives, with national skills councils and social partners playing an important role. Numerous countries already have national skills programmes in place which can provide a roadmap for others in developing and building training initiatives.

In South Africa, comprehensive required skills mapping for the renewable energy value chain, hydrogen and the wider energy market is helping guide the roll out of training and form partnerships among educators, government and industry. International co-operation on workforce planning in the Philippines, with support from the United States and Denmark, has helped identify skills and competencies to be developed in their growing offshore wind sector.

In Australia, the Powering Skills Organisation collects and publishes detailed information on current and forecasted energy employment and training. Bringing together multiple stakeholders, information is used to conduct workforce planning, develop relevant learning products and ensure that current training options are fit for purpose. In Korea, energy-specific Industrial Skills Councils have been set up to develop and manage industry-driven energy workforce skills.

In Europe, cross-national stakeholder collaboration has led to industry, trade unions, and educational institutions forming a large-scale partnership in offshore renewables to provide guidance and support for the qualification of between 20 000 and 54 000 new workers.

Strengthening collaboration between training providers and industry is also important because many programmes lack structured input from employers, which can result in mismatches between what is taught and the competencies required on site. Greater engagement of industry actors in curriculum design, practical training delivery, apprenticeships and certification processes can help ensure that graduates leave with the applied knowledge and technical skills needed. According to the *IEA Industry Employment Survey*, many companies are involved in workforce development and provide funding for new training programmes. However, less than 25% of respondents actively engage with educational institutions. Examples of industry involvement with educators include Germany's dual vocational training system, which combines classroom education with apprenticeship placements, Europe's "Skills for Solar" task force, connecting industry with training providers, and Viet Nam's Industry Advisory Board for Renewable Energy, which works to co-ordinate vocational and educational training with the wind and solar industry.

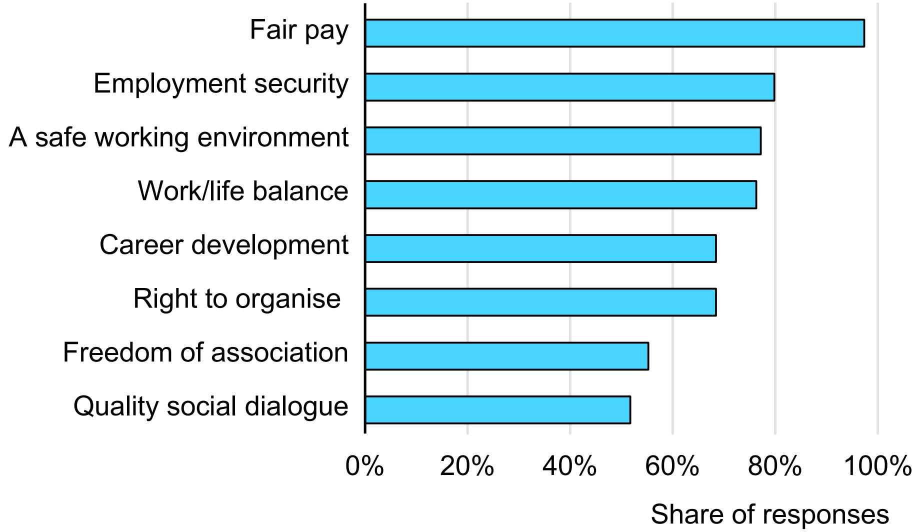
Creating decent jobs is a key incentive for people to join the workforce

Ensuring that energy jobs are decent jobs can help overcome the current skilled labour shortages but many occupations in low-skill green-driven employment (including in low-emissions energy sectors) often have worse job quality than comparable roles in other sectors, according to OECD analysis. This was supported by the *IEA Labour Employment Survey* where only 35% of respondents classified clean energy jobs as quality jobs with both good working conditions and good pay, suggesting that the jobs in the sector need to be improved to become more attractive.

The ILO describes decent work as employment that delivers a fair income, with job security and social protection, equal opportunity for men and women, and freedom for workers to express their concerns, organise and participate in the decisions that affect their work. The *IEA Labour Employment Survey* identified the top three decent job requirements as fair pay (90%), employment security (73%) and a safe working environment (71%).

Challenges related to job location should be considered in just transition strategies given that many workers wish to remain in the same location. Efforts to create new equivalent jobs in the same area should be prioritised and are important for local economics. When workers are required to relocate, additional assistance such as relocation support may be needed. Wages are an important benchmark for workers to evaluate the attractiveness of energy jobs. The *IEA Labour Employment Survey* found that 66% believe ensuring that energy jobs pay better than the national average could help attract more workers to the sector. This was mirrored in the *IEA Industry Employment Survey*, which found that 40% of respondents have increased wages to address hiring difficulties. Wages were the most important decent job criteria for workers, with 90% of respondents to the *IEA Labour Employment Survey* stating that fair pay was required for a job to be decent.

Share of energy workers and workers representatives reporting decent job requirements, 2025



Source: *IEA Labour Employment Survey*, 2025.

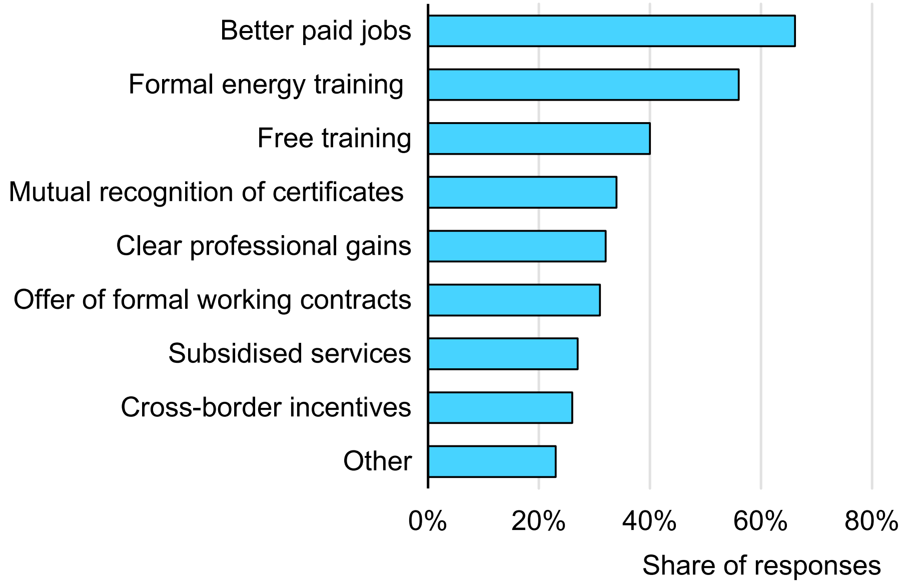
IEA analysis has found that wages continue to be highest in the oil and gas sector, followed by nuclear. The oil and gas sector also continues to have the biggest pay discrepancies between higher and lower skilled workers. Wages in low-emissions energy sectors, such as solar and wind, tend to have higher wages than the coal sector. In the low-emissions energy sectors, wind occupations tend to have higher wages than in solar.

The high levels of informal work can also exacerbate labour and skills shortages and create additional difficulties in workforce mapping and skills planning due to a lack of information on employees and their skill levels, including formal training and qualifications.

Levels of informal work are particularly high in some EMDEs, reaching over 80% in Indonesia and India, compared to 4% in most advanced economies. Informal work includes all remunerative work that is not registered, regulated or protected by existing legal or regulatory frameworks, as well as non-remunerative work undertaken in an income-producing enterprise. Even in a large sector such as energy, informal work without formal employment contracts or social protection exists in the supply chain. While some countries report lower informality in mining and electricity supply than in construction and transport, it remains persistently high in several EMDEs.

Policy measures could help address large-scale informal work which in turn could ensure employment security, decent jobs, and good working conditions. Transitioning workers in the energy sector from informal to formal employment could also help better track labour and skills needs and ensure that upskilling and reskilling opportunities exist. Equally, governments would benefit from the additional income which could go towards providing social protection, including health care for workers.

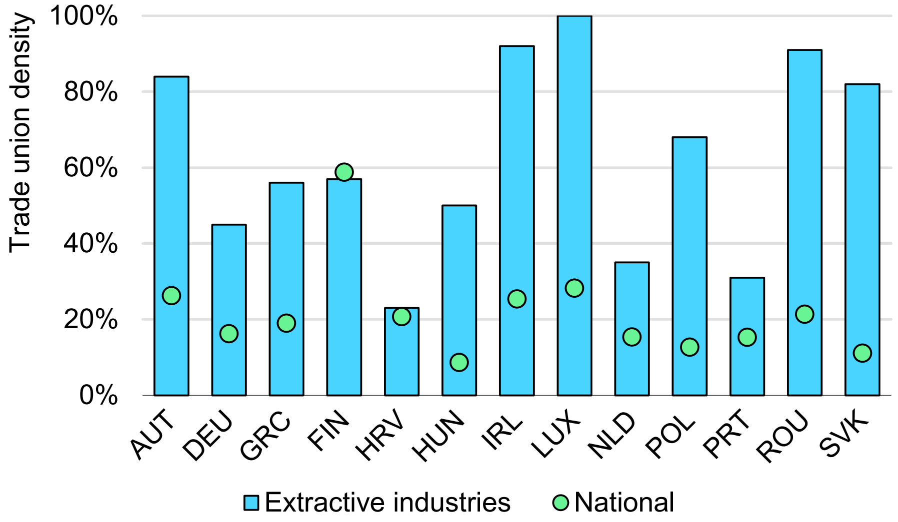
Solutions identified by education and training providers to attract skilled workers to the energy sector, 2025



Source: *IEA Educators' Employment Survey*, 2025.

Targeted training aimed at informal workers can also help improve the lives of these workers. In India, joint collaboration between the Sector Council for Green Jobs, the United Nations Environment Program, ReNeW Power and the Self-Employed Women's Association (SEWA) has resulted in almost 600 women completing free training on solar installation, solar repair and maintenance, and solar pump handling and repairing. The training provides nationally recognised certifications with participants reporting improved employment opportunities, wages, job quality, and social security. The initiative aims to train up to 1 000 women working in the low-paid informal salt-pan sector.

Share of employees who are members of a trade union in extractive industries for selected European Union countries



Notes: 'Extractive industries' includes the mining of hard coal, lignite, iron-ore, non-ferrous metals and other relevant mining activities. Values represent trade union density in extractive industries and national average trade union in selected EU countries: Austria, Germany, Greece, Finland, Croatia, Hungary, Ireland, Luxembourg, Netherlands, Poland, Portugal, Romania, and Slovakia.

Source: IEA analysis based on data from ILOSTAT and Eurofound.

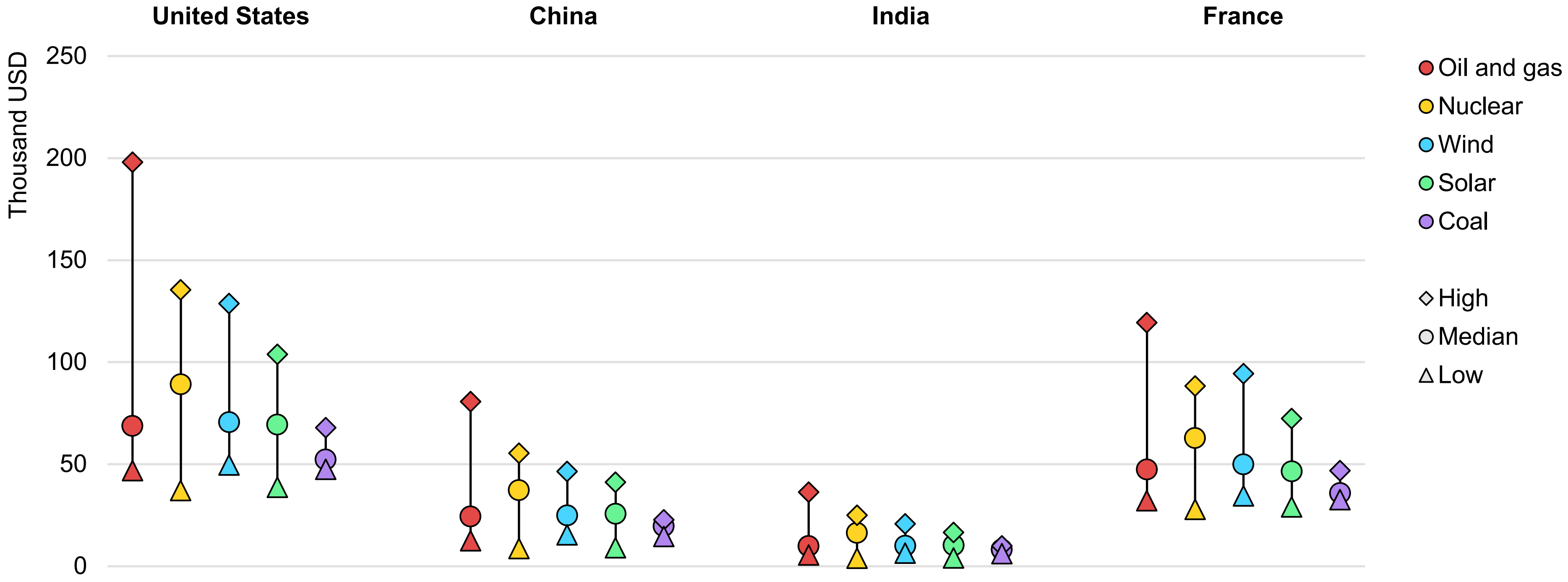
Unionisation rates are not the same in all energy sectors. This can be seen in the extractive industries sector in the European Union where trade union density tends to be higher than the national average which is reflective of prevailing unionisation rates for coal. These workers transferring to new sectors often expect future jobs offer similar compensation, job quality, and engage workers in social dialogue[2] in a comparable way.

Many newer industries, such as solar PV and batteries, have lower levels of unionisation due to a number of factors. Unionisation can be an important conduit to push for higher wages and improved job quality, still, non-unionised workers can garner good wages, especially in contexts where there is high competition over a limited pool of needed skilled workers.

[2] Social dialogue: All types of negotiation, consultation and information exchange between or among representatives of governments, employers and workers.

Wages in oil and gas continue to be the highest, followed by nuclear and wind energy

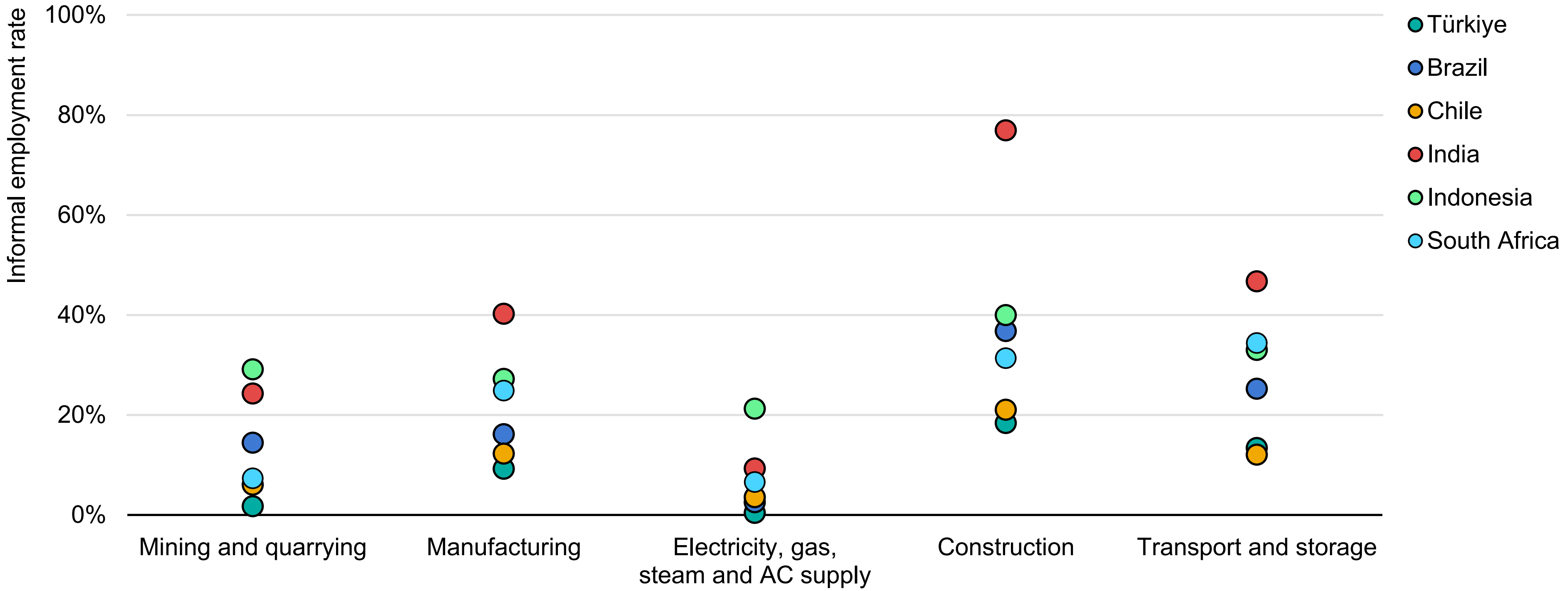
Occupational ranges of median annual salary by energy subsector and country, 2025



Notes: All data presented are gross salaries, with a range given for the median salary for highest paid ("high"), lowest-paid ("low") and median non-executive occupations in a given sector. For example, in the United States oil and gas industry the high point represents the median salary of a well servicing foreman, and the low point represents the median salary of an oil field labourer.
Source: IEA analysis based on data from the Economic Research Institute (ERI).

Informal work is higher in lower-income countries, although lower in mining and energy than in other sectors

Informal employment rate by economic activity in selected countries, 2024



Note: AC = air conditioning. All values are from 2024, except Indonesia (2023).
Source: IEA estimates based on data from ILOSTAT.

Social dialogue is helping define what constitutes a just energy transition around the world.

Social dialogue is the negotiation, consultation, and exchange of information between or among representatives of governments, employers, and workers. In this context parties negotiate agreements on important topics such as pay, working hours and other terms on work conditions. The OECD has found that decent work requirements, such as social dialogue and collective bargaining[3], can have a positive impact on working conditions and can improve a job's attractiveness.

Social dialogue and stakeholder participation was one of the Principles for Just and Inclusive Energy Transitions adopted by the G20 in 2024. The importance of social dialogue is also highlighted in the ILO Just Transition Guidelines and the recent IEA Clean Energy Labour Council Paper (2025).

Worker participation, including through effective social dialogue, allows for impacted workers to be part of the discussions on their futures and provides a formal process for planning and implementing energy transitions. Information and consultation are central to social dialogue and are a priority for trade unions in ensuring a just transition. However, the level and quality of social dialogue on the topic of just transition is uneven.

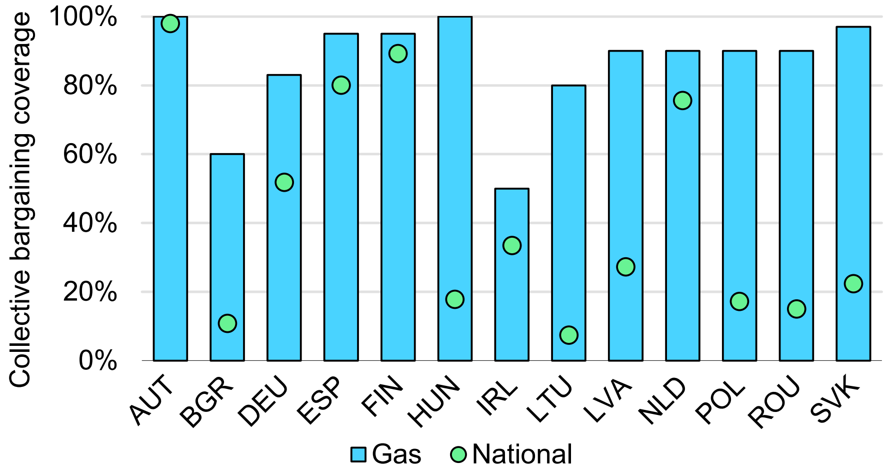
Tripartite social dialogue has been used successfully to ensure a just and inclusive energy transition in a number of countries. In Chile, tripartite social dialogue between the government, employers and trade unions representing workers in the wider supply chain on the phase out of coal has led to successful job transitions for workers with public support for training. Tripartite social dialogue also led to the Spanish Just Transition Strategy, which has resulted in economic diversification with new projects and job creation in the impacted regions. Canada's new Sustainable Jobs Partnership Council aims to ensure that all key stakeholders are heard in discussions on sustainable job creation. This tripartite social dialogue, established under the Canadian Sustainable Jobs Act, this ensures that stakeholders are included and that activities and policy measures are co-ordinated.

Social dialogue provides a platform for collective bargaining – the process by which employers and workers through their respective organisations and trade unions, negotiate pay levels, work conditions and other work-related issues – also improves outcomes for workers. However, coverage, level and scope of collective bargaining differ from country to country depending on laws and practices. Collective bargaining has been used as a tool to prepare companies and workers for energy transitions and agreements, including reskilling

[3] Collective bargaining: Negotiations between employers and trade unions with the aim to reach a Collective Agreement.

and upskilling for workers and aid for workers, as well as early retirement with additional financial support.

Share of workers covered by a collective bargaining agreement in the gas sector for selected European Union countries



Note: Values represent collective bargaining coverage in the gas sector and national average collective bargaining coverage in selected EU countries: Austria, Bulgaria, Germany, Spain, Finland, Hungary, Ireland, Lithuania, Luxembourg, Latvia, Netherlands, Poland, Romania and Slovakia.
Source: IEA analysis based on data from ILOSTAT and Eurofound.

In Italy, a new sectoral agreement covering around 40 000 energy workers includes a pay rise, improvements in working conditions and focuses on managing the energy transition with increased worker engagement in the creation of a training booklet to certify workers' skills, which can assist in transitioning to other energy jobs. Global union federations can also sign voluntary agreements at an international level, such as the Global Framework Agreement between the energy company EDF and IndustriALL Global Union. This agreement is based on joint principles such as an enhanced just transition framework with increased attention to worker protection and training.

In the gas sector, coverage in many EU countries remains higher that the national average. However, evidence suggests that those working in low-emission energy are not as well represented in collective bargaining as those in high-emission activities. Measures to promote quality social dialogue and collective bargaining could help make energy jobs more attractive to workers during energy transitions in a just and inclusive manner.

Chapter 4. Fuel supply, power sector and end uses

Fuel supply and critical minerals

Fuel supply and critical minerals employment by region and sector, 2024 (thousand workers)

	North America	Central and South America	Europe	Africa	China	India	Other Asia Pacific	Middle East	Eurasia	Global
Supply: Coal	100	<50	100	200	2 800	1 500	1 000	<50	300	**6 100**
Supply: Oil	1 100	900	400	1 000	1 100	600	600	2 000	800	**8 500**
Supply: Gas	600	200	200	400	400	200	600	800	500	**3 900**
Supply: Bioenergy	100	500	200	400	200	400	300	<50	<50	**2 200**
Supply: Other clean fuels	<50	<50	<50	<50	<50	<50	<50	<50	<50	**100**
Critical minerals	<50	100	<50	400	<50	<50	100	<50	<50	**800**
Supply: Total	**2 000**	**1 800**	**1 000**	**2 500**	**4 500**	**2 700**	**2 500**	**2 800**	**1 700**	**21 600**

Note: 'Other clean fuels' includes nuclear and hydrogen supply.

Oil and gas supply employment expanded globally, driven by LNG project developments

Oil and gas fuel production and distribution employed 12.4 million people in 2024, up 210 000 y-o-y. Despite this 2% growth, oil and gas jobs have yet to return to pre-Covid-19 levels, reflecting a slow recovery since early-pandemic layoffs. Around two-thirds of these workers were employed in oil supply, with the remainder in natural gas-related activities. Oil and gas supply added 142 000 and 73 000 jobs, respectively. Natural gas supply employment, which does not include workers in power generation or retail, was boosted by new liquified natural gas (LNG) facilities and associated manufacturing of related equipment. Oil and gas jobs slightly decreased in advanced economies, with growth now almost exclusively concentrated in emerging markets and developing economies (EMDEs). Notably, EMDEs outside of China added over 260 000 jobs in 2024, a 3% y-o-y increase.

Most additional oil and gas jobs are underpinned by the development of wells and supporting infrastructure, both for the exploitation of new fields and for sustaining output from existing assets. Approximately one-third the workforce was involved in the development of new production capacity, including drilling, infrastructure installation, and mechanical assembly.

The employment gains generated by new projects was scattered around the world, with high growth rates in Southeast Asia and Africa. Major projects launched in 2024 include the Block B-O Mon integrated gas field and pipeline project in Viet Nam, with production capacity of 490 million cubic feet per day (Mcf/d). Uganda's massive Tilenga oil production development and the East African Crude Oil Pipeline (EACOP) project around Lake Albert is generating an estimated 22 000 direct local jobs during its construction phase.

The Middle East remains the centre of oil and gas employment, accounting for more than one-fifth of the sector's global workforce. Oil and gas jobs represent two-thirds of total energy employment in the Middle East – compared to a global average of just 16% – and highlights the sector's dominant role in the regional economy and labour market. In 2024, Middle Eastern companies increased their oil and gas supply capital investments by 10%, creating around 83 000 new jobs. Countries in the region have invested heavily in the development of their national oil and gas workforces, building education programmes domestically after decades of sending students overseas for relevant degrees. Companies like Saudi Aramco co-finance vocational training centres through public-private partnerships to equip young job seekers with the specialised skills required for careers in the oil and gas industry.

LNG remains the driving force behind natural gas employment growth. Worldwide investments in the sector increased by 11% since 2023, led by North America and the Middle East, which together made up two-fifths of total spending. This expansion was fuelled by multiple LNG construction projects in 2024, including Ruwais in the United Arab Emirates (UAE), Marsa in Oman, North Field South in Qatar, and Cedar in Canada, as well as the start of production at new facilities such as Plaquemines in the United States. The LNG sector is expected to drive employment growth for the rest of the decade, with almost 300 bcm/yr of new LNG export capacity scheduled to come online by 2030.

The latest LNG investment cycle has been characterised by acute labour shortages leading to escalated development costs. Demand for skilled workers, particularly welders, pipefitters and electricians, in a tight labour market led to substantial increases in wages for some occupations. In the United States, for instance, LNG construction workers have seen a 20% rise in wages since 2021. This is driving up project costs in some markets and contributing to a wider pivot to offshore floating LNG, which generally has lower capital costs and location flexibility.

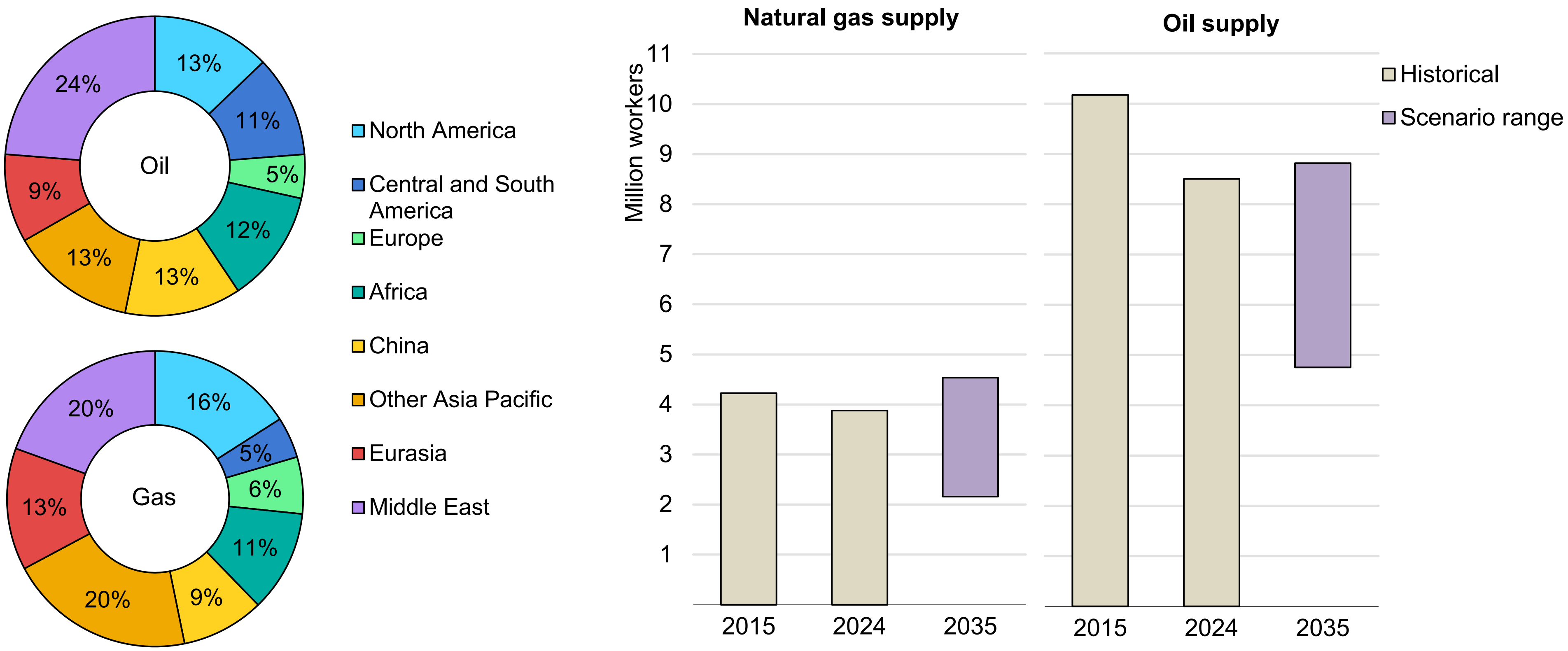
The outlook for oil and gas employment spans a range of possible outcomes, with the workforce projected to reach between 6.9 million and13.4 million by 2035. In the Current Policies Scenario (CPS), demand for oil is slightly higher in 2035 than in 2024, while in the Stated Policies Scenario (STEPS), it peaks around 2030. Employment in oil supply increases by 4% in the CPS and drops by 14% in the STEPS. In the Net Zero Emissions by 2050 Scenario (NZE Scenario) pathway, oil supply employment declines by 44%. Natural gas demand continues to increase both in the STEPS and the CPS into the 2030s, with employment growing by 6% and 17%, respectively, while it declines by 44% in the NZE Scenario by 2035.

Oil and gas companies are adopting a range of strategies to manage uncertainty surrounding the sector's long-term outlook. Declining oil and gas prices are already translating into workforce reductions, particularly among international oil companies (IOCs). Some IOCs are increasingly shifting funds toward improving the production rates of existing fields with automation, improved drilling techniques and artificial intelligence to reduce the labour intensity of their operations. At the same time, IOCs are also investing in clean energy and reallocating resources to diversify and attract young talent. TotalEnergies has launched 32 internal upskilling programmes since 2022, offering various courses on electricity, climate challenges and artificial intelligence to its global workforce. In 2024, Eni launched a training programme to help its oil and gas workforce address skills gaps and support their transition into offshore wind and other clean energy sectors.

The refining sector is already feeling the effects of the uncertain oil demand outlook. In 2024, global investment in oil refineries declined by 4%, with most funding concentrated in emerging and developing economies. Today, China and India together account for 40% of global refinery employment. Companies such as Sinopec and Reliance Industries have begun developing integrated refinery-petrochemical complexes, which can shift refinery operations between fuel-focused production and chemical feedstock output. Refinery workers share many of the same skills required to work in related chemical sectors, however parallel efforts in those sectors to increase automation, reduce costs, and improve safety may reduce the need for medium-skilled workers.

Oil employment edges lower in the Stated Policies Scenario, while gas jobs grow globally

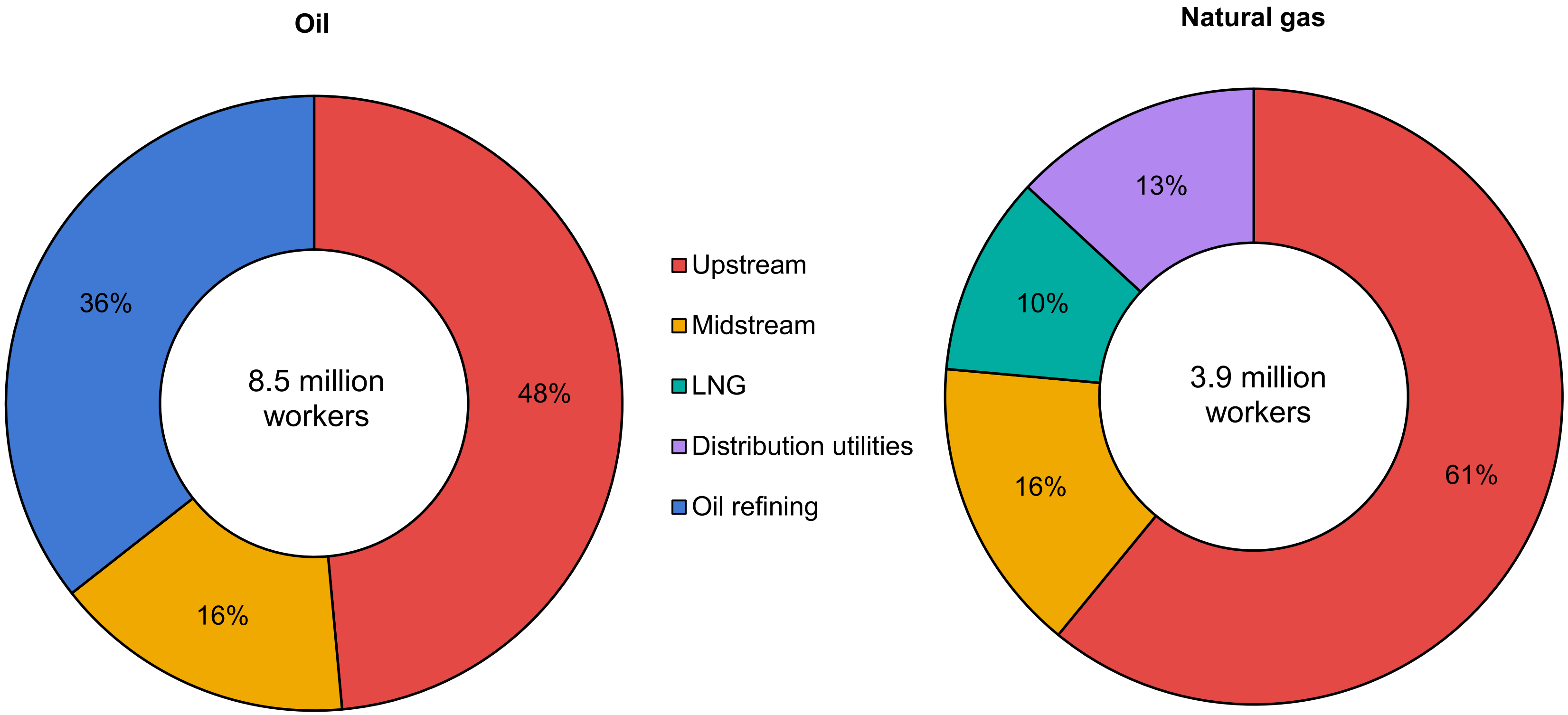
Employment in oil and gas supply by region in 2024, and by scenario in 2035



Note: The scenario range covers outcomes across three IEA scenarios: Current Policies Scenario (CPS), Stated Policies Scenario (STEPS), and the Net Zero Emissions by 2050 Scenario (NZE Scenario).

The majority of oil and gas workers focus on upstream projects

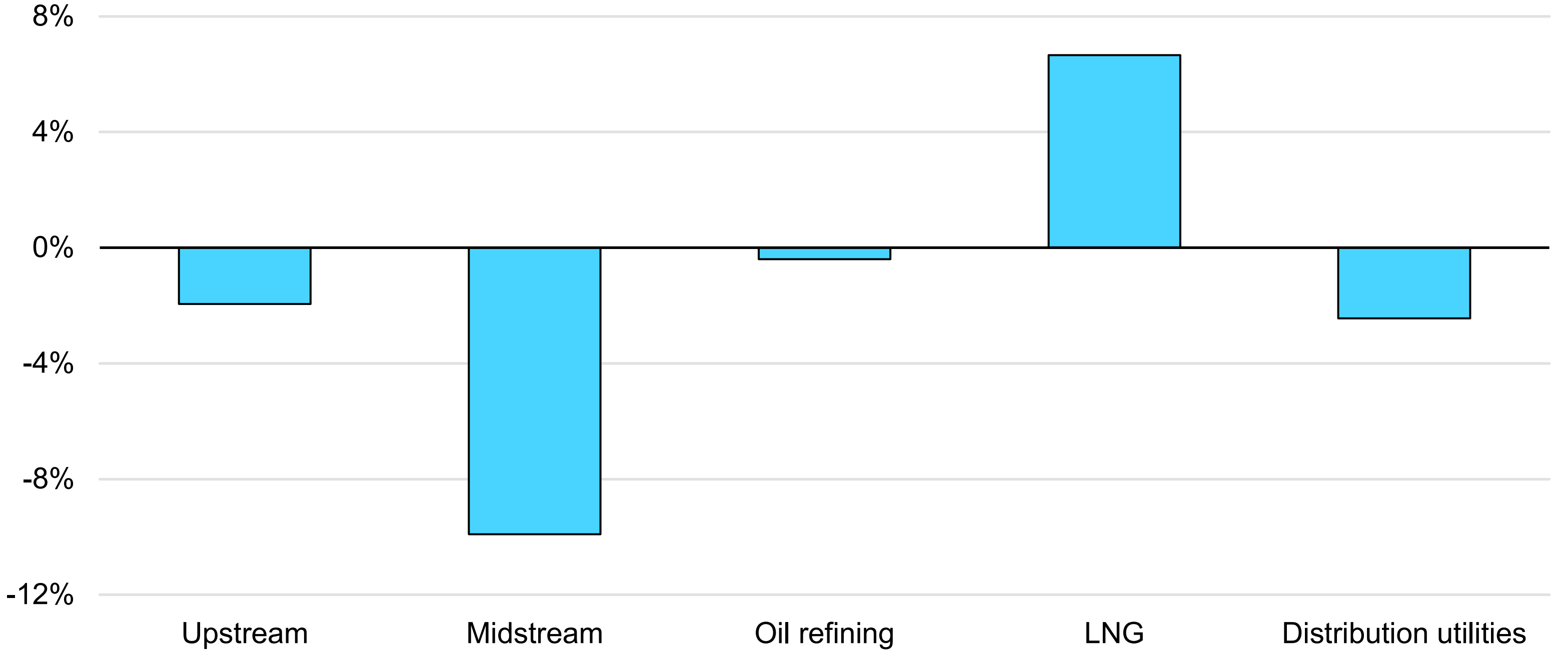
Employment in oil and gas supply by supply chain segment, 2024



Notes: LNG = liquefied natural gas. These figures include employment in oil production, transportation, and refining. Our estimates do not include workers who are employed at retail fuelling stations, as many of these jobs are connected to services and are not linked exclusively to oil (stations also sell biofuels, compressed natural gas (CNG) and electric charging services, as well as an array of other items). Midstream excludes all LNG-associated employment, including LNG transport.

Oil and gas production and transportation jobs remain below pre-pandemic levels, but LNG employment shows steady growth

Employment growth in oil and gas supply by supply chain segment (2019-2024)

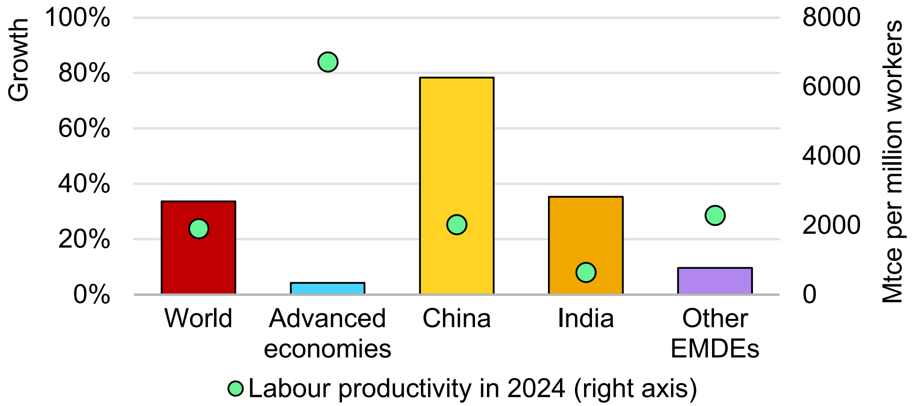


Notes: These figures include employment in oil production, transportation, and refining. Our estimates do not include workers who are employed at retail fuelling stations, as many of these jobs are connected to services and are not linked exclusively to oil (stations also sell biofuels, compressed natural gas (CNG) and electric charging service, as well as an array of other items). Midstream excludes all LNG-associated employment, including LNG transport.

Coal supply employment stable as global production continued to rise

Global coal supply jobs remained steady at around 6.1 million in 2024. The bulk of the coal workforce is concentrated in Asia Pacific, accounting for almost nine out of ten jobs worldwide. China and India alone account for around three-quarters of global coal supply employment. In China, coal supply jobs declined by around 3% between 2023 and 2024, due to productivity gains. India's coal supply workforce grew by nearly 74 000 jobs in 2024, a trend expected to continue into 2025. This growth is driven by increased domestic coal production, which reached a record high in 2024. Contributing factors include the development of new (greenfield) projects, the expansion of existing mines, and the reopening of closed sites. Recent policies of India's Ministry of Coal are aimed at boosting domestic production to reduce reliance on coal imports and ensure energy security.

Change in labour productivity in coal mining from 2015 to 2024 (Indexed to 2015)



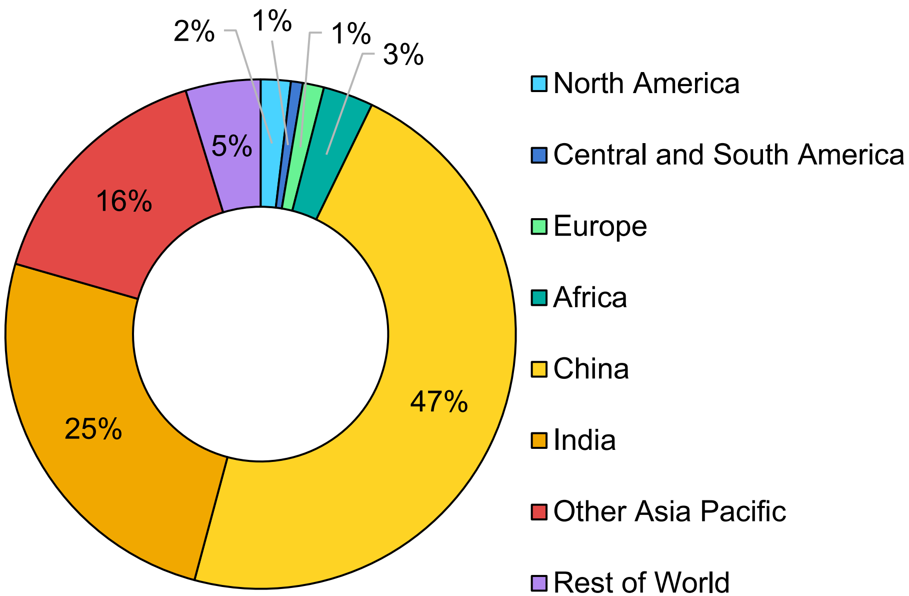
Over the past decade, output per worker has increased significantly in many EMDEs, with labour productivity up by 10% (outside China and India) between 2015 and 2024. In advanced economies, coal output per worker increased only slightly, reflecting the region's already high level of labour productivity. Since 2015, global coal mining productivity has risen 34%, with greater mechanisation driving the gains. Firms are increasingly deploying autonomous equipment such as drones and driverless trucks, which not only boost efficiency but also improve safety for employees.

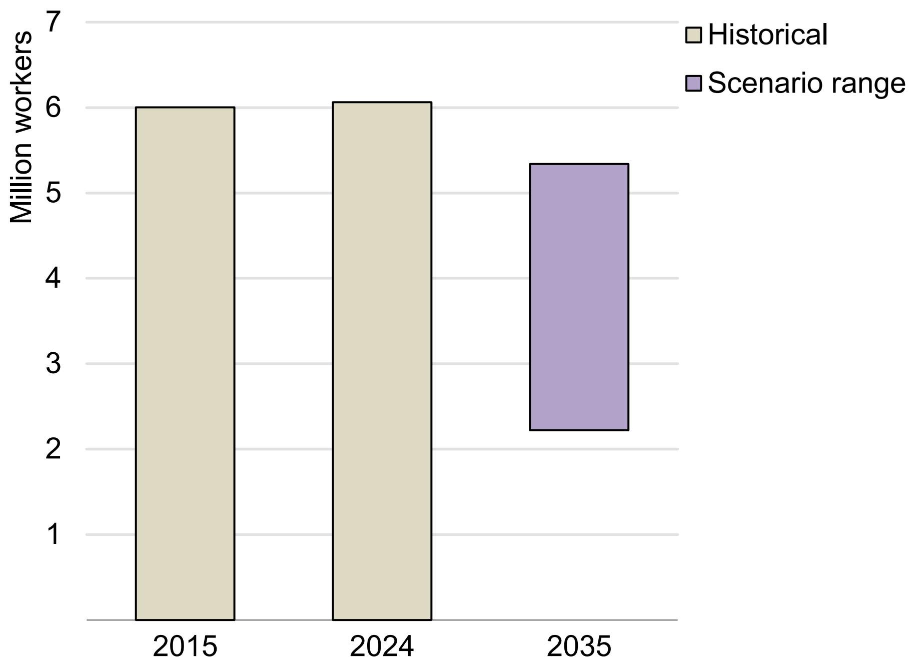
Global coal supply employment is set to decline across all IEA scenarios by 2035 as coal production falls and productivity levels remain high or continue to improve in most cases. China will account for at least five out of the ten job losses under all scenarios.

Coal mine workers tend to possess skills that are not easily transferable, making it difficult to find similarly paid employment or retrain within the same region. These challenges are especially acute in countries where a significant share of the workforce is informal, such as in India and Indonesia, and for women, who are disproportionately affected by the socio-economic impacts of the transition. Communities living in coal producing regions in advanced economies are also not spared from the impact of this phase down. As such, governments around the world need to safeguard that the shift away from coal is accompanied by just transition policies that incorporate appropriate economic diversification initiatives in the affected areas to create new employment opportunities.

Supported by growing production in Asia, coal supply employment remains near 2015 levels, but declines by 2035 across all IEA scenarios

Employment in coal supply by region in 2024, and by scenario in 2035





Note: The scenario range covers outcomes across three IEA scenarios: Current Policies Scenario (CPS), Stated Policies Scenario (STEPS), and the Net Zero Emissions by 2050 Scenario (NZE Scenario).

Modern bioenergy employment continues to climb as fuel blending targets reach new highs

Production of modern bioenergy continued to increase in 2024, driven by higher blending targets. This covers liquid biofuels, advanced solid biomass and biogas, while traditional biomass, such as charcoal and fuelwood, falls outside the scope of this analysis due to limited data availability. Demand for biogas and bioliquids grew by 4-5%, while consumption of modern biomass increased by 2% in 2024. Jobs followed consumption trends, as the sector surpassed 2.2 million workers in 2024. The production of modern solid biomass accounts for almost three-quarters of all workers, while bioliquid and biogas represent 21% and 9%, respectively. Bioenergy employment is led by India and Brazil, each accounting for around 20% of total employment, followed by China and Indonesia, at 10% and 7%, respectively.

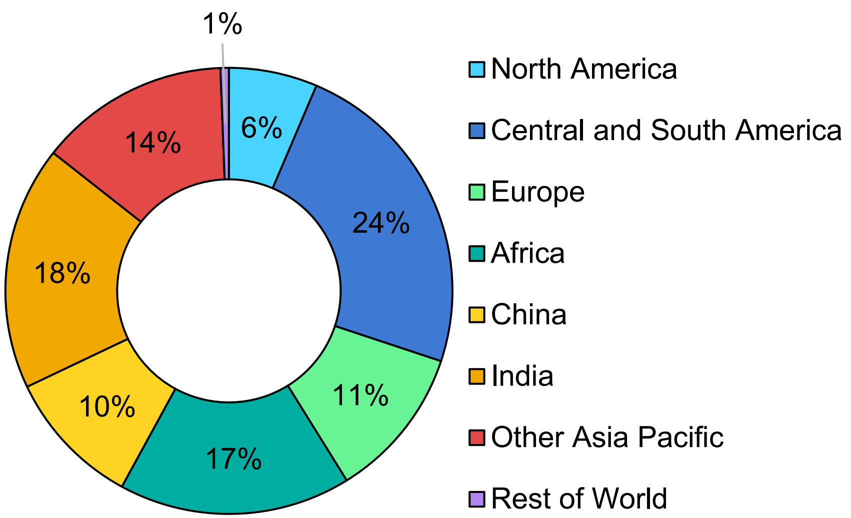
Two-fifths of the global bioenergy supply workforce is occupied in agricultural cultivation, processing and refining, as these processes require more manual labour performed by low- and medium-skilled workers. The prevalence of informal labour in this sector is high, especially in emerging and developing economies, leaving many workers unreported and unprotected. These workers, for instance, produce crops for bioethanol, collect agricultural waste into pellets, or operate biogas production plants. The number of workers in this segment continued to grow in 2024, supported by expanding consumption in the Asia Pacific region and South America. For instance, India and Brazil increased their ethanol blending rates to 18% and 27%, respectively, while Indonesia and China both reinforced their biodiesel policies. India and Indonesia also increased the co-firing rate of biomass pellets in their thermal plants. Biomass pellet production is gaining ground in Africa to modernise biomass use in many industries, with over 20 plants in the region, including a new one in Malawi.

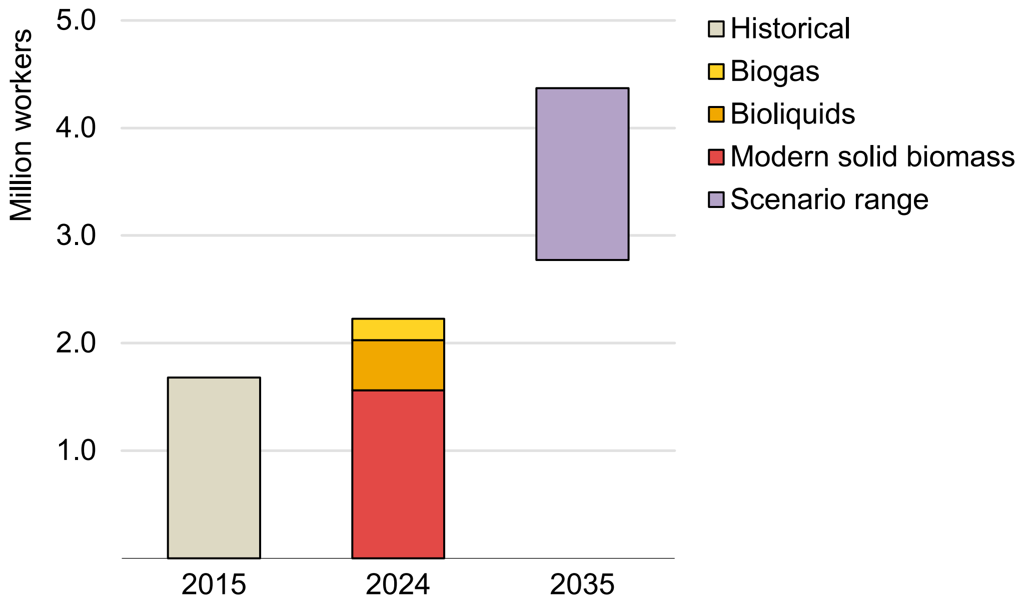
Around 45% of bioenergy workers were engaged in the construction and operation of production facilities, as well as the delivery of products to the market. Two-thirds of all biogas investments were concentrated in Europe, motivated by higher natural gas prices, which are still more than double the pre-2022 levels. Employment numbers followed this trend, as workers in biogas equipment manufacturing and installation grew by 9%, contributing to installed capacity of 18 GW in the region in 2024. In Western Europe, three new plants were opened in 2024 with production capacity of 270 000 Mt of pellets.

Bioenergy employment expands through the coming decade in all IEA scenarios, led by strong demand in EMDEs, including efforts to modernise informal biomass supply chains. Both in the CPS and the STEPS, bioenergy consumption increases by around 30%, which in turn results in employment demand rising by around 26% compared to today’s levels. Under the NZE Scenario, growth in total consumption would lead labour demand in bioenergy production to double by 2035.

All scenarios point to large bioenergy employment growth by 2035, supported by rising consumption

Employment in bioenergy supply by region and value chain step in 2024, and by scenario in 2035





Note: The scenario range covers outcomes across three IEA scenarios: Current Policies Scenario (CPS), Stated Policies Scenario (STEPS), and the Net Zero Emissions by 2050 Scenario (NZE Scenario).

Low-emission hydrogen employment continued to expand, fuelled by project developments

The global low-emission hydrogen supply workforce reached 40 000 in 2024, up from 35 000 the previous year. While most of the low-emission hydrogen supply was produced by steam-methane reforming through carbon capture, utilisation and storage (CCUS), electrolytic hydrogen, already accounting for almost 90% of workers in the sector, played a more significant role in job creation owing to its construction and manufacturing boom.

The majority of additional low-emission hydrogen supply jobs were created by the construction of new facilities, as global electrolyser installed capacity has almost reached 2 GW. The surge was driven by the Middle East, where electrolytic hydrogen projects under construction account for a combined capacity of 9 million Mt/yr. This includes the Neom project in Saudi Arabia, which will produce 600 Mt of hydrogen per day upon completion. China established 35 electrolytic hydrogen projects in 2024, while 76 projects are expected to come online in the United States by 2030.

Equipment manufacturing and RD&D make up more than two-thirds of low-emission hydrogen employment. Currently, half of the sector's global manufacturing workforce is in China, and around 60% of the world's electrolyser supply is made in the country. Other notable manufacturers include the European Union and the United States, each accounting for 13% and 14% of the global low-emission hydrogen manufacturing workforce.

CCUS spans across many sectors of the energy industry, including hydrogen. Employment in hydrogen production via steam-methane reforming with CCUS increased by 5% in 2024. This expansion was largely due to retrofitting existing production plants with CCUS technology, as well as the manufacturing of equipment.

The workforce is expected to grow throughout the coming decade as low-emission hydrogen production takes off. Production capacity expands rapidly in the coming decades in all IEA scenarios, although the growth rates vary depending on demand, cost competitiveness and financing conditions. Broader deployment is already aided by policies promoting the localised production of hydrogen, for instance in the European Union, Australia and Japan. In the CPS and the STEPS, low-emission hydrogen production reaches around 10 GW of installed capacity in 2035, creating 46 000 to 58 000 jobs. Aligning with the NZE Scenario pathway would require adding 208 GW capacity of low-emission hydrogen, which would need employment to grow by 28% each year on average until 2035 compared with 2024 – similar to the growth rate of battery storage employment in the last nine years.

A number of public-private partnerships were founded in 2024 to train workers in hydrogen-related skills, including several companies collaborating to set-up joint learning centres in Saudi Arabia, the United States and Mexico. Vocational programmes were designed by experienced technicians, engineering graduates and other knowledgeable professionals.

Critical minerals mining employment rose by 3% in 2024 despite slowing investments

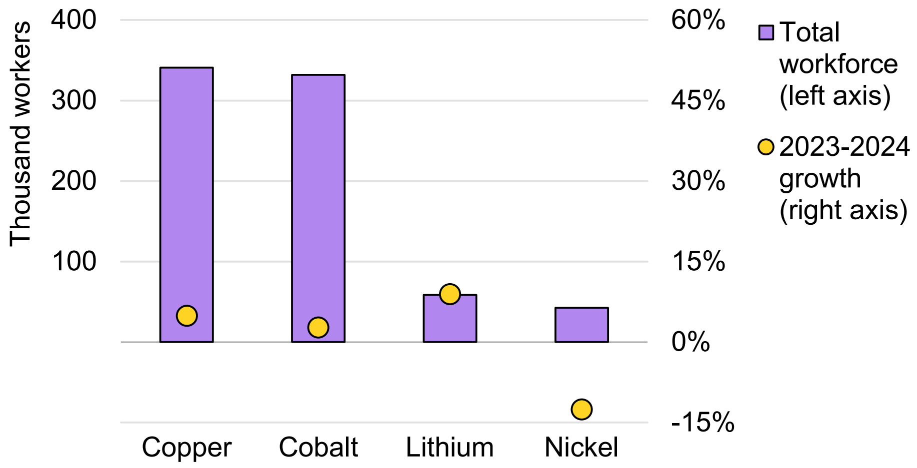
The production of critical minerals continued to rise in 2024, however new mine development slowed due to a decline in battery metal prices. As a result, growth in total critical mineral extraction employment eased to 3% y-o-y, to 770 000 workers worldwide in 2024. Lithium and copper employment saw growth rates of 9% and 5%, respectively, while jobs in cobalt extraction rose by 3%. Employment in nickel mining fell by 13% in 2024.

Expanding labour growth in mining operations was concentrated in a handful of countries. China's identified lithium reserves rose by three times in the past five years, led by increased exploration and technological breakthroughs, and is positioned to surpass Australia to become the world's largest producer in 2025. Chinese mining firms have accordingly raised their headcount by 13% in 2024. Meanwhile, the Indonesian mining workforce grew by 17% as its nickel output reached 2.4 Mt in 2024.

Africa employs more than half of the global mining sector with 415 000 workers. The Democratic Republic of Congo (DRC) was the main source of growth, underpinned by a production increase of 14 kt in cobalt output. The labour intensity of cobalt mining is higher than that of other minerals due to the prevalence of artisanal and small-scale mining (ASM). ASM relies on low-skilled labour with manual extraction methods. The lack of formal employment leads to unsafe working conditions in the mines, marked by child labour. With demand for miners expected to rise in the future, providing equitable and decent working conditions is needed for a just transition.

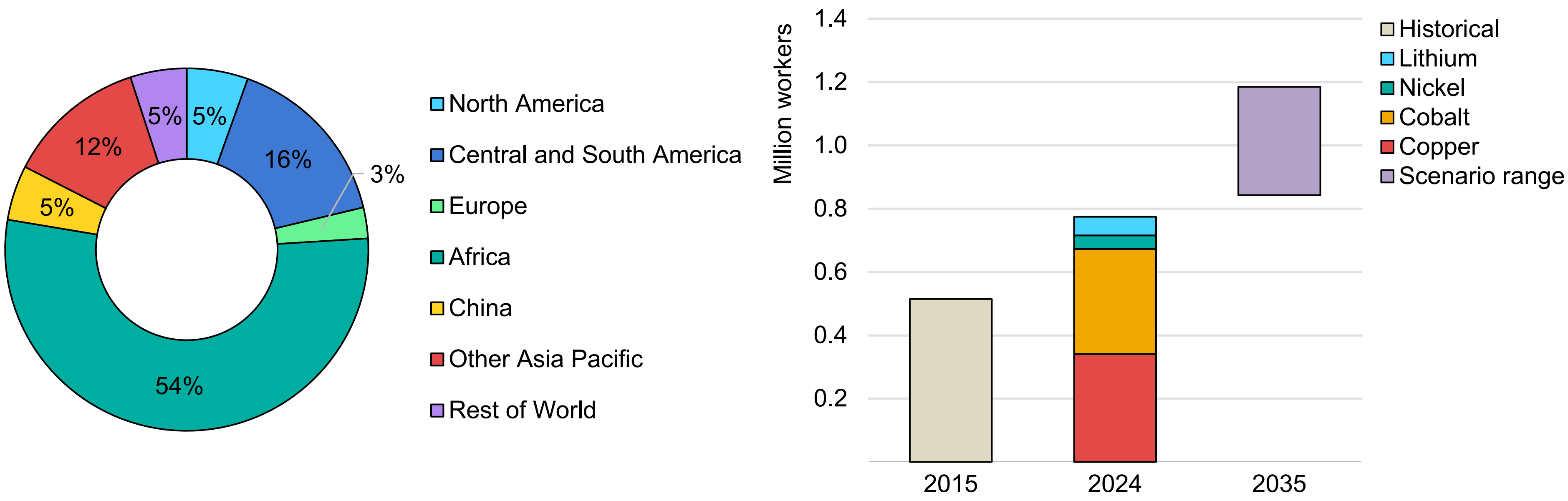
Critical mineral employment is expected to increase, driven by lithium, copper and nickel extraction, while the labour needs for cobalt mining will ease due to changes in battery chemistry choices. The critical minerals workforce is expected to grow across all IEA scenarios, reaching between 880 000 and 1.2 million workers by 2035. However, the current pipeline of lithium and copper mining projects is insufficient to meet projected demand even in the STEPS, potentially leading to market shortfalls by 2035.

Employment and year-on-year employment growth by critical minerals, 2023-2024



Critical mineral mining employment is concentrated in Africa, but growing in Asia Pacific

Employment in critical minerals by region in 2024, and growth by scenario and region in 2035



Note: The scenario range covers outcomes across three IEA scenarios: Current Policies Scenario (CPS), Stated Policies Scenario (STEPS), and the Net Zero Emissions by 2050 Scenario (NZE Scenario).

Power sector employment

Power sector employment by region and sector, 2024 (thousand workers)

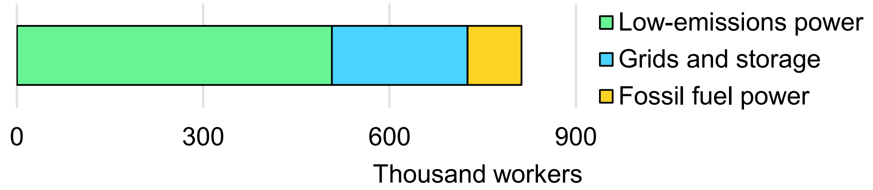
	North America	Central and South America	Europe	Africa	China	India	Other Asia Pacific	Middle East	Eurasia	Global
Solar PV	300	100	500	100	3 000	500	500	<50	<50	**5 000**
Wind	200	100	300	<50	800	100	200	<50	<50	**1 700**
Nuclear	100	<50	300	<50	300	200	100	<50	200	**1 200**
Hydropower	100	300	200	200	400	300	400	<50	100	**2 000**
Other low-emissions power generation	100	100	100	<50	100	100	100	<50	<50	**600**
Coal power generation	100	<50	100	<50	1 000	700	300	<50	100	**2 200**
Oil and gas power generation	200	100	100	100	100	<50	300	300	100	**1 400**
Grids	1 000	500	1 000	500	2 400	1 800	800	200	200	**8 500**
Power sector: Total	**2 000**	**1 200**	**2 600**	**1 000**	**8 200**	**3 700**	**2 600**	**600**	**700**	**22 600**

Notes: ‘Other low-emissions power generation’ includes marine, bioenergy, geothermal and concentrating solar power (CSP). ‘Grids’ includes transmission, distribution and storage.

Power sector jobs continue to rapidly expand, with low-emissions technologies and grids accounting for 90% of the total workforce gains

The power sector, including generation and grids (and excluding fuel supply) employed 22.6 million workers in 2024. Around 65% of the jobs, or 14.2 million, were in power generation, while 8.5 million workers were employed in grids, including transmission, distribution and storage. Power sector employment grew by 800 000, or 4% y-o-y, propelled by strong growth in low-emissions power generation technologies, which were responsible for around 65% of all power sector job additions in 2024.

Job additions in the power sector, 2024

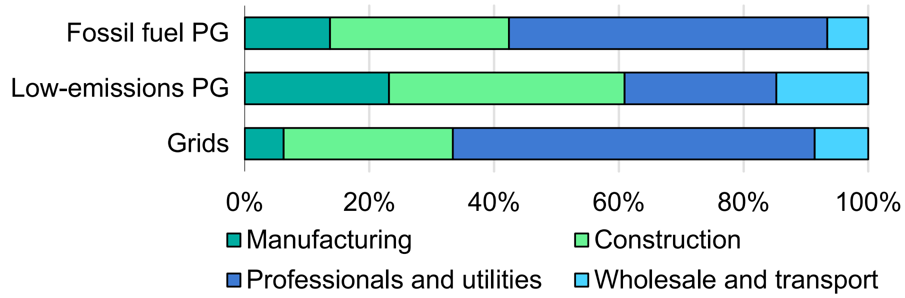


IEA. CC BY 4.0.

Notes: “Low-emissions power” includes power generation in renewables, nuclear and CCUS. “Grids and storage” includes transmission, distribution and storage. ‘Fossil fuel power’ includes unabated fossil fuel power generation, including, gas, oil and coal.

Solar PV alone accounted for 40% of all job additions in the power sector, almost three-quarters of which were in China. Grids were responsible for most of the remaining growth, adding 220 000 jobs, while the oil and gas power workforce grew more moderately, adding 87 000 jobs. Coal power employment fell by 12 000 jobs between 2023 and 2024 as capacity additions declined.

Share of power sector employment by economic activity, 2024



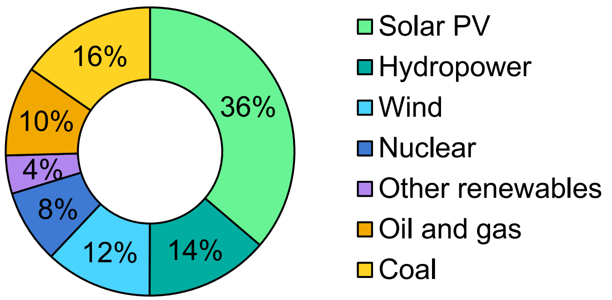
IEA. CC BY 4.0.

Notes: Low-emissions PG = low-emissions power generation, including renewables, nuclear and CCUS. Fossil fuel PG = unabated fossil fuel power generation, including gas, oil and coal.

One-third of power sector workers, or 7.3 million, were involved in the construction and installation of power plants, dams, grids, batteries, and auxiliary systems. The construction sector added the most jobs year-on-year, driven by record investment in sources of low-emissions generation, as well as grids and battery storage. Another 3.5 million workers were employed in the manufacturing of system equipment, such as inverters, solar panels, generators or batteries. Around 9.4 million workers were engaged in professional and utility services, which encompasses roles like engineering, maintenance technicians, grid operators, and regulatory oversight. The remaining 2.5 million were employed in wholesale and transport, including logistics co-ordination, equipment handling, and fuel distribution. However, the profile of the workforce varies by sector. In power grids and fossil fuel generation, most jobs are in operations and maintenance, while 70% of workers in low-emissions power generation are involved in developing and building new projects. These numbers, however, conceal significant regional variation. In China, where manufacturing is highly concentrated, the sector accounts for more than 20% of total power sector employment, compared with around 10% or less in Europe and the United States.

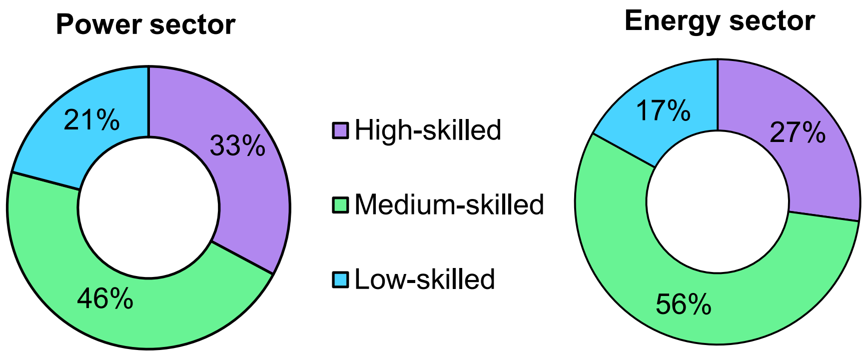
Within power generation specifically, which excludes grids, three-quarters of the workforce is employed in low-emissions technologies, led by solar PV with for 5 million workers. Coal power employed 2.2 million workers, followed by hydropower with 2 million, wind at 1.7 million, oil and gas at 1.4 million, and nuclear 1.2 million. Around 85% of new jobs in power generation between 2023 and 2024 came from low-emissions technologies, with solar PV creating 310 000.

Employment in power generation by technology, 2024



The power sector demands a higher proportion of highly skilled workers compared to the broader energy industry. Both in power generation and grids, the share of high-skilled workers such as engineers and technicians exceeds the energy-wide average, reflecting the sector's technical complexity.

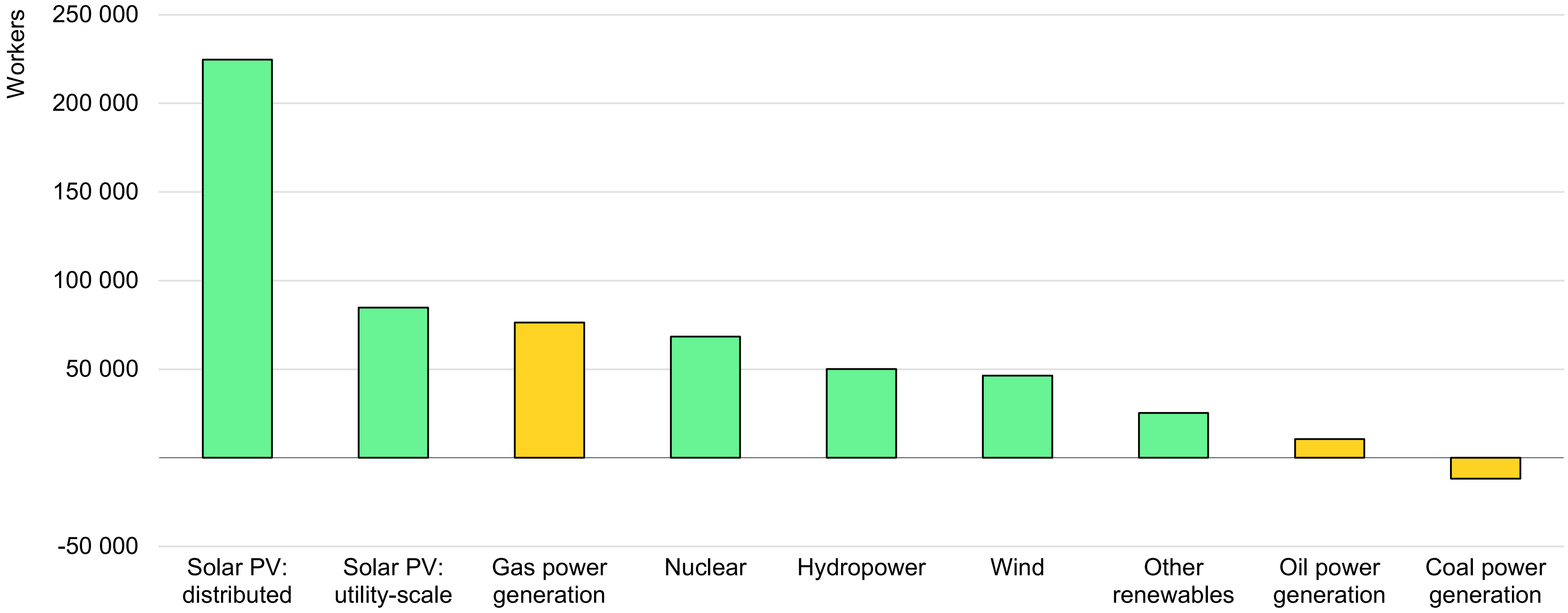
Share of high-, medium- and low-skilled workers by sector, 2024



Mirroring the broader energy industry, the power sector is dominated by medium-skilled occupations. Among skilled trades, grid line workers and electricians are in particularly high demand, with line worker shortages especially acute in utilities due to high retirements rates, physically demanding work conditions, and a limited pipeline of apprentices. Electricians, particularly those with industrial and high-voltage expertise, are becoming harder to source as electrification projects ramp up, with parallel demand from fast-growing AI and tech sectors further straining supply. The power sector employs more low-skilled workers (21% vs. 17% across energy), largely due to its greater reliance on labour-intensive construction work such as trench digging and site preparation. Many large infrastructure projects also depend on short-term labour in their early stages, further contributing to this higher share.

Low-emissions sources were responsible for 85% of job additions in the power generation workforce, dominated by distributed solar PV

Employment change in power generation by technology, 2023-2024



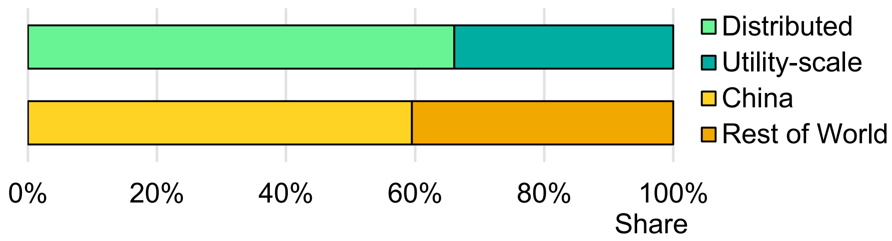
Notes: Distributed solar PV refers to rooftop, buildings, and other small-scale installations. Utility-scale solar PV refers to solar farms, parks and larger commercial assets. Other renewables include marine, bioenergy, geothermal and concentrated solar power (CSP).

Solar PV employment reached 5 million in 2024, led by a 30% increase in capacity additions

With over 5 million workers in 2024, solar PV, including utility-scale installations and distributed assets, accounts for well over one-third of the power generation workforce, the largest employer in the sector. While investment growth in solar PV slowed in 2024, largely due to declining costs, capacity additions reached 540 GW, a 30% year-on-year increase.

China remains the dominant employer in the solar PV sector, with 60% of the global workforce. About 42% of these jobs are tied to domestic construction activities. Europe, India and Other Asia Pacific each account for around 10% of the solar PV workforce. In the United States, solar employment grew at a faster year-on-year rate than the average across advanced economies, driven by a surge in activity as developers accelerated project timelines to meet tax credit eligibility deadlines.

Solar PV employment by sectors and by region, 2024



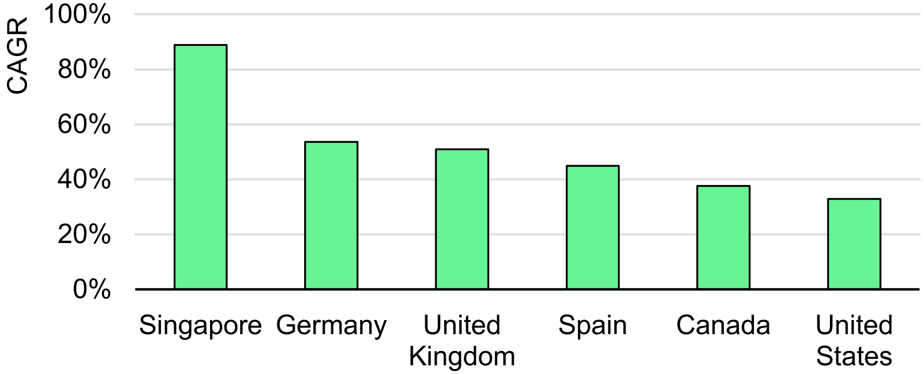
Notes: Distributed solar PV = rooftop, buildings, and other small-scale installations. Utility-scale solar PV = solar farms, parks and larger commercial assets.

Africa saw the highest year-on-year employment growth at around 23% due to new utility-scale projects, with East, West and Central Africa responsible for most of the growth. The expansion of off-grid solar systems, including micro-solar and PAYGo, is also boosting solar employment in the region. India's solar PV workforce also saw notable growth of around 18% on the back of strong support from the PM-Surya Ghar: Muft Bijli Yojana programme.

Distributed solar – such as rooftop and other small-scale installations – accounts for two-thirds of all solar PV employment, despite representing only 43% of installed capacity. On average, distributed solar creates nearly three times more jobs per megawatt than utility-scale solar. This is largely due to the individualised nature of rooftop installations, which need tailored permitting, design, and installation. These projects also involve substantial sales and administrative work. Unlike utility-scale projects, which may benefit from automation and economies of scale, residential and small commercial installations rely heavily on manual labour and in-person customer service, further boosting employment in roles like sales, support and logistics. As a result, jobs in wholesale and transport make up about 25% of employment in distributed solar, compared to just 13% in utility-scale solar.

Around two-thirds of the solar PV workforce is employed in the development and installation of new capacity. About 21% of solar PV workers are engaged in the manufacturing of polysilicon, wafers, cells, modules and inverters, while 46% work in the installation of solar projects in both individual homes and utility-scale solar farms. The construction-heavy nature of the solar PV sector means it relies extensively on elementary occupations, which account for around a quarter of all jobs. These roles typically involve routine manual and physical tasks that require little formal training, such as carrying materials, preparing and cleaning work sites, digging trenches for wiring, assisting with panel assembly, and loading or unloading equipment.

Average annual growth rate in job postings for skilled trades and technicians in solar PV by selected country, 2018-2023



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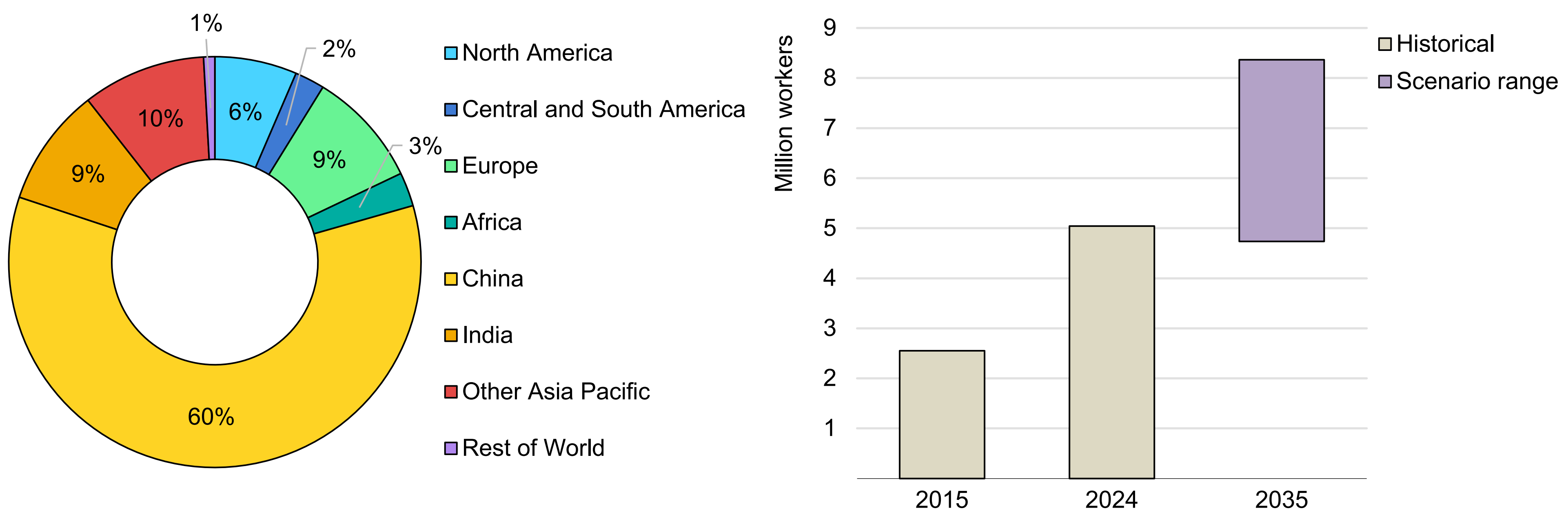
Note: CAGR = compound annual growth rate.
Source: IEA analysis based on Lightcast data (2024).

At the same time, the sector relies heavily on skilled trades – such as electricians, solar PV installers, and welders – which make up more than one-fifth of the solar PV workforce. This occupational group is also where the most severe labour shortages are being reported, especially for qualified electricians, whose skills are essential for system integration, grid connection, and ensuring compliance with safety standards. Labour market indicators, such as job postings (a proxy measure for the demand of selected skills and occupations), reflect the growing demand for skilled trades workers in the solar PV sector. Between 2018 and 2023, job postings for skilled trades, technicians, and associated professionals in solar PV in Singapore, Germany, the United Kingdom, Spain, Canada and the United States showed an average annual growth rate of 50%, highlighting the consistent rising demand for these roles.

While investment spending decreases by 2035 in both the CPS and the STEPS due to falling prices of PV modules, capacity grows more around fourfold as more is added per USD spent. Solar PV employment rises by 14% in the STEPS and 66% in the NZE Scenario, while it declines by 6% in the CPS. As installed capacity expands, a growing share of the workforce is employed in operations and maintenance of solar PV systems. These jobs include regular inspection and cleaning of panels, performance monitoring, inverter servicing, electrical system checks, and ensuring the long-term reliability and safety of both rooftop and utility-scale installations. Over time, replacing ageing solar panels will also become an important source of employment.

China accounts for 60% of the solar PV workforce, with the next highest share just 9% for both India and Europe

Employment in solar PV by region in 2024, and by scenario range in 2035



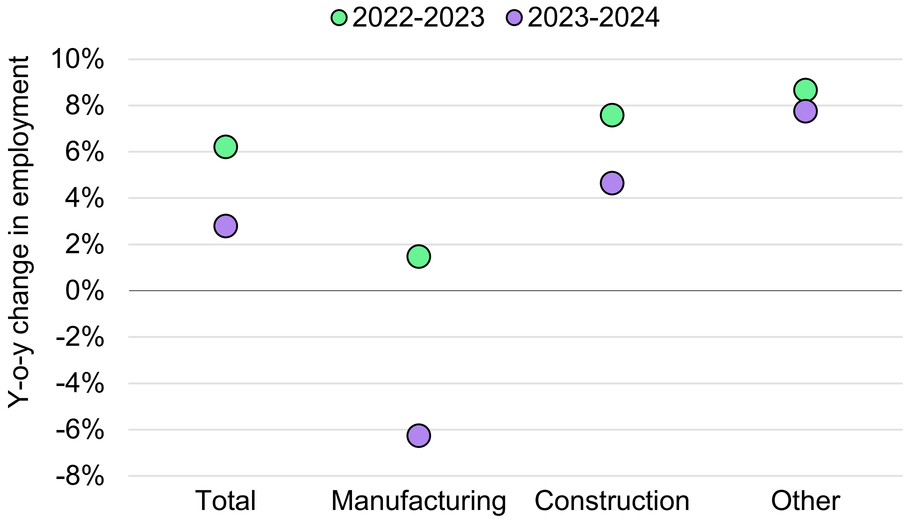
Note: The scenario range covers outcomes across three IEA scenarios: Current Policies Scenario (CPS), Stated Policies Scenario (STEPS), and the Net Zero Emissions by 2050 Scenario (NZE Scenario).

Wind employment grows more slowly than in previous years amid persistent increasing project costs in the offshore market

Employment in wind power generation rose to over 1.7 million in 2024, up 3% from 2023, driven mainly by growth in onshore wind. Nearly three-quarters of job additions came from the onshore segment. A quarter of wind power workers were in the manufacturing of wind turbine components such as blades and towers, while over a third were involved in the construction of onshore and offshore wind farms. The remaining 40% of workers were engaged in operations, maintenance, and support roles across sectors such as turbine technicians (professional services), grid management (utilities), parts distributors (wholesale), and heavy-haul drivers (transport).

Upstream price pressures have eased significantly for wind manufacturers since 2023 but rising seller's prices have made some prospective projects uneconomical, especially when combined with reduced government financial support. As a result, employment growth slowed in 2023-24, falling short of the compound annual growth rate of 5% recorded over the previous five years (2019-23). This deceleration has been most evident in manufacturing, which experienced a 6% decline in employment as demand for new turbines and components fell due to delays and cancellations in project development. The offshore market in particular showed signs of continued weakness as developers significantly pared back investment plans in response to increasing project costs. Major wind developers, including RWE, GE Vernova, and Orsted, have announced job cuts globally, with Europe seeing the most significant reductions, marked by a 4% decline in its offshore workforce between 2023 and 2024. However, the downturn is not limited to Europe, with layoffs also announced in the United States, Brazil and India.

Year-on-year employment growth in wind power by sector, 2022-2024

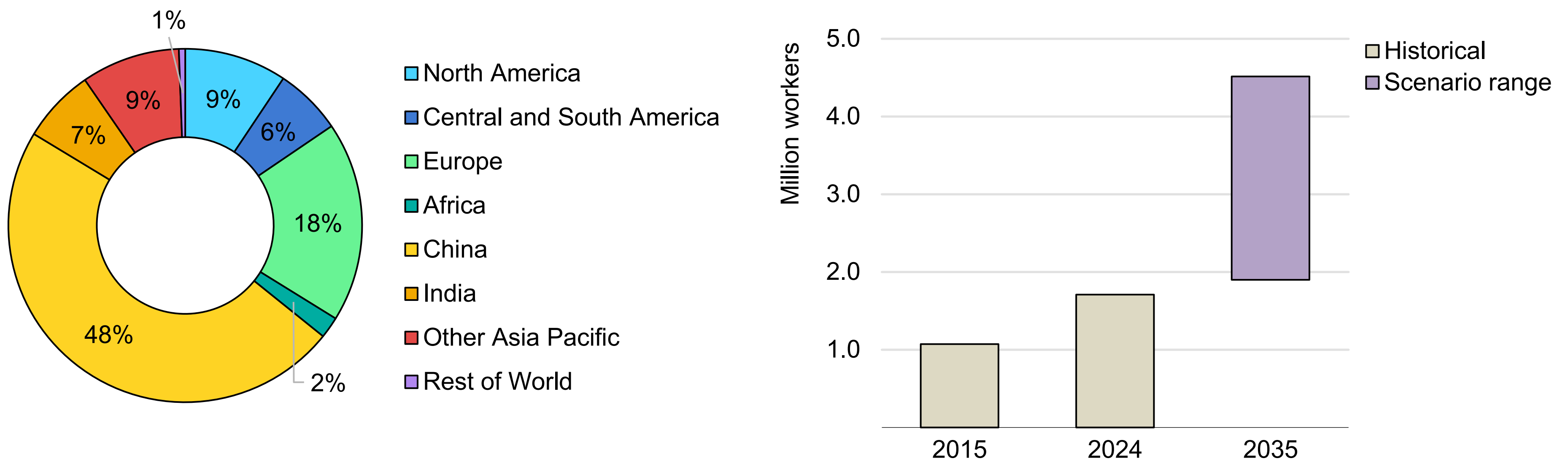


Note: 'Other' includes professionals and utilities, and wholesale and transport.

Employment growth in construction slowed to 5% in 2024 compared to 8% in 2023, reflecting a deceleration in the rate of new capacity additions, even as total installed capacity continued to increase. Segments focused on operation and maintenance saw employment growth keep pace or accelerate as these activities are tied to existing infrastructure and are less affected by shifts in project investment.

Global wind employment is projected to continue to increase in 2025, but considerable uncertainty remains in several markets. In the United States, the outlook is clouded by an executive order pausing federal wind leasing and permitting. In the first quarter of 2025, a wave of industry layoffs were announced by major players such as RWE and Vineyard Offshore. Employment in wind power varies widely across scenarios. In the NZE Scenario, jobs grow rapidly at a compound annual rate of 9% through 2035, compared with 2% in the STEPS. In the CPS employment grows more modestly, and even declines if operating jobs are excluded. This divergence across scenarios highlights the uncertainty facing the industry, necessitating companies to prepare for a broad range of outcomes and policy-driven regional shifts. Many may look to diversify globally, while firms anchored in regions with strong domestic policies are likely to be better positioned to strengthen their international competitiveness.

Employment in wind power by region in 2024, and by scenario range in 2035



Note: The scenario range covers outcomes across three IEA scenarios: Current Policies Scenario (CPS), Stated Policies Scenario (STEPS), and the Net Zero Emissions by 2050 Scenario (NZE Scenario).

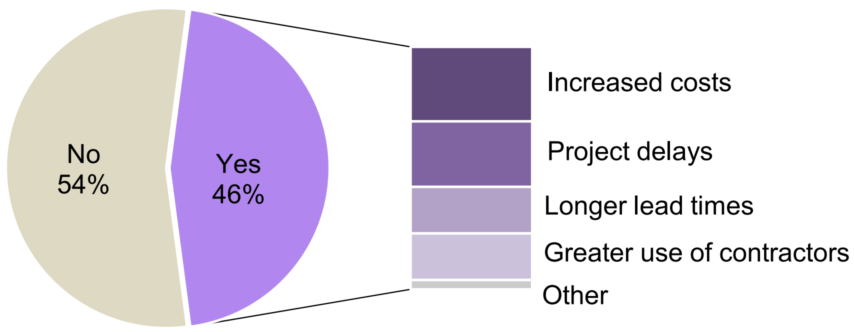
Nuclear employment rises as investment makes a comeback, but a shortage of workers is complicating the pace of project development

Jobs in the nuclear industry totalled 1.2 million in 2024, a 6% increase over 2023. Nuclear investment grew by 6% y-o-y, and rose by 50% over the past five years, led by China. Europe's investment has steadily declined since 2022, falling from USD 26 billion to USD 16 billion by 2024.

The United States, France, China and Russian Federation (hereafter, "Russia") maintain their position as the four most dominant players, with 244 reactors in operations, more than the rest of the world combined. However, the profile of workers varies by region, and countries with sizeable existing capacity do not necessarily constitute the largest portion of nuclear employment. Only about 30% of jobs in the nuclear industry are focused on operating and maintaining existing plants, and most jobs are concentrated in the manufacturing and construction of nuclear plants. China's nuclear construction workforce grew by over 20% in 2024 to about 76 000 workers, due to its sustained leadership in reactor construction – a lead it maintains in 2025 with 29 reactors under construction. China is also strengthening its position as a manufacturer of components for both domestic and international nuclear power plants, leading to a significantly higher share of manufacturing in its total nuclear employment – 50% compared to a global average of 38%. By contrast, in North America and Europe nuclear employment is concentrated in the operation and maintenance of existing infrastructure, with these roles making up more than 50% of their workforces.

With investment expected to rise and 63 new reactors already under construction, nuclear employment is projected to grow in all IEA scenarios, at compound annual rates of 1.5% in the CPS, 2% in the STEPS and 6% in the NZE Scenario through 2035. However, the shortage of skilled nuclear workers has been a growing concern in the industry over past few years, already threatening the pace of certain projects. Around 46% of nuclear companies surveyed by the IEA reported hiring difficulties leading to operational bottlenecks, with project delays, longer lead times and increased reliance on contractors cited as the main consequences.

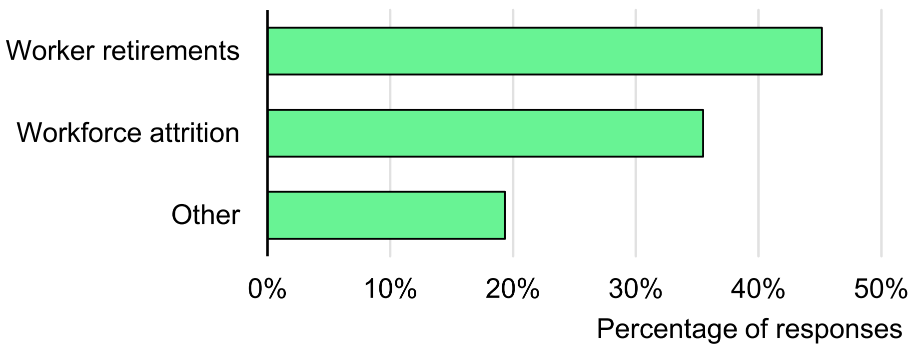
Responses to "Have labour shortages created operational bottlenecks?" and main consequences identified, 2025



Source: *IEA Nuclear Energy Employment Survey*, 2025.

These shortages are especially acute in high-skilled occupations. Nuclear companies surveyed by the IEA identified engineers as the primary source of workforce bottlenecks, followed by project managers, electrical trades and construction trades such as welders and pipefitters. Some companies reported having to bring in workers from other regions – a practice known as long-distance deployment – which led to cost increases of 10% to 20%, illustrating how labour shortages can directly drive-up project costs.

Primary factors for workforce departures reported by over 30 nuclear companies, 2025



Note: 'Other' includes the completion of major projects, cost-cutting/efficiency initiatives and funding challenges.
Source: *IEA Nuclear Energy Employment Survey*, 2025.

The skills shortage has been partly driven by a wave of baby boomer retirements. The Global Energy Talent Index estimates that 25% of the current nuclear workforce is over 55 years old compared to 20% in the oil and gas sector, and just 10% in the renewable energy sector. According to the French nuclear trade association Gifen, of the 100 000 extra full-time hires in core nuclear jobs that will be needed in France in the next ten years, half will be required simply to replace people leaving the industry. In the United States, 60% of nuclear workers are ages 30 to 54, exceeding both the wider energy workforce and national average. This reality was echoed in the survey of over 30 nuclear companies operating across the globe conducted by the IEA in which worker retirements were reported as the leading factor contributing to departures in the workforce.

In addition, nearly 60% of surveyed nuclear companies reported experiencing high or very high competition for skilled workers, particularly from other nuclear firms, the oil and gas sector, tech companies and government agencies. Minimising the negative effects of this competition will require targeted initiatives to improve public perception of careers in the nuclear sector, which often involve advanced technical skills, are more likely to be unionised, and may offer average wages approximately 50% higher than those in other forms of electricity generation.

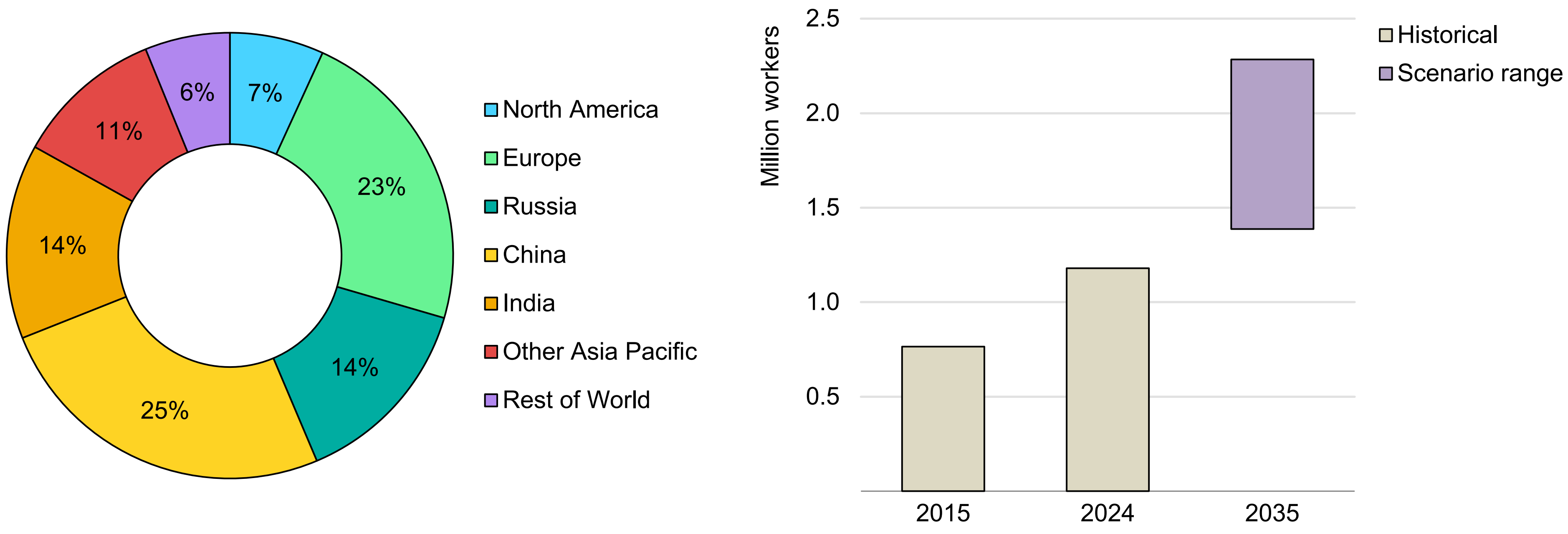
The combined pressures of an ageing workforce and growing competition for skilled workers highlight the need to develop a new pipeline of young talent to sustain the global nuclear sector. Notably, 60% of nuclear companies surveyed by the IEA indicated that collaboration between the industry and educational institutions is insufficient – mirroring company estimates that 60% of the skills their workers need are acquired through on-the-job training, rather than through formal education or prior experience. Some promising initiatives are beginning to emerge – for example, France's Mon

Avenir dans le Nucléaire brings together government, industry, and training organisations to raise awareness, standardise training pathways, and improve job placement for young professionals entering the nuclear field.

Artificial intelligence is also beginning to play a role in addressing labour shortages in the nuclear sector. In Japan, for example, AI tools are being deployed to support safety inspections and plant maintenance amid a shrinking workforce. However, the broader application of AI in the nuclear industry remains constrained by strict security protocols, regulatory complexity, and the sector's inherently risk-sensitive nature. When asked about the biggest barriers to adopting AI technologies in their daily operations, the majority of nuclear companies surveyed by the IEA cited concerns around data protection, privacy, and cybersecurity as the primary obstacles. As a result, while AI offers potential for efficiency gains and workforce support, its integration into nuclear operations is likely to remain cautious and highly selective.

Europe, Russia and China account for over 60% of the global nuclear workforce

Employment in nuclear by region in 2024, and by scenario in 2035



Note: The scenario range covers outcomes across three IEA scenarios: Current Policies Scenario (CPS), Stated Policies Scenario (STEPS), and the Net Zero Emissions by 2050 Scenario (NZE Scenario).

Growth in hydropower employment was supported by a substantial increase in investments in 2024, with pumped-storage hydroelectricity capturing a growing share of new projects

Hydropower was the third largest employer in power generation, reaching nearly 2 million jobs globally in 2024, up 2.6% y-o-y. Investments in the hydropower sector were significantly higher than in previous years, rising by 6% y-o-y in 2024, compared with an average annual growth rate of 2% in 2019-2023. The sustained pace of capacity additions – averaging about 26 GW each year since 2015 – has supported steady job growth over the past decade.

Employment growth since 2019 has been mostly driven by India, Africa and Asia Pacific outside of China, as North America, Europe and Brazil focussed on modernising legacy infrastructure, with only a marginal increase in new construction of conventional hydropower. Africa saw strong employment gains, particularly in construction roles, as it posted record capacity additions in 2024, including the Grand Ethiopian Renaissance Dam, the largest hydropower project in Africa. However, financing remains an issue across the continent. Investment began to decrease in 2023 and is set to continue its downward trajectory in following years, resulting in slower employment in the region in 2024.

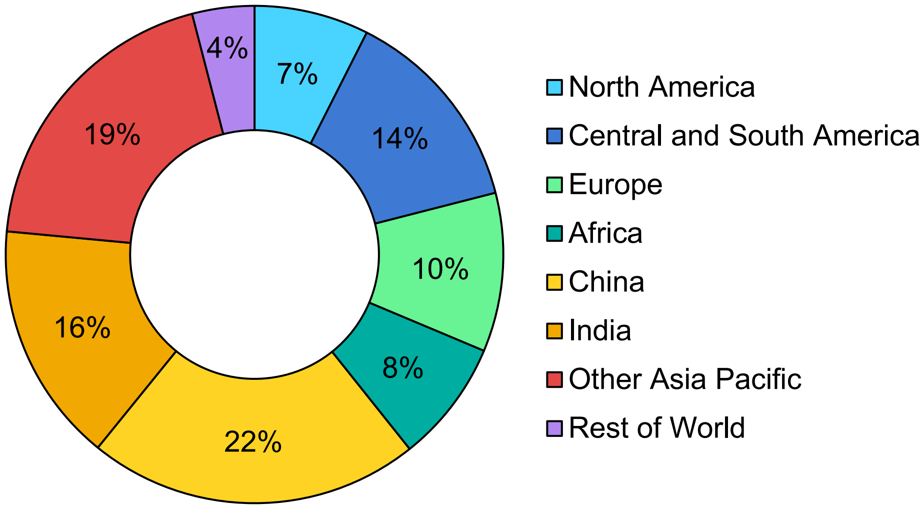
While China accounts for over 20% of the global hydropower workforce, this share is down from around 30% in 2019. Amid falling investment in conventional hydropower dams compared with previous years, employment in the sector continued to decrease in 2024. However, China's Three Gorges Corporation, the largest hydropower development and operation firm in the world, has been actively developing hydropower projects abroad, including a 209 MW facility under construction in Peru and a 1 124 MW dam in Pakistan.

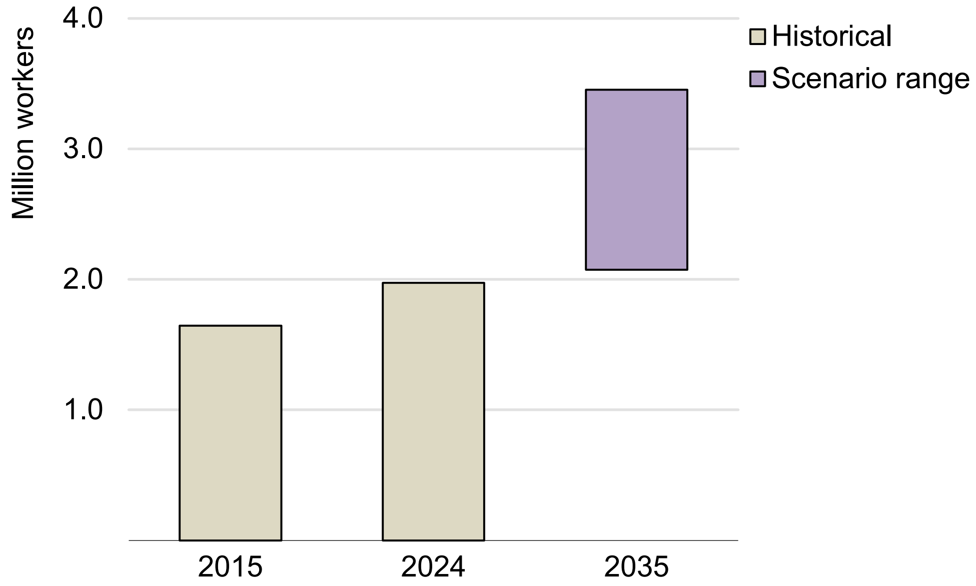
Ongoing geopolitical changes and rising curtailment of variable renewable energy (VRE) are increasing demand for flexible generation and electricity storage, leading to the rapid expansion of pumped-storage hydropower (PSH) in many countries. In Europe, investment in hydropower rose by 13% over 2023 levels, buttressed by the strong business case for PSH, which contributed to the region's job additions. Similarly, China's Three Gorges is scaling up pumped storage as a national infrastructure priority, and PSH is emerging as China's primary growth area in the hydropower sector.

However, uncertainties around hydropower output, market volatility, and policy misalignment continue to pose challenges for the sector. Compounding these issues is the ageing hydropower workforce – over 25% of employees in countries like the United States are aged 55 years or older, with thousands expected to retire by 2030. The International Hydropower Association has highlighted the sector's ageing workforce and the struggle to attract new talent, raising concerns over potential skills shortages and the loss of institutional knowledge. However, hydropower installed capacity increases in all IEA scenarios by 2035, reflecting the sector's essential role in providing secure and flexible generation. As a result, hydropower jobs grow across scenarios by 2035, though the rate of growth varies with investment levels.

Growing hydropower capacity drives employment by 2035 in all IEA scenarios

Employment in hydropower by region in 2024, and by scenario in 2035





Note: The scenario range for 2035 covers outcomes across three IEA scenarios: Current Policies Scenario (CPS), Stated Policies Scenario (STEPS), and the Net Zero Emissions by 2050 Scenario (NZE Scenario).

Gas-fired power generation employment accelerates as electricity demand grows in EMDEs

Gas-fired power generation employment continued to rise in 2024, reaching 1.2 million globally, a strong 7% increase year-on-year. Employment in the sector remains concentrated in the Middle East, Asia Pacific and North America. Almost half of the workforce is engaged in the construction of new facilities and the manufacturing of equipment, with three-quarters of the jobs in EMDEs. By 2040, 890 GW of new gas-fired generation capacity is expected globally, led by projects such as fuel switching in countries like Indonesia or Malaysia, and rising electricity demand from data centre expansion in markets, especially the United States.

Despite surging power demand, a history of boom and bust cycles and limited availability of skilled labour have led manufacturers of turbines to be more cautious about expanding production capacity, contributing to lead times of up to seven years. The other half of gas-fired generation workers are in plant operation and maintenance, which is generally less labour-intensive than the construction and commissioning of new facilities. In the European Union, tight natural gas markets since Russia's invasion of Ukraine contributed to a slowdown in job growth to 5% last year versus 6% in 2022. The trajectory of global employment in gas-fired power generation depends on factors such as prices, fuel competition, and policy developments, with the workforce projected to range from 522 000 to 1.4 million by 2035, and growth led by the Middle East and Africa.

Efforts to retrofit gas power plants are increasing as part of broader strategies to adapt to future energy system needs. In 2024, Germany announced subsidies for converting 2 GW of gas power plant capacity to operate on hydrogen, while IHI and GE Vernova jointly developed a 2 MW turbine powered exclusively by ammonia. However, the transition to hydrogen and ammonia in power generation requires the upskilling of the existing gas workforce, particularly in safety protocols and handling procedures.

Oil-powered generation employs around 200 000 workers – the smallest share among fossil fuel-based sources. Oil maintains an important position in the electricity mix in the Middle East, which accounts for 30% of global oil-powered generation jobs. Increasingly, severe natural disasters have boosted off-grid diesel generator sales, prompting firms such as Generac to expand their manufacturing workforce by nearly 10%. In Africa, diesel generators continue to play an important role in providing reliable electricity access in remote areas. However, employment in oil-fired power generation declines to around 120 000 and 126 000 workers by 2035 in the STEPS and the CPS, respectively, driven by gas and solar PV additions in the Middle East and the expansion of pay-as-you-go solar kits and micro-grids across Africa. In the NZE Scenario employment drops to around 72 000 jobs.

As the number of gas-fired power generation plants equipped with CCUS technology increases, demand for CCUS-related skills is on the rise. Education centres are increasingly following these trends, as CCUS is gaining ground in higher education and vocational training curricula.

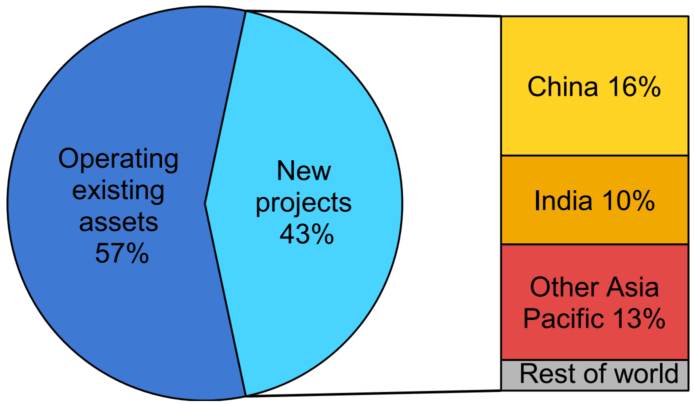
Investments in new coal-fired generation capacity helped maintain coal power jobs at high levels in 2024

In 2024, 2.2 million people worked in coal-fired power generation, the second largest employer in the power generation sector, with 15% of all jobs. Compared to other fossil fuel power generation technologies, whose installed capacity is more evenly dispersed across different regions of the world, coal-fired power plants and associated jobs are particularly concentrated in the Asia Pacific region. Close to 80% of these jobs are in India or in China, while Indonesia accounts for 5% of the global coal power workforce.

Although coal-fired power plant capacity additions reached the lowest level in two decades in 2024, a large pipeline of announced and permitted projects in Asia Pacific continues to sustain substantial coal power employment, with global investment in coal-fired generation rising to its highest level since 2017. Currently, two out of five jobs in the coal power sector are in construction or manufacturing activities directly related to the development of new generation capacities. China and India have been the main forces behind the recent momentum in coal power development, with approvals and final investment decisions for new plants in both countries reaching their highest levels in a decade.

Amid rising geopolitical uncertainty, energy security considerations are increasingly mentioned to justify building new coal power capacity or extending the life of existing power plants. At the same time, reliance on coal has been steadily decreasing in advanced economies. Coal-fired generation accounted for 5% of electricity generation and 3% of power sector jobs in 2024, down from 11% and 7%, respectively, in 2015. In 2024, advanced economies represented less than 3% of the 40 GW of new capacity added and more than 85% of the 21 GW of coal capacity retired last year.

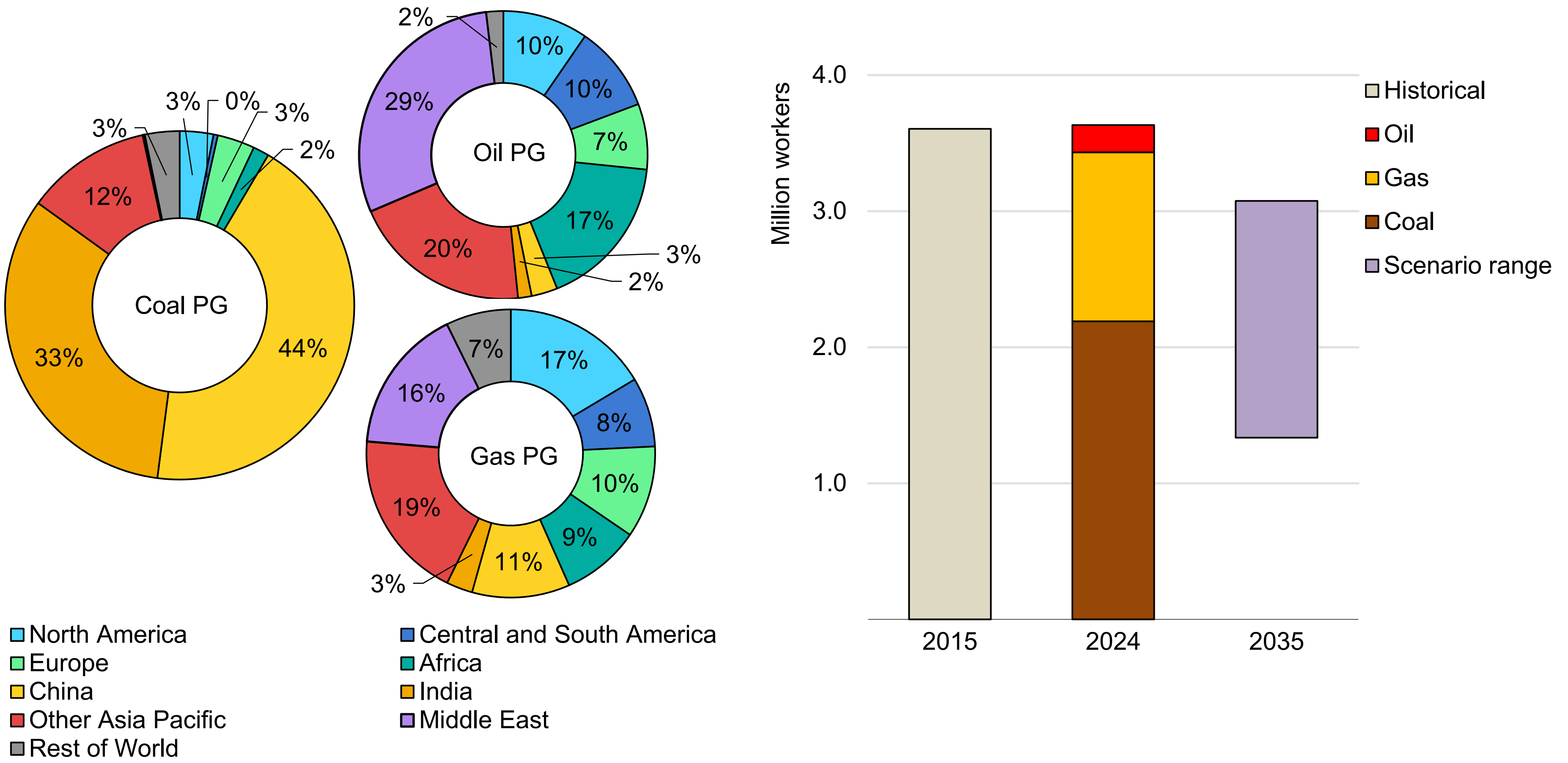
Employment in coal power by asset status and region, 2024



Across all IEA scenarios, employment in unabated coal-fired power generation declines by 2035. Between 2024 and 2035, employment falls by 28% under the CPS, 41% under the STEPS, and 66% under the NZE Scenario, though retrofitting existing plants with CCUS technologies helps offset some losses by creating new jobs.

Coal is the largest employer in fossil fuel power generation, but gas drives growth

Employment in fossil fuel power generation by region in 2024, and by scenario in 2035



Note: The scenario range covers outcomes across three IEA scenarios: Current Policies Scenario (CPS), Stated Policies Scenario (STEPS), and the Net Zero Emissions by 2050 Scenario (NZE Scenario).

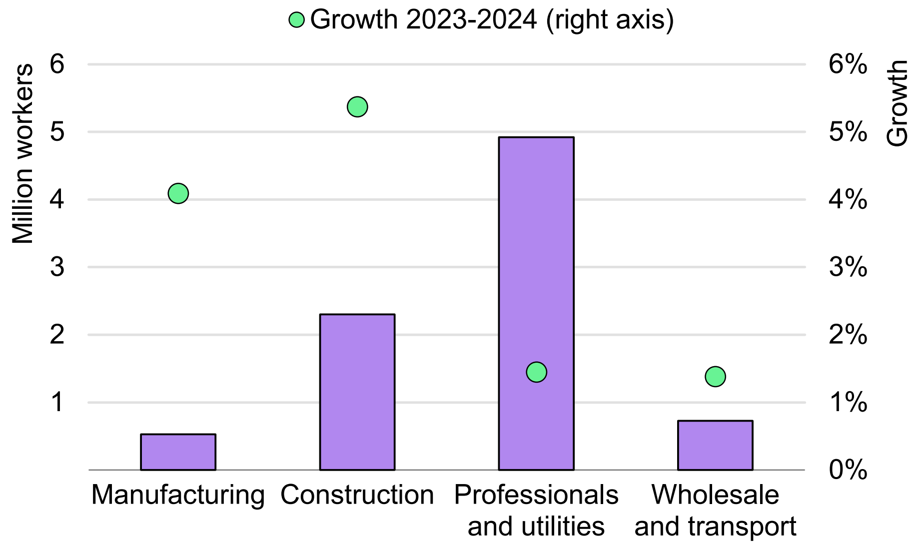
Power grid employment remains supported by strong construction activity

Employment in power grids, which includes power transmission, distribution and storage, totalled 8.5 million workers globally, marking a 2.6% year-on-year increase as grid investment reached a new high of USD 390 billion. However, employment growth slowed compared to the previous year – a trend that reflects a broader imbalance in the sector. Investment in transmission and distribution is lagging behind, with only USD 0.40 now invested in grids for every dollar spent on new generation capacity, down from USD 0.60 in 2016, despite falling renewable energy costs and rising prices for essential components like transformers and cables.

Around 530 000 workers were employed in the manufacturing of grid components such as transformers, switchgear and smart meters in 2024, while 27% of the grid workforce was in the construction and expansion of transmission and distribution infrastructure, including substations and high-voltage lines. Nearly 9% were engaged in wholesale and transport activities, ranging from equipment supply to specialised logistics. The majority of grid workers (58%) were employed in professional and utilities roles such as responding to outages, managing customer connections, and performing tasks like meter reading.

The share of workers employed in operation and maintenance roles in the transmission and distribution segments has been gradually declining, from 59% in 2019 to 56% in 2024. This shift reflects broader changes in the occupational profile of the grid workforce. Advances in digital technologies have made some operations and maintenance roles redundant: the adoption of smart meters has lessened the demand for manual meter readers, while drone inspections are increasingly replacing routine line-checking tasks carried out by field technicians. At the same time, the expansion of grid development projects, particularly in EMDEs, has led to a growing share of workers in construction, rising from 25% in 2019 to 27% in 2024. A record 2 900 km of transmission and distribution lines were added worldwide in 2024.

Employment and growth in grids by economic activity, 2023-2024



This trend is particularly pronounced in China, where large-scale electrification efforts have driven a surge in grid construction activity

(China was responsible for 40% of additional transmission lines globally in 2024). The share of construction workers in the country's grid workforce reached 42% in 2024, continuing the steady rise in recent years. By contrast, EMDEs outside of China have experienced much slower growth in their grid workforce, and even declines in some regions such as Africa and South America, reflecting lagging investment levels. Advanced economies and China together accounted for over 85% of total investment growth in transmission and distribution infrastructure in 2024. Without targeted policy support, many EMDEs – particularly in sub-Saharan Africa and parts of Latin America – risk falling further behind in building grid infrastructure and developing the technical workforce needed to support electrification and other energy transition goals.

Grid employment increases across all IEA scenarios. By 2035, the size of the workforce is projected to range from 10.5 million to 12.6 million workers. However, job growth varies significantly across regions, with EMDEs in particular requiring greater investment in modern, digitalised grid infrastructure to unlock employment potential.

Although battery storage currently represents a small share of grid employment, at around 2%, it has experienced rapid growth, with jobs increasing by 17% y-o-y in 2024, led by a surge in global battery storage investment and falling costs of utility-scale batteries. As the need for system flexibility rises, battery storage is expected to become one of the fastest-growing technologies in the power sector by 2035. In the CPS, employment grows by 43%, while in the STEPS it more than doubles by 2035, and increases by 3.6 times under the NZE Scenario. The booming workforce has already begun to materialise in recent years, with labour market indicators such as job postings increasing fourfold between 2018 and 2022.

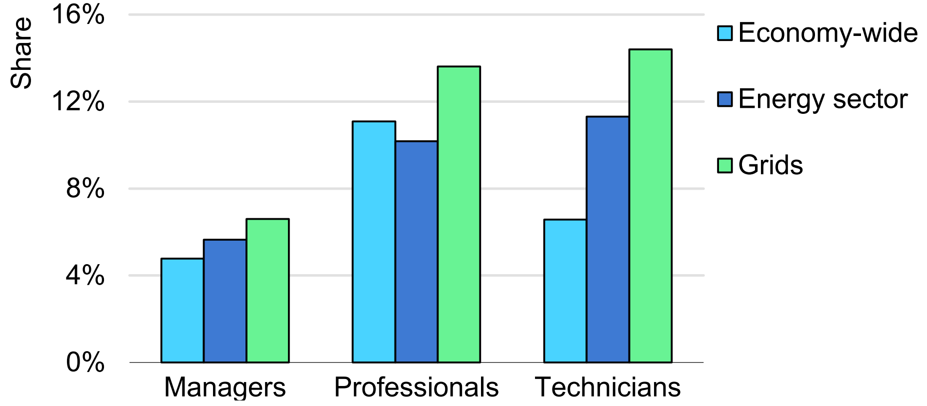
Skilled labour constraints are emerging as a key barrier to delivering grid infrastructure at the speed and scale required

While the grid workforce is expected to continue to grow globally in the coming years, a shortage of skilled workers is increasingly emerging as a bottleneck for development plans. As countries continue to scale up both investment and project pipelines, the availability of adequately trained personnel is becoming a limiting factor in delivering new infrastructure on time. This challenge has been further compounded by the fact that investment is not keeping pace with needs in many regions, making it more difficult to attract, train, and retain the talent required to support the expansion and modernisation of power networks.

Surveys and interviews conducted by the IEA with grid companies underscore these concerns, highlighting widespread skills shortages and a tight labour market. Over 40% of grid companies surveyed stated that they are experiencing "high" or "very high" competition for skilled labour, regularly losing candidates to other employers. Half of the respondents said they had to adjust hiring requirements due to shortages. The most commonly cited barriers to recruitment were a lack of grid-specific technical skills and a limited pool of qualified applicants. Labour and skills shortages are further compounded by an ageing grid workforce. IEA analysis shows that for every young person joining, 1.4 workers are aged 55 years or above – a ratio much higher than the economy-wide average.

Many of the challenges faced by the industry reflect the high-skilled nature of grid-related work, with 35% of roles classified as high-skilled compared to 27% across the broader energy sector, and 22% in the general economy. These roles include professionals, such as power systems engineers and grid planners. Technicians, who typically support engineering functions including system monitoring, equipment testing, and maintaining digital control systems like SCADA, account for 14.5% of the grid workforce, 30% more than the energy sector average.

Share of high-skilled occupations by sector, 2024



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The demand for these specialised roles underscores the urgency of expanding grid-tailored technical training programmes. However, some successful models are beginning to emerge. In France, the Grid School is an industry-wide initiative that provides hands-on training for grid technicians and skilled trades, launched through a collective effort involving the distribution company ENEDIS, the transmission system operator RTE, the Ministry of National Education, and other professional bodies. Since 2023, the number of participating vocational schools has grown from 45 to over 200, enabling more than 2 000 students with specialised training in electrical grids to join companies each year. In Italy, grid operator Enel launched initiatives linking schools and small and medium-sized enterprises (SMEs) to upskill students according to evolving energy sector needs and ensure a better match with future workforce demands. The company's Energie per la Scuola initiative, launched in 2022, partners with vocational schools to prepare students for entry-level roles in the electricity sector. Through this programme, Enel collaborated with 127 schools and 70 companies, reaching an estimated 10 000 students during career events. Of those students, approximately 1 700 went on to participate in training courses and were subsequently hired by Enel's suppliers. Companies support this effort by offering hands-on training at their facilities, giving students practical experience. These partnerships help schools, utilities, and suppliers work together to bridge the skills and employment gap, and are often tied to public tenders, helping align local training efforts with upcoming infrastructure projects.

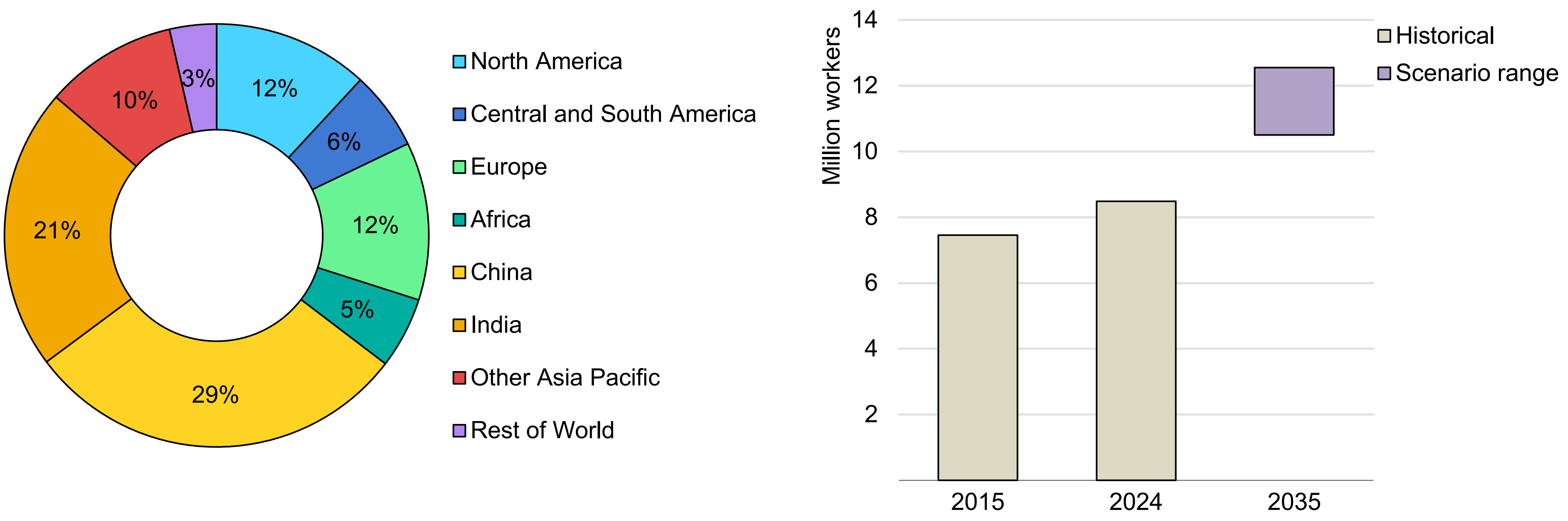
These initiatives are a positive evolution in workforce development, but significant challenges remain. Many training programmes are still too limited in scale to meet the growing demand, particularly in emerging markets. Curricula often lag behind the technological advancements in smart grids, automation, and digitalisation. There is also a shortage of qualified instructors with up-to-date industry experience, and limited alignment between education pathways and real-world job requirements. In some countries, vocational and technical careers still suffer from low social recognition, making it harder to attract young talent.

In addition to these obstacles, diverging technical standards and equipment norms across countries make it difficult to deploy grid workers during emergencies. Diverging equipment specifications, control systems, and voltage standards can delay or even prevent the deployment of grid workers from neighbouring countries during emergencies. For example, following storm-related outages in early 2025, several EU member states reported that efforts to bring in cross-border support were hampered because technical teams could not operate each other's equipment or connect to local systems due to incompatible protocols. The Centre on Regulation in Europe (CERRE) highlighted such challenges, noting that even where mutual assistance frameworks exist, divergent technical standards continue to limit the speed and effectiveness of emergency response efforts. Greater standardisation could enable more rapid workforce mobility when urgent grid support is required.

Labour and skills shortages in grids are further intensified by evolving skills requirements. With the growing share of variable renewable generation and an increasing need for improved data management, digitalisation is essential for maximising the efficiency of existing grids. The expanding role of AI and digital tools in grid operations underscores the need to update training curricula, increase cross-disciplinary learning pathways, and ensure workforce development keeps pace with the sector's technological transformation.

Power grid employment rises in all IEA scenarios, however greater investment in resilient and digitalised infrastructure is needed

Employment in grids by region in 2024, and by scenario in 2035



Note: The scenario range covers outcomes across three IEA scenarios: Current Policies Scenario (CPS), Stated Policies Scenario (STEPS), and the Net Zero Emissions by 2050 Scenario (NZE Scenario).

End-use sectors: Vehicles and efficiency technologies

End-use sectors employment by region and sector, 2024 (thousand workers)

	North America	Central and South America	Europe	Africa	China	India	Other Asia Pacific	Middle East	Eurasia	Global
ICE vehicles	2 000	700	2 900	200	3 900	1 200	2 700	200	300	**14 000**
EVs and batteries	300	<50	600	<50	2 400	<50	200	<50	<50	**3 500**
Industrial efficiency	300	200	400	200	1 200	300	600	300	100	**3 600**
Building retrofits	300	<50	200	100	100	<50	100	<50	<50	**800**
Efficient appliances and lighting	700	200	1 500	200	1 200	1 100	700	200	200	**5 900**
Heat pumps	200	<50	200	<50	300	<50	100	<50	<50	**800**
Other efficient and renewable HVAC	400	100	1 000	<50	1 000	100	300	<50	<50	**3 100**
End-use sectors: Total	**4 100**	**1 200**	**6 800**	**800**	**10 200**	**2 800**	**4 600**	**700**	**700**	**31 800**

Notes: ICE vehicles = internal combustion engine vehicles; EVs = electric vehicles; and HVAC = heating, ventilation and air conditioning. 'Other efficient and renewable HVAC' includes heating from geothermal, bioenergy, or solar thermal sources, as well as HVAC systems other than heat pumps which meet a certain level of efficiency requirement.

EVs remain the major engine of growth in vehicle employment, with China positioned to lead the global expansion

Vehicle manufacturing jobs rose in 2024 as sales ticked upward, with electric vehicle (EV) and EV battery jobs claiming an ever-larger share of the total, as employment in internal combustion engine (ICE) vehicles declined again. Together, these sectors added 300 000 jobs in 2024, up 1.8% y-o-y, for a total of over 17.5 million worldwide.

EV production continued its recent surge, now accounting for more than 20% of global car sales. Global EV manufacturing employment rose to 3.1 million in 2024, up 34% y-o-y, an almost fivefold increase since 2020, and more than ten times higher than in 2015. Increasing demand for EVs has also generated strong growth in the EV battery workforce, which grew to nearly 425 000 in 2024, compared to just 110 000 jobs in 2015.

However, manufacturing of ICE vehicles has not recovered from the significant blow to sales seen during the pandemic, with most major producing regions seeing output in 2024 falling to between 20% and 40% below their respective peaks in the 2010s. Following a brief rally in 2023, ICE vehicle manufacturing jobs fell again in 2024, down 490 000 jobs to 14 million, and 17% below the global peak of 17 million in 2017.

Although nearly 90% of vehicles sold globally are passenger cars, as opposed to light commercial and heavy-duty vehicles, they account for only 70% of global vehicle manufacturing employment, since the latter group are more labour intensive. These heavier vehicle segments have been slower to electrify, with only 6% of this workforce currently engaged in assembling and producing components for EVs.

China has consolidated its position as the leading producer of EVs and EV batteries in global markets, with jobs rising by 570 000 in 2024, to 2.4 million. Although China has long been a major producer of vehicles, with a global share of around 20-30% throughout the 2010s, it now accounts for more than 70% of EV production worldwide. Around 70% of the global EV workforce is employed in China, including 93% of EV battery jobs. At just over 6.3 million, total employment in motor vehicle manufacturing in China remains similar to 2015 levels, although its central role in the EV sector positions it for strong growth in the global automotive market.

Significantly, much of China's growth in EV employment is from Chinese brands that serve the domestic market, where EVs account for nearly half of all car sales. Chinese original equipment manufacturers (OEMs) accounted for more than 80% of domestic EV car production in 2024, up from two-thirds in 2021. The country's OEMs are also positioned to generate growth in EV manufacturing employment in other parts of the world, as BYD and GWM announced new production facilities in Brazil, Thailand, Indonesia and Malaysia, which will become operational in the coming years. These countries are also a significant source of export demand for

Chinese EVs, as they negotiate tariff exemptions for EVs in exchange for investment in local manufacturing facilities.

Mexico benefits from a similar relationship with advanced economy OEMs, as 70% of the country's EV car output was accounted for by United States-headquartered brands, with the remainder from European and Japanese manufacturers. At the same time, EMDE-based EV brands are beginning to gain a foothold in both domestic and foreign markets, with Viet Nam's VinFast, India's Tata, and Argentina's Tito each marking significant increases in EV production in 2024. With 80 000 EV jobs in 2024, EMDEs outside of China doubled their workforce in 2024, though they still represent a modest 2% share of global EV employment.

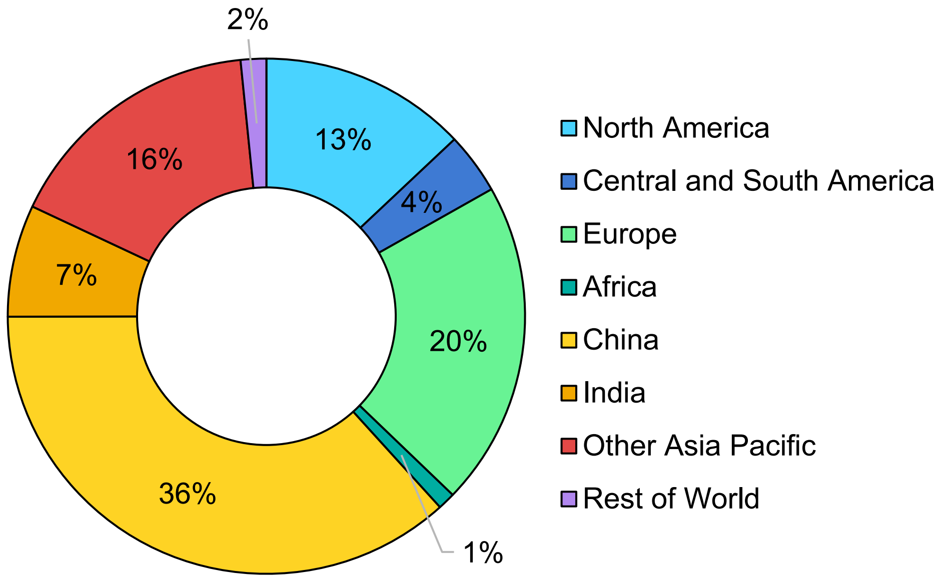
EMDEs outside of China have also historically formed an integral part of distributed supply chains in vehicle components. Around three-quarters of global vehicle manufacturing jobs are accounted for by the production of components such as drivetrains, chassis, windows and seats, as opposed to assembly of the vehicles themselves. Countries such as Mexico, Poland, and Southeast Asian economies have benefitted from lower labour costs and proximity to major regional centres of production to specialise in the supply of these parts. These factors have helped to contribute to total vehicle manufacturing employment of 3.9 million in EMDEs outside of China, with a 22% share of the global workforce, larger than their 18% share of world production would suggest.

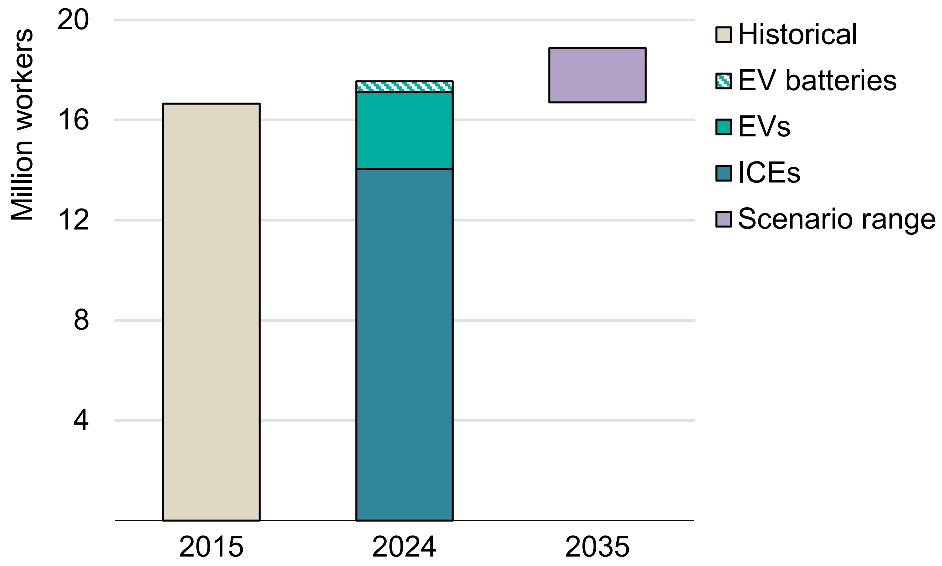
Advanced economies remain the largest employers in the vehicle manufacturing industry, with 7.3 million total jobs in 2024. The EV manufacturing workforce has seen strong gains in these regions in recent years, although the pace of growth stalled somewhat in 2024 (up 23% y-o-y) relative to that seen in China (30%) and other EMDEs (90%). In advanced economies, employment in ICE manufacturing fell by 1.5% y-o-y, extending the decline in recent years linked to lower ICE vehicle production.

The transition in employment from ICE vehicles to EV jobs seen over the past decade is set to continue in the coming years, although the pace of this transition varies across IEA scenarios. At the high-end, EV and EV batteries manufacturing could reach 15.2 million workers in 2035, with the low-end estimate at 6.1 million. In either case, this would represent a narrowing of the gap with ICE vehicle manufacturing, where the labour force could be within the range of 1.5 million at the low-end, and 12.8 million at the high-end.

EVs dominated growth in automotive employment in 2024, and will continue to drive significant increases to 2035

Employment in motor vehicles and EV batteries by region in 2015, 2024, and by scenario in 2035





Note: The scenario range covers outcomes across three IEA scenarios: Current Policies Scenario (CPS), Stated Policies Scenario (STEPS), and the Net Zero Emissions by 2050 Scenario (NZE Scenario).

Energy efficiency employment remained stable as investment momentum faltered in 2024

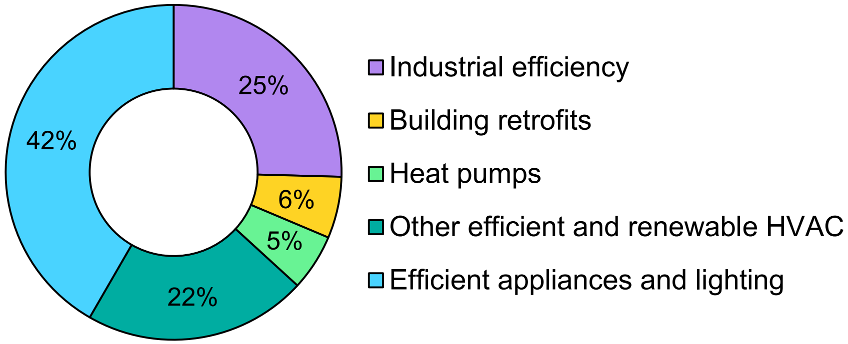
Global energy efficiency progress stabilised in 2024, as primary energy intensity, a metric used to assess efficiency, improved by 1%, consistent with 2023 levels. Efficiency-related investment is set to reach nearly USD 800 billion in 2025, up 6% y-o-y, but public support schemes have decreased amid budgetary constraints. Energy efficiency employment climbed by 1.9% to 14.3 million in 2024. Most workers are concentrated in China, the European Union and North America, but year-on-year job growth was fastest in emerging markets and developing economies like India (9%), Africa (4%) and other Asia Pacific (4%), all outpacing the global average.

Building energy efficiency employment reached 10.6 million in 2024, covering a range of subsectors. Efficient appliances and lighting represent the largest share at nearly 6 million jobs, followed by heat pumps and other efficient and renewable HVAC equipment, which together account for nearly 3.9 million workers. The buildings sector includes around 850 000 working in retrofitting activities.

Governments continue to adopt energy efficiency policies for buildings, which remain a catalyst for employment. Major initiatives include the launch of the Indonesian National Roadmap for Green Building Implementation, and the Indian Energy and Sustainable Building Code. However, jobs in renewable HVAC systems remain below pre-pandemic levels as investments in the sector have declined, rooted in high upfront costs and tight investment budgets.

Industry efficiency employment levelled off at 3.6 million, mostly due to a slowdown in China, which accounts for the largest share of the sector's workforce. A pronounced decline was seen in the European Union, where the limited availability of skilled labour posed a major investment challenge for firms. Nevertheless, the Asia Pacific region (outside of China) continued to boost employment in the sector.

Employment in end-use efficiency by subsector, 2024

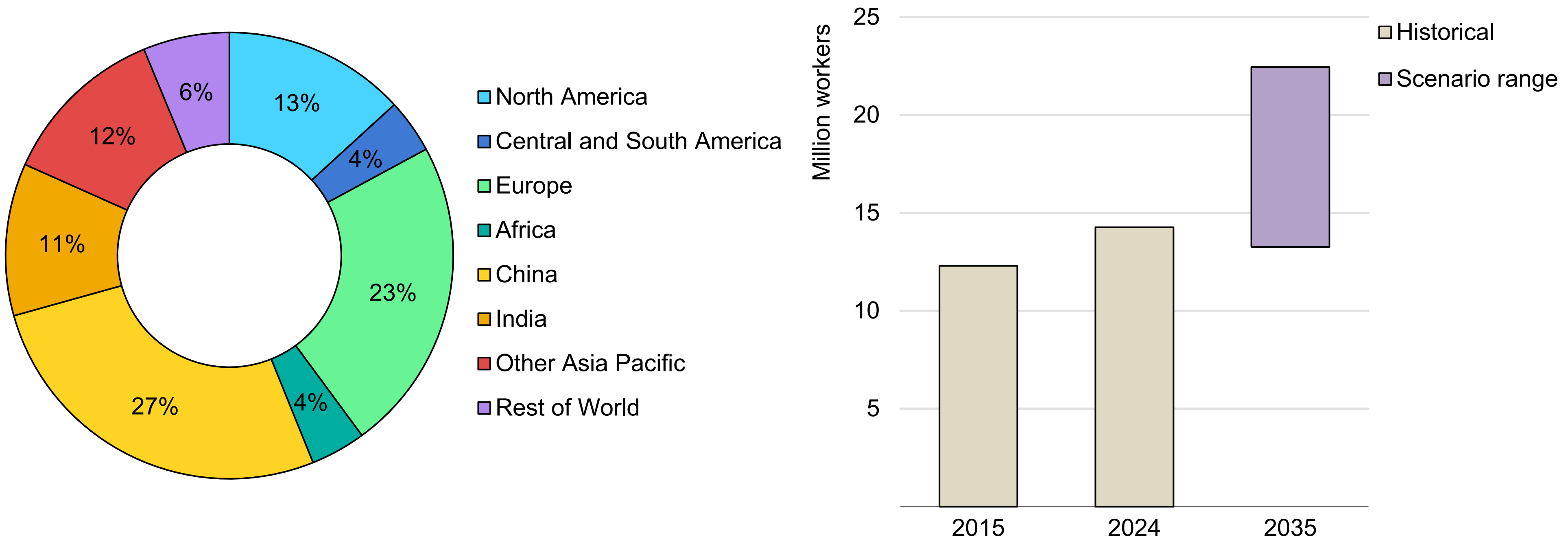


Notes: HVAC = heating, ventilation and air conditioning. 'Other efficient and renewable HVAC' includes heating from geothermal, bioenergy, or solar thermal sources, as well as HVAC systems other than heat pumps which meet a level of efficiency requirement.

The future demand for energy efficiency workers is largely influenced by policies. In the CPS, the energy efficiency workforce would slightly decline in the coming decade to 13.3 million, while in the STEPS and the NZE Scenario, it would continue to expand, to reach 16.3 million and 22.4 million workers, respectively.

Energy efficiency jobs are expected to grow gradually through 2035, fuelled by a take-off in the Asia Pacific region

Employment in energy efficiency by region in 2015, 2024, and by scenario in 2035



Note: The scenario range covers outcomes across three IEA scenarios: Current Policies Scenario (CPS), Stated Policies Scenario (STEPS), and the Net Zero Emissions by 2050 Scenario (NZE Scenario).

Heat pump work is in demand to satisfy ambitious growth targets

Global employment in heat pumps saw growth slow in 2024, to below 4%, compared to the 6% CAGR seen between 2020 and 2023, as sales fell due to discontinued or scaled back government subsidies and easing natural gas prices. The slowdown has been particularly pronounced in advanced economies, especially in Europe where heat pump jobs have first stagnated in 2023 and then declined in 2024. However, early indicators suggest a turnaround is in sight, and based on current policy settings, heat pump jobs are set to continue growing at a CAGR of 4.5% between 2024 and 2035.

In Europe, the increased demand for workers in heat pumps is in line with ambitious targets for installations. The European Union aims to install 60 million heat pumps by 2030 and meeting this demand would require 500 000 skilled workers across the bloc, up from about 165 000 in 2024. Germany and France reported that they would need 60 000 and 30 000 additional installers, respectively, to reach the 2030 target. In order to make heat pump installation accessible, in 2009, the European Union included an obligation for all member states to offer a heat pump certification programme or equivalent qualifications in the Renewable Energy Directive. The EUCERT Programme, administered by the European Heat Pump Association (EHPA), aims to offer a common level of qualification in 14 countries.

Outside of such initiatives, heat pump installer qualifications and certifications are very heterogenous from country to country. While some countries have certifications specific to heat pumps, others include them in wider HVAC certifications or require the installer to have both air conditioner and general heating certificates. Such constructs form a significant access barrier and may slow the qualification of heat pump installers.

Another key difference is whether certification is mandatory or voluntary – either to legally perform the trade or to access certain incentive schemes. Under current policies, heat pump incentive schemes often make certification more critical, even when not legally required. Most certifications are issued to individuals, but in some systems, companies can be certified instead – provided they demonstrate that their employees have the necessary skills, sometimes using voluntary personal certificates as evidence.

Finally, not all certificates cover the same skill sets. For example, plumbing skills are typically included only in regions where hydronic heat pumps make up a significant part of the market. In the European Union, handling refrigerants requires a separate mandatory F-Gas certificate and is therefore not part of general heat pumps certifications. And while all analysed heat pump certificates featured electrical work, a main differentiation is whether that includes advanced electrical works like intervening on the central switchboard.

Heat pump installer certifications vary widely among countries

Selected national and regional certification schemes for heat pump installers with main characteristics, 2025

					Skills included								
Country/ Region	**Certification**	**Granted to**	**Specific to heat pumps**	**Mandatory/ Voluntary**	**Electrical**	**Adv. electrical**	**Plumbing**	**Dimensioning**	**Efficiency**	**Refrigerants**	**Maintenance**	**Safety**	**Regulation**
Australia	RAC01 Full Refrigerant Handling Licence	Person	No	Mandatory	x					x	x	x	x
Canada	Red Seal Occupational Standard: Refrigeration and air conditioning mechanic	Person	No	Mandatory[1]	x	x	x		x	x	x	x	x
European Union	EHPA EUCert heat pump installer	Person	Yes	Voluntary[2]	x		x	x	x		x	x	x
France	QualiPAC	Person	Yes	Incentive	x		x	x	x			x	
Germany	Fachbetrieb Wärmepumpen	Company	Yes	Incentive	x		x	x	x		x	x	x
Italy	FER Certification	Person	Yes	Mandatory	x		x	x			x	x	x
Spain	RITE Certification	Person	Yes	Mandatory[3]	x		x				x	x	x
Sweden	SKVP CIN 2	Person	No	Voluntary[4]	x		x	x	x	x	x	x	
The Netherlands	BRL 6000-21 with ISSO 98	Company	Yes	Incentive	x		x	x	x		x	x	
United Kingdom	MCS MIS 3005	Company	Yes	Incentive	x		x	x	x		x	x	x
United States	NATE Certified HVAC Professional (CHP-5)	Person	No	Incentive[5]	x			x	x	x	x	x	x
United States (California)	C-20 Warm-Air Heating, Ventilating, and Air-Conditioning Contractor license	Person	No	Mandatory	x	x	x	x			x	x	x

Notes: Adv. electrical = Advanced electrical. Includes electrical works such as intervention on the switchboard that requires a full electrician license.
1 Mandatory in provinces where it is a compulsory trade.
2 Can be used to prove employee skills in some company-based certifications.
3 Can be replaced by higher education degrees or combining general heating and air conditioning certifications.
4 Certification has strong focus on safety, including refrigerants, but an F-Gas certification is still required.
5 Can be used to acquire EPA-recognised certifications like AHRI to access funding schemes.

Annexes

Methodology – the World Energy Employment model

Our quantitative model of energy employment provides estimates of demand for labour by energy technology, economic activity, region and year, based on a number of key drivers. This modelling adds value by providing comprehensive, detailed labour estimates for the energy sector with global coverage.

By contrast, most official labour statistics do not cover the energy sector in detail. While they often provide specific estimates for some traditional parts of the sector (such as oil and gas extraction), they do not do so for many other emerging subsectors, (such as solar power or building retrofits). The level of detail available is also not consistent across countries, and categories are not harmonised. In addition, energy jobs exist across economic activities, such as construction and manufacturing, which make the entire value chain difficult to capture without secondary surveys. The annual *World Energy Employment* report and the associated model aim to address this gap, although is not a replacement for official labour statistics or secondary survey-based approaches to assess energy employment.

Definition and scope of employment

Employment literature typically classifies job creation impacts by the following schema:

- ***Direct****: Jobs created to deliver a final project, product or operate a facility.*
- ***Indirect****: Supply chain jobs created to provide inputs to a final project or product.*
- ***Induced****: Jobs created by wages earned from the projects and spent in other parts of the economy, thereby creating additional employment.*

Our employment analysis includes all direct jobs and the indirect jobs from suppliers that manufacture key energy-producing or energy-using technologies. Other indirect jobs, as well as induced jobs, are not included. In employment literature, indirect jobs sometimes include jobs ‘supported’ by the purchase of equipment that is a key enabler for another job. For example, automobile manufacturing is a key enabler for delivery and taxi driving jobs. These ‘supported’ jobs are not included in our analysis. This sets a clear boundary around the jobs that energy investment creates to deliver new projects, or the jobs required to operate existing energy facilities.

Jobs are normalised to full-time employment (FTE) for consistent accounting. One FTE job represents one person’s work for one year at regulated norms (e.g. 40 hours a week for 52 weeks a year, excluding holidays). For example, two separate, six-month jobs are counted as one FTE job.

Employment numbers include our best estimate of the number of informal workers. In alignment with International Labour Organization (ILO) guidelines, informal employment includes all remunerative work that is not registered, regulated, or protected by existing legal or regulatory frameworks (ILO, 2003). This comprises own-account workers and workers employed in informal sector enterprises; contributing family workers; employees holding informal jobs; members of informal producers' co-operatives; and own-account workers engaged in the production of goods exclusively for own final use by their own household. Estimates are based on ILO data and a literature review of informality rates by region and sector.

Categorisation by energy technology

Employment modelling now covers 55 energy subsectors. The scope of energy employment technologies covered includes:

- *The **supply** of energy and related minerals, including: coal, oil and gas, modern bioenergy, critical minerals extraction (lithium, copper, cobalt and nickel), nuclear fuels and low-emissions hydrogen.*
- *The **power sector**, including: electricity generation by source (fossil fuels, renewables, and nuclear) and power transmission, distribution and storage.*
- *Energy **end uses**, including: vehicle manufacturing (plus electric vehicle batteries) and energy efficiency (in buildings and industry).*

Categorisation by economic activity

Employment is categorised not only by energy technology, but also by economic activity, in accordance with the International Standard Industrial Classification of All Economic Activities (ISIC), Revision 4 (UN DESA, 2008). In the employment module, the economic activities covered are grouped into the following five categories:

- ***Raw materials**: Agriculture (ISIC Section A) for bioenergy production and Mining and quarrying (ISIC Section B) for production of coal, oil and gas.*
- ***Manufacturing**: ISIC Section C.*
- ***Construction**: ISIC Section F.*
- ***Professionals and utilities**: Electricity, gas, steam, and air conditioning supply (ISIC Section D) as well as professional and business services (ISIC Sections J-N and S).*
- ***Wholesale and transport**: Wholesale and retail trade (Code G) plus Transportation and storage (Code H).*

Categorisation by asset life stage

Employment is also categorised according to whether the job is associated with building a new project or operating and maintaining existing energy infrastructure. This split is based on IEA energy balances and related data. For example, the ratio between capacity additions and installed total power capacity informs the split between power sector employees working on new projects versus existing power plants. The category "Operations and maintenance" (O&M) is used to refer to the workers in existing energy infrastructure or assets, as an indication of all ongoing jobs required to support the proper operation of an energy project.

Categorisation by occupation and skill level

Employment is also categorised by occupation and skill level, in line with the International Standard Classification of Occupations 2008 (ISCO-08) laid out by the ILO (ILO, 2025a). Occupations are defined by the ILO as a "set of jobs whose main tasks and duties are characterised by a high degree of similarity".

At the one-digit level, the ISCO-08 classification covers nine major occupational groups:

1. Managers
2. Professionals
3. Technicians and associate professionals
4. Clerical support workers
5. Service and sales workers
6. Skilled agricultural, forestry and fishery workers
7. Crafts and related trades workers
8. Plant and machine operators, and assemblers
9. Elementary occupations

Categorisation by scenario

The report's focus is predominantly on today's energy employment trends, but also includes projections to 2035 for three scenarios used in the *World Energy Outlook 2025*:

- *The Current Policies Scenario (CPS), which sets a pathway for the energy system in which no change in energy-related policies is assumed beyond what is already in law or regulation.*
- *The Stated Policies Scenario (STEPS), which takes into account policy intentions that have been formally proposed but not codified into current laws and regulations. The STEPS considers targets and pledges only insofar as they are backed by detailed policies, and does not assume that aspirational goals are met.*
- *The Net Zero Emissions by 2050 Scenario (NZE Scenario), a normative scenario which sets out a narrow but achievable pathway for the global energy sector to reach net zero CO_2 emissions by 2050, while meeting key energy-related Sustainable Development Goals.*

Estimating current employment

Our model uses IEA data on energy investment and spending, energy production and consumption, power capacity and electricity generation, and technology stocks, and sales as the basis to estimate global employment. These datapoints are multiplied by employment multipliers tailored to each energy subsector to estimate total employment in the base year.

Multipliers are produced via a comprehensive review of labour statistics, industry and firm-level data, academic research, and using wage data for each subsector and region where available. Multipliers and employment estimates have been tested with companies within

IEA's Energy Business Council, peer reviewers, academics, industry groups and international organisations such as the IMF and ILO.

Estimating job multipliers

Broadly, three types of multipliers are used in the model, based on investment (jobs per million US dollars invested), volumetric data (jobs per unit produced), and facilities and capacity in operation (jobs per unit capacity). Multipliers vary by region to reflect differences in the local cost of labour and worker productivity. They also vary by energy subsector, reflecting different project cost breakdowns, in other words how much of each million US dollars invested is allocated to spending on labour versus materials. The primary sources used to estimate multipliers include:

- *Wage data from national statistics and international databases, for investment multipliers.*
- *Legal financial filings that provide information on employment and revenue, cost breakdowns for projects, firm revenues and average wages.*
- *Academic, intergovernmental research and modelled estimates.*
- *Individual company and industry group estimates.*

Government surveys of businesses were prioritised, when available with sufficient detail, to support the subsectoral analysis. Employment and financial information were extracted from the annual reports of major companies in each sector, though this method could only be used for sectors with a high degree of consolidation in major firms that are publicly listed. Material from academic and industry sources was screened to ensure harmonised definitions and reference values were adjusted to adhere to the framework described. Where values from these sources were unavailable, estimates were based on employment multipliers for similar technologies. Where wage data specific to energy industries is not available, generalised wage data by region is used.

Allocating employment throughout project development stage

Our employment estimates comprise both jobs in the operation of existing assets, and jobs associated with the build-out of new projects. The latter are estimated based on overnight investment totals for each project. However, the totals recorded for overnight investment fall in the year of project completion, whereas jobs are generated throughout the project development phase, in the years leading up to this completion date. In our model, we therefore spread the overnight investment totals across prior years, based on typical project delivery timelines for each technology. These spread investment totals represent an estimate of the investment funds spent in each year of the project planning and construction phases. Employment in the build-out of new projects is then estimated by multiplying these investment spending estimates by the employment multipliers.

Calibration to available employment data

A rich collection of employment data from external sources is collected annually, to serve as benchmarks for the calibration of multipliers. These data sources include:

- *National statistics for all major countries*
- *ILOSTAT databases (ILO, 2025c)*
- *United Nations Industrial Development Organization (UNIDO) IndStat database (UNIDO, 2023)*
- *Reports by international organisations and industry associations*
- *Academic literature*
- *Annual reports of major companies*
- *Company interviews*

Where data is collected from broad labour databases, we focus on categories relevant to energy, including the complete list of ISIC codes presented in the United Nations' International Recommendations for Energy Statistics (IRES, 2011). Our scope includes codes such as 0510 (mining of hard coal), 0610 (extraction of crude petroleum), 0620 (extraction of natural gas), 1920 (manufacture of refined petroleum products), 2910 (manufacture of motor vehicles), 3510 (electric power generation, transmission and distribution), 4322 (plumbing, heat and air conditioning installation), and 4930 (transport via pipeline), and others. A mapping between ISIC and other classifications such as the North American Industry Classification System (NAICS) or the European Nomenclature of Economic Activities (NACE) enabled a harmonised approach to collecting official statistics from different countries. Data of the highest granularity available is used in each case.

Allocating employment across global supply chains

For energy technologies with highly globalised supply chains, employment estimates reflect where upstream manufacturing capacity is located in the world, rather than where the corresponding technologies are deployed. Data about the regional manufacturing capacity for specific technologies (such as solar PV panels, wind turbines, gas turbines, etc.) was sourced from internal IEA databases produced for the *Energy Technology Perspectives* (ETP) report, as well as other sources, and the global total of manufacturing jobs was redistributed across Global Energy and Climate (GEC) Model regions accordingly. For technologies that have very localised production, such as building materials and biofuels, all manufacturing jobs were assumed to be created locally.

Outlook for employment

Projections by scenario are based on IEA scenario results for all of the same inputs that were used to estimate base year employment. These are multiplied by the corresponding job multipliers – which are differentiated by region and energy industry – to estimate total jobs in coming years until 2035, and thereby estimate changes in job gains and losses relative to the base year, as well as what portion of existing jobs are maintained.

Estimating labour productivity improvements

Multipliers evolve over time to reflect assumptions about labour productivity improvements. Where industry-specific historic time series of employment and corresponding production (or another relevant metric) are available, the historic rate of change is extended forward. Where specific time series are not available, data from the UN and ILO on value added by economic activity and employment by economic activity are used to compute historic labour productivity improvement rates by region and applied to future multiplier improvements.

Note on revisions of historical employment estimates

For the first time, this report features historical employment estimates back to 2015, allowing for a more rigorous assessment of medium-term trends.

In addition, *WEE 2025* includes noteworthy baseline adjustments as part of our continued efforts to maintain the world's most up-to-date and comprehensive energy labour force inventory data. Together, these baseline changes resulted in an increase of 6.7 million in our estimate of total energy employment, compared to previously published estimates.

The largest upward revisions result from an extension of the scope of our coverage of energy employment. Specifically, our estimates now include new categories of employment in energy efficiency, including in efficient lighting (covering LED systems and smart lighting controls) and buildings renewables. Together, these added an additional 5.8 million jobs to our 2024 employment estimates.

Other changes to historical estimates were the result of model refinements. For vehicle manufacturing, employment is now modelled separately by vehicle weight class, rather than as a single group, allowing the model to capture the higher labour intensity of heavier vehicle categories. In addition, the model now incorporates employment in vehicle component manufacturing, including in regions that do not assemble vehicles but contribute significantly to the supply chain. On the whole, these changes resulted in an increase of 3.4 million jobs compared to previous estimates for 2024.

Finally, model development work was carried out for bioenergy technologies. Employment is now disaggregated across biogas, bioliquids, and solid biomass, rather than treated as an aggregate category. This more refined approach resulted in greater accuracy in estimates of overall employment in bioenergy, which has fallen by 1.2 million compared to previous reports. Other changes have resulted from updates published in 2025 to official employment statistics and input data on energy investment, capacity and production, which have resulted in a net reduction of 1.3 million jobs in 2024, compared to the provisional estimates published in *WEE2024*.

Methodology – IEA employment surveys

The *WEE 2025* report draws on a new set of dedicated surveys conducted by the IEA. The purpose of these surveys was to gather new insights on workforce dynamics across the energy sector through the perspectives of energy companies, labour unions, and educational organisations, which animate and contextualise the findings of the energy employment model.

When referenced as such, the analysis and figures presented throughout the *WEE* report are based on responses from the following targeted surveys:

- *IEA Industry Employment Survey*
- *IEA Labour Employment Survey*
- *IEA Educators' Employment Survey*

The *IEA Industry Employment Survey* collected the insights of 429 respondents, from 56 countries, with every region represented. Surveyed companies spanned major industries such as mining and extractives, manufacturing, and utilities, and operated across a wide range of energy subsectors including power generation, fuels, grids, vehicles, and energy efficiency. Over 60% of the responses came from small and medium-sized enterprises (SMEs) with 1-249 employees, and the rest were received from large companies with 250+ employees. The survey included a special focus on grids and nuclear, with dedicated questionnaires designed to capture sector-specific insights.

The *IEA Labour Employment Survey* and gathered 213 responses, covering 65 countries, from energy workers and workers' representatives, including trade unions.

The *IEA Educators' Employment Survey* collected 92 responses from individuals conducting energy training in 36 countries, including those working at vocational schools, universities, and in internal training departments within energy companies.

Across the three surveys, 52% of respondents came from emerging market and developing economies (EMDEs), and 48% from advanced economies.

The data was collected via three separate online questionnaires, each tailored to either energy firms, energy workers and their representatives, and educators specialised in the energy sector. The data collection period started on 10 April 2025 and finished on 10 June 2025.

The surveys included various types of questions, such as multiple-choice questions, Likert scale questions, dropdown questions and open-ended questions. An example from the questions asked is presented below.

Survey question example from the IEA Industry Employment Survey 2025

15. For each occupational group for which you hire, please indicate the level of difficulty finding qualified applicants compared to the average hiring process.

	Very difficult	Somewhat difficult	Not difficult	Very easy	N/A
Managers (e.g. project manager, grid operations manager)	○	○	○	○	○
Professionals (e.g. engineers, R&D)	○	○	○	○	○
Technicians (e.g. wind turbine technicians, substation technician, petroleum technician)	○	○	○	○	○
Craft and related trades workers (e.g. electrician, lineworker, welder, construction workers)	○	○	○	○	○
Plant and machine operators, and assemblers (e.g. power plant operators, control room operators)	○	○	○	○	○
Service and sales workers (e.g. customer service representative)	○	○	○	○	○
Skilled agricultural, forestry and fishery workers (e.g. forestry machine operator for bioenergy, vegetation management workers)	○	○	○	○	○

Definitions and classifications

Education and training

As a part of this report's special focus on the Future of Energy Skills, the IEA has conducted a thorough analysis of education and training outcomes and requirements for the energy sector. The definitions and classifications used in this report relating to education and training generally follow those outlined in the International Standard Classification of Education 2011 (ISCED-11), except where otherwise stated.

The main category of education and training considered in this report is formal educational programmes delivered by educational institutions. The data presented on these programmes follow the ISCED-11 classification, which divides educational programmes and qualifications into different levels, fields, and orientations.

Education levels are presented as an ordered set from 0 to 9, from early-childhood education at the lowest level, to doctoral or equivalent level at the highest. These ten levels can be further grouped into early childhood (0), primary (1), secondary (2-3), post-secondary non-tertiary (4) and tertiary (5-8) levels.

For levels 2-5 (lower secondary to short-cycle tertiary), the ISCED classification additionally distinguishes the orientation of a programme, which can be either general or vocational. Vocational education is defined as education programmes that are designed for learners to acquire the knowledge and skills specific to a particular occupation, trade, or class of occupations or trades. The term "general" education covers all non-vocational programmes, and is defined as education programmes that are designed to develop learners' general knowledge and skills, often to prepare participants for more advanced education programmes at a higher ISCED level.

For vocational and tertiary degrees, the ISCED classification additionally distinguishes among a set of fields of education (also known as subjects or disciplines). The categories used in this report follow the ISCED Fields of Education and Training 2013 (ISCED-F 2013) classification, which groups all educational programmes into 11 broad fields, numbered from 0 to 10.

Engineering, manufacturing and construction degrees (field code 07) are of particular interest in the context of the energy sector, as these subject areas (for both general and vocational qualifications) will be most relevant for those involved in design, construction, operation and maintenance of physical energy infrastructure. For convenience, these engineering, construction and manufacturing qualifications are referred to in this report as "energy-relevant" qualifications.

A wider category of interest is science, technology, engineering and mathematics (STEM) education, which is of broader relevance to the energy sector, particularly in R&D and innovation contexts. Using the ISCED-F classification, STEM education is defined as the group including ISCED field codes 05, 06 and 07.

ISCED-11 education levels

Broad education level	ISCED-11 level code	ISCED-11 level name	Orientation(s)	**Disaggregation by field** of education
Early childhood	0	Early childhood education	General	No
Primary	1	Primary education	General	No
Secondary	2	Lower secondary education	General or Vocational	Yes, for vocational only
Secondary	3	Upper secondary education	General or Vocational	Yes, for vocational only
Post-secondary non-tertiary	4	Post-secondary non-tertiary education	General or Vocational	Yes, for vocational only
Tertiary	5	Short-cycle tertiary education	General or Vocational	Yes
Tertiary	6	Bachelor's or equivalent level	General	Yes
Tertiary	7	Master's or equivalent level	General	Yes
Tertiary	8	Doctoral or equivalent level	General	Yes
Other	9	Not elsewhere classified	General	No

ISCED-F 2013 fields of education

ISCED-F 2013 field code	ISCED-F 2013 field name	STEM field	"Energy-relevant" field
00	Generic programmes and qualifications	No	No
01	Education	No	No
02	Arts and humanities	No	No
03	Social sciences, journalism and information	No	No
04	Business, administration and law	No	No
05	Natural sciences, mathematics and statistics	Yes	No
06	Information and communication technologies	Yes	No
07	Engineering, manufacturing and construction	Yes	Yes
08	Agriculture, forestry, fisheries and veterinary	No	No
09	Health and welfare	No	No
10	Services	No	No

Note: STEM = science, technology, engineering and mathematics.

This report also considers education and training delivered outside of formal educational institutions.

Much of the knowledge and skills required for the performance of a particular occupation is acquired in the workplace. This includes work-based education, which is education or training that takes place in a real work environment and is an integral part of a formal education programme. Work-based education is typically included as a core component of apprenticeships, which combine classroom-based instruction with structured, work-based learning under the guidance of experienced professionals.

Formal education of this kind can be distinguished from both non-formal education and informal learning. Non-formal education is education that is institutionalised, intentional and planned by an education provider, but does not necessarily apply a continuous pathway-structure. It is therefore considered an alternative or a complement to formal education, which in contrast does imply a progression through formally recognised and standardised levels. Non-formal education is typically provided in the form of short courses, workshops or seminars. Non-formal education delivered in a workplace context is referred to as “on-the-job” (OTJ) training. Meanwhile, informal learning refers to learning that is not delivered through an organised course or by an institution, but is gained through activities and interactions in the workplace or through self-directed study.

Formal and non-formal education programmes typically award a qualification upon completion of the programme. Definitions of terms used to refer to different types qualifications (degrees, certifications, certificates, etc.) are not standardised across different national systems, so for this report we use the following definitions for convenience:

- Degrees refer to qualifications awarded at the end of a formal tertiary education programme.
- Vocational qualifications are awarded upon completion of a formal vocational education programme.
- Certificates refer to qualifications awarded from non-formal educational programmes such as short-courses.
- Certification refers to a document which recognises and validates certain skills or competencies. Certifications are typically awarded upon successful completion of an examination, in some cases with additional criteria, but are not necessarily associated with an organised programme of learning. Certifications are often awarded and recognised by an industry body, and are typically not recognised as part of formal educational frameworks.
- A licence is a form of certification which is considered as a requirement (legal or otherwise) in order to perform in a certain profession, such as an electrician. Licenses typically require completion of an organised programme of learning, often in the form of a vocational education programme.

Types of qualifications: Degrees, certificates, certifications, and licenses

Credential Type	Definition	Purpose	Typical Duration	Example	Training Modality	Notes
Degree	Academic qualification awarded upon completion of a tertiary educational programme	In-depth knowledge and theoretical understanding in a field	Several years	Master's in Electrical Engineering	University	Often required for high-level roles; strong theoretical foundation
Vocational qualification	Qualification awarded upon completion of a vocational educational programme	Knowledge, skills and competencies specific to a particular occupation, trade, or class of occupations or trades	Several years	NVQ Level 3 Electrical Installation / Maintenance	Vocational or technical school	Often required for trades and other vocational occupations
Certificate	Proof of completing a specific course or programme	Verifies education or training in a specific area	A few days to several months	Solar Energy International Certificate	Short course	Does not necessarily mean the person is "certified"; often a step toward a license or certification
Certification	Awarded after passing an exam and meeting criteria (e.g. work experience); usually from a non-governmental/industry body	Validates skills and competency in a professional area	Varies	NABCEP Certified Solar Installer	Varies – can involve short course, or self-directed learning	Usually voluntary but highly valued
License	Government/regulatory approval to legally practice a profession	Legally authorises someone to work in regulated professions	Varies (includes training plus exam)	Electrician License	Apprenticeship, technical school, on-the-job training	Often mandatory; requires education, experience, and an exam

Occupations, skill levels, and educational matching

For the first time, the *WEE 2025* report presents modelled employment results at the occupational level. The occupational dimension in our model follows the International Standard Classification of Occupations 2008 (ISCO-08), at the one-digit level, covering nine major occupational groups:

1. *Managers*
2. *Professionals*
3. *Technicians and associate professionals*
4. *Clerical support workers*
5. *Services and sales workers*
6. *Skilled agricultural, forestry and fisheries workers*
7. *Craft and related trades workers*
8. *Plant and machine operators, and assemblers*
9. *Elementary occupations*

These occupational employment results are also presented in this report by grouped skill level. We classify managers, professionals, and technicians as high-skilled occupations. Medium-skilled occupations include clerical support workers, services and sales workers, skilled agricultural workers, craft and related trades workers, and plant and machine operators. Low-skilled workers include elementary occupations.

Each occupation and skill level is associated with a typical requirement for attainment of a particular education level, in line with the ILO's approach to assessing educational mismatch. Attainment of primary education is considered as a normal minimum requirement for low-skilled jobs; for medium-skilled jobs secondary or post-secondary non-tertiary education is a normal requirement; and high-skilled jobs usually require some form of tertiary education. Workers with educational attainment above and below the typical requirement are considered overqualified and underqualified, respectively. The table below outlines the standard matching of occupations, educational requirements, and characteristic tasks normally observed at each skill level.

In this report, the IEA has assessed the adequacy of vocational educational capacity to fill occupational demand for these vocational roles in the energy sector. For this purpose, we define "applied technical roles" in the energy sector as those occupations typically requiring some kind of energy-relevant vocational or short-cycle education, including technicians, crafts and trades workers, and plant and machine operators.

Occupations, skill levels and typical educational requirements

Skill level	Occupational group (ISCO-08)	Typical minimum educational requirements (ISCED-11 levels)	Characteristics
High-skilled	1. Managers 2. Professionals 3. Technicians and associate professionals*	ISCED Levels 5-8: Tertiary education	• Performance of complex technical and practical tasks and/or complex problem solving and decision making, in either case requiring an extensive body of specialised knowledge • Extended levels of literacy and numeracy and well-developed to excellent interpersonal communication skills
Medium-skilled	4. Clerical support workers 5. Service and sales workers 6. Skilled agricultural, forestry and fishery workers 7. Craft and related trades workers* 8. Plant and machine operators, and assemblers*	ISCED Level 2: Lower secondary education ISCED Level 3: Upper secondary education ISCED Level 4: Post-secondary non-tertiary education.	• Performance of tasks such as operating, maintaining and/or repairing machinery and electronic equipment; driving vehicles; manipulation and storage of information • Simple to advanced literacy and numeracy is generally required; some occupations may require significant manual dexterity
Low-skilled	9. Elementary occupations	ISCED Level 1: Primary education	• Performance of simple/routine physical/manual tasks • Literacy and numeracy, if required, are not a significant portion of work

* Included in the definition of applied technical roles in the energy sector.

Glossary

Academic education: Formal education programmes, typically offered by universities or higher education institutions, that focus on theoretical knowledge and lead to degrees in fields such as engineering, environmental science, or energy economics.

Applied technical roles: Occupations in the energy sector which typically require some form of vocational education. Includes technicians, craft and trades workers, and plant and machine operators and assemblers.

Apprenticeship: Combines classroom-based instruction with structured, work-based learning under the guidance of experienced professionals.

Certification: Assessment and formal recognition of specific competencies – often related to technical or digital tasks – acquired through various means, including informal or non-formal learning.

Education level: A grouping of education programmes in relation to gradations of learning experiences, as well as the knowledge, skills and competencies which each programme is designed to impart. Examples of education levels include primary education and upper secondary education.

Employment: All persons of working age who are engaged in any activity to produce goods or provide services for pay or profit, whether this is in paid employment or self-employment. Excludes unpaid trainee work, volunteer work, and own-use production work. Employment estimates in this report are expressed in full-time equivalent (FTE) terms. Used synonymously in this report with “workers”, “jobs”, and “workforce”.

Energy-related education: Refers to educational qualifications in the fields of engineering, manufacturing and construction (ISCED-F 2013 field code 07).

Field of education: The broad domain, branch or area of content covered by an education programme or qualification. Can also be referred to as a "subject" or “discipline”.

General education: Education programmes that are designed to develop learners’ general knowledge, skills and competencies, as well as literacy and numeracy skills, often to prepare participants for more advanced education programmes at the same or a higher ISCED level and to lay the foundation for lifelong learning. Covers all education programmes not categorised as vocational education (see below).

Informal employment: Includes all persons in employment that are not registered, regulated or protected by existing legal or regulatory frameworks, as well as non-remunerative work undertaken in an income-producing enterprise in accordance with guidelines concerning a statistical definition of informal employment by the 17th International Conference of Labour Statisticians.

Informal learning: Learning that is not delivered through an organised course or by an institution, and but is gained through activities and interactions in the workplace or other social contexts, or through self-directed study.

Job: See “Employment”.

Labour force: All individuals who fulfil the requirements for inclusion among the employed or the unemployed. The employed are defined as those who work for pay or profit for at least one hour a week. The unemployed are defined as people without work but actively seeking employment and currently available to start work.

Low-emissions: In power, low-emissions energy includes generation from renewable sources, nuclear and fossil fuels fitted with CCUS; battery storage; and electricity grids. In end-use applications, low-emissions energy includes electric vehicles and energy efficiency in buildings and industry. In fuel supply, low-emissions energy includes modern bioenergy, low-emissions hydrogen and nuclear fuels.

Non-formal education: Education provided by educational institutions, but sitting outside of recognised formal educational frameworks, in that it does not imply a progression through standardised levels. Typically provided in the form of short courses, workshops or seminars, and considered as an alternative or a complement to formal education.

Occupation: A set of jobs whose main tasks and duties are characterised by a high degree of similarity.

On-the-job training: Learning that occurs directly in the workplace, enabling workers to acquire new skills or adapt existing ones in response to evolving technologies or job requirements, often without formal certification.

Unabated fossil fuels: Includes energy resources based on coal, oil, natural gas, or peat. In fuel supply, unabated energy includes coal, oil, natural gas extraction, refining and processing. In power, unabated fossil fuel energy includes generation from coal, oil or natural gas that is not abated through CCS or CCUS technology. In end-use applications, unabated fossil energy includes internal combustion engine (ICE) vehicles.

Vocational education and training (VET): Education and training programmes that are designed for learners to acquire the knowledge, skills and competencies specific to a particular occupation, trade, or class of occupations or trades.

Worker: see “Employment”.

See the IEA glossary for a further explanation of many of the terms used in this report.

Regional groupings

Advanced economies: Australia, Austria, Belgium, Bulgaria, Canada, Chile, Colombia, Costa Rica, Croatia, Cyprus[1,2], Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Malta, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Republic of Türkiye (Türkiye), United Kingdom and United States.

Africa: Algeria, Angola, Benin, Botswana, Cameroon, Côte d'Ivoire, Democratic Republic of the Congo, Egypt, Eritrea, Ethiopia, Gabon, Ghana, Kenya, Libya, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Tunisia, Republic of the Congo (Congo), Senegal, South Africa, South Sudan, Sudan, United Republic of Tanzania (Tanzania), Togo, Zambia, Zimbabwe and other African countries and territories.

Asia Pacific: Australia, Bangladesh, Brunei Darussalam, Cambodia, Chinese Taipei, Democratic People's Republic of Korea (North Korea), India, Indonesia, Japan, Korea, Lao People's Democratic Republic (Lao PDR), Malaysia, Mongolia, Myanmar, Nepal, New Zealand, Pakistan, People's Republic of China (China), Philippines, Singapore, Sri Lanka, Thailand, Viet Nam and other Asia Pacific countries and territories.

Central and South America: Argentina, Plurinational State of Bolivia (Bolivia), Brazil, Chile, Colombia, Costa Rica, Cuba, Curaçao, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Nicaragua, Panama, Paraguay, Peru, Suriname, Trinidad and Tobago, Uruguay, Bolivarian Republic of Venezuela (Venezuela), and other Central and South American countries and territories.

China: Includes the People's Republic of China and Hong Kong.

Emerging market and developing economies (EMDEs): All countries not included in the advanced economies regional grouping.

Eurasia: Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Russian Federation (Russia), Tajikistan, Turkmenistan and Uzbekistan.

Europe: Albania, Austria, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus[1,2], Czech Republic, Denmark, Estonia, Finland, France, Germany, Gibraltar, Greece, Hungary, Iceland, Ireland, Israel, Italy, Kosovo, Latvia, Lithuania, Luxembourg, Malta, Montenegro, Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Serbia, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Republic of Moldova, Republic of Türkiye (Türkiye), Ukraine and the United Kingdom.

North America: Canada, Mexico and the United States.

Middle East: Bahrain, Islamic Republic of Iran (Iran), Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic (Syria), United Arab Emirates and Yemen.

[1] Note by Republic of Türkiye: The information in this document with reference to “Cyprus” relates to the southern part of the island. There is no single authority representing both Turkish and Greek Cypriot people on the island. Türkiye recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Türkiye shall preserve its position concerning the “Cyprus issue”.
[2] Note by all the European Union Member States of the OECD and the European Union: The Republic of Cyprus is recognised by all members of the United Nations with the exception of Türkiye. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

Abbreviations and acronyms

AI	Artificial intelligence
ASM	Artisanal and small-scale mining
BLS	Bureau of Labour Statistics
CAGR	Compound annual growth rate
CCS	Carbon capture and storage
CCUS	Carbon capture, utilisation and storage
CPS	Current Policies Scenario
DAC	Direct air capture
DRC	Democratic Republic of the Congo
EHPA	European Heat Pump Association
EMDE	Emerging market and developing economy
ERI	Economic Research Institute
EU	European Union
EUR	Euro
EURES	EURopean Employment Services
EV	Electric vehicle
FTE	Full-time equivalent
G20	Group of 20
GDP	Gross domestic product
GW	Gigawatt
HVAC	Heating, ventilation and air conditioning
ICE	Internal combustion engine
IEA	International Energy Agency
ILO	International Labour Organization
IMF	International Monetary Fund
ISCED	International Standard Classification of Education
ISCED-F	International Standard Classification of Education Fields of Education and Training
ISCO	International Standard Classification of Occupations
ISIC	International Standard Industrial Classification of All Economic Activities
LFS	Labour force survey
LNG	Liquefied natural gas
MER	Market exchange rates
Mt	Million tonnes
MW	Megawatt
NEET	Not in employment, education or training
NZE	Net Zero Emissions by 2050 Scenario
ODA	Official Development Assistance
OECD	Organisation for Economic Cooperation and Development
OEM	Original equipment manufacturer
OJT	On-the-job training
PPP	Purchasing power parity

PV	Photovoltaic
R&D	Research and development
RD&D	Research, development and demonstration
STEM	Science, technology, engineering and mathematics
STEPS	Stated Policies Scenario
TVET	Technical vocational education and training
UAE	United Arab Emirates
UK	United Kingdom
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNIDO	United Nations Industrial Development Organization
US	United States
USD	United States dollar
USEER	United States Energy and Employment Report
VET	Vocational education and training
VR	Virtual Reality
WEE	World Energy Employment report

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