World Energy Employment 2023

INTERNATIONAL ENERGY AGENCY

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Abstract

The second edition of the *World Energy Employment* (WEE) report tracks the evolutions of the energy workforce from before the pandemic, through the global energy crisis, to today. The report provides a comprehensive stock-take of energy employment with estimates of the size and distribution of the labour force across regions, sectors, and technologies. The dataset provides granularity on workers along the entire energy value chain, covering fossil fuel supply, bioenergy, nuclear, low-emissions hydrogen, power generation, transmission, distribution, and storage; and key energy-related end uses, including vehicle manufacturing and energy efficiency for buildings and industry, among other segments. Additionally, WEE 2023 includes for the first time employment data for the extraction of selected critical minerals, including copper, cobalt, nickel and lithium.

This year's report also benchmarks energy employment needs against an outlook to 2030 across IEA scenarios, outlining key policies that could help countries cultivate and maintain a skilled energy workforce throughout the energy transition.

WEE 2023 explores in depth the risks of skilled labour shortages and how this may influence the outlook for the industry and includes new analysis on skills, certifications, wages, and job postings. The findings signal that the ongoing shifts in energy employment will continue and can present both opportunities and risks. With the right enabling measures in place, policy makers, energy companies, labour representatives, educational and vocational training institutions, and other key stakeholders can work in concert to avoid labour transition risks while ensuring the transition to cleaner sources of energy remains people-centred.

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Table of contents

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Executive summary

The second edition of the *World Energy Employment* report arrives at a time of extreme flux in the global energy sector. The last three years saw the Covid-19 pandemic precipitate sweeping layoffs, including in the energy industry, followed by the global energy crisis. Governments pursued urgent measures to ensure energy security, including unprecedented financial support for clean energy. Clean energy investment has grown by 40% over the past two years, creating strong demand from leading energy firms to bring on more workers in clean sectors. Still, the fragile global economic recovery and fresh geopolitical uncertainties continue to cast a shadow over the outlook for the industry and workers. Some regions continue to face tight labour markets and high interest rates, contributing to cautious hiring in parts of the energy sector. The *World Energy Employment (WEE) 2023* report tracks employment trends over the entire energy supply chain through this turbulent period — by fuel, technology, sector, and region. The report also provides an outlook to 2030 for energy employment needs by sector across IEA scenarios, outlining key policies that could help countries cultivate and maintain a skilled energy workforce throughout the transition.

More people work in the energy sector today than in 2019, almost exclusively due to growth in clean energy, which now employs more workers than fossil fuels. Energy employment reached nearly 67 million in 2022 — growing by 3.4 million over pre-pandemic levels. Clean energy sectors added 4.7 million jobs globally over the same period and stand at 35 million, while fossil fuels jobs recovered more slowly after layoffs in 2020 and remain around 1.3 million below pre-pandemic employment levels, at 32 million. As a result, clean energy employment surpassed that of fossil fuels in 2021. More than half of job growth in this period is attributable to just five sectors: solar PV, wind, electric vehicles (EVs) and battery manufacturing, heat pumps and critical minerals mining. These five sectors employ around 9 million workers today. Solar PV is the largest of these sectors, at around 4 million jobs, while manufacturing of EVs and their batteries was the largest source of growth, adding globally well over 1 million jobs since 2019. Many of the new jobs are in construction and manufacturing, which represent over half of energy jobs today, and grew by 2.6 million jobs since 2019.

The uptick of clean energy jobs occurred in every region of the world, with China's energy workforce undergoing an unprecedented reorientation toward clean energy. Clean energy jobs were the major driver of energy job growth in virtually all parts of the world over the last three years, but several regions also saw fossil fuel employment rise above 2019 levels, notably India, Indonesia, and the Middle East. In regions that saw declines in fossil fuel jobs from 2019-22, clean energy outweighed these losses in all but a few, notably Russia and North Africa. China, home to the largest energy workforce today with nearly 30% of the global total, witnessed the largest rebalancing over the 2019-22 period, with clean energy jobs growing by 2 million and fossil fuel-related jobs falling by 600 000, largely in coal. Today, 60% of China's energy workforce is employed in clean sectors, compared to just over 50% in 2019. China's build out of clean tech manufacturing has been a major source of employment growth. China's clean energy manufacturing sectors employ roughly 3 million workers, accounting for 80% of solar PV and EV battery manufacturing jobs globally.

Amid the many positive trends emerging for clean energy employment, skilled labour shortages are already plaguing the sector and require attention. The energy sector needs higher skilled workers than most other industries — 36% of energy jobs are within high-skilled occupations by International Labour Organization definitions, compared with 27% in the broader economy. Job vacancy rates, a key indicator of labour shortages, have been rising for years in many major economies in the construction, manufacturing, utility and other energy-related sectors. Construction occupations, which make up nearly half of new energy-related jobs to 2030 on a path to net zero, are facing particularly acute shortages, limiting the availability of labour needed to install clean energy technologies and retrofit buildings.

A proprietary survey of over 160 energy companies conducted by the IEA indicates that installation and repair work positions were the number one occupation segment for which respondents had the greatest difficulty hiring. This was mostly due to a lack of industry-specific knowledge. Developing a sufficiently large and skilled local workforce is an imperative in every region, as most energy jobs are tied to the location where installations are developed. Roughly 60% of energy jobs today cannot be offshored.

The number of workers pursuing degrees or certifications relevant to energy sector jobs are not keeping pace with growing demand. Science, technology, engineering and mathematical degrees relevant to the energy sector are not rising fast enough to meet demand for new workers with these credentials. The gap is even more severe for vocational jobs. Conferrals of certifications relevant to energy, such as electricians and heating technicians, have flatlined in the United States and the European Union, and in China they fell by around 9% per year in the years leading up to the pandemic. Meanwhile, jobs demanding these certifications are projected to grow by around 8% per year through 2030 on a net zero aligned pathway. Clean energy training programmes are becoming more available — for instance 19 of the G20 members have training courses for solar PV installers — but governments must address direct and indirect costs borne by workers pursuing retraining if this skilled labour gap is to be closed. Cultivating a skilled labour pool should be considered a key strategic pillar for regions looking to be competitive in new clean energy industries, as is attracting more women, who represent 15% of the energy workforce today.

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Many fossil fuel workers have the skills and specialisations needed to fill clean energy roles. We estimate that half of workers in fossil fuel sectors who face redundancy risks this decade have skills demanded by growing clean energy sectors. Many of these workers could switch into new roles with around four weeks of additional dedicated training, such as the 1.2 million workers that could shift from fossil fuel heating to heat pumps and the 4 million workers who could shift from internal combustion engine (ICE) manufacturing to EVs between now and 2030 in the Net Zero Emissions by 2050 Scenario (NZE scenario). Much of this training can be done on the job and within firms making the transition. For other workers, slightly more retraining would be required, such as is the case for oil and gas workers with skills relevant to the offshore wind, hydrogen and CCUS sectors.

This transition risk is particularly acute for coal miners in emerging and developing countries. The coal supply workforce shrank by 225 000 jobs between 2019 and 2022, and under current policies is expected to further contract by 1.4 million jobs by 2030 — however most losses in coal mining are related to improvements in labour productivity and other efficiencies. Coal employment declines would be higher in the NZE Scenario pathway. Many coal producing regions have already successfully managed coal transitions over the past century, generating important policy lessons for other regions. Targeted reskilling and community support policies for declining coal regions can help transfer these workers to other sectors, like critical minerals. Our analysis finds that over 180 000 jobs were added in critical mineral mining in the last three years, and 40% of current coal miners work within 200 km of a critical mineral deposit.

Oil and gas workers face less immediate transitions risks, but the long-term decline of fossil fuels demand is already shaping labour trends in the industry. Around 150 000 fewer people work in oil supply than in 2019, where companies have been wary of rehiring given changing trends. Conversely, jobs in natural gas increased by 350 000 thanks to strong growth in LNG, making natural gas the only fossil fuel to have surpassed pre-pandemic employment levels by 2022. Future labour needs in oil and gas vary widely depending on the pace of the transition. Under current policies, the oil and gas workforce grows by nearly 300 000 workers by 2030 —but in the NZE Scenario employment falls by over 2.5 million. Some oil and natural gas companies are diversifying their portfolios into other energy sectors, which could guard against skill retention risks in the face of this uncertainty. In the NZE Scenario, job growth in hydrogen, CCUS, geothermal and biofuel and biogas processing nearly offsets decreases in core oil and gas business to 2030.

Higher wages in the energy sector have helped attract workers from other industries, but wage disparities between energy segments could impede the transfer of needed skills. Compensation in the energy sector is typically higher than for similar occupations in the broader economy, mostly reflecting higher skilling requirements. For example, solar PV installers can earn

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around 15% more than general roofers and 40% more than telecommunication installers, occupations requiring comparable skills. Still, wages vary greatly across the energy sector, reflecting differences in skill level and the sectors' ability to offer high compensation. Wage differentials could create headwinds for worker transfers within the energy sector and could contribute to some workers switching out of the energy sector entirely. Today, workers in nuclear, oil and gas benefit from some of the highest wages in the entire economy. Some clean energy technologies offer comparable wages, as is the case in biofuel processing, while others like wind, solar and hydrogen see the average worker earning 15-30% less today.

In all scenarios, job growth outweighs declines to 2030, but avoiding skills shortages calls for more attention from policy makers, as does maximising the benefits of new jobs created. Based on today's policies, 8 million clean energy jobs will be added worldwide by 2030, with fossil fuel jobs declining by 2.5 million, for a net increase of 5.7 million. The increase in energy jobs to 2030 would be even greater in the NZE Scenario, reaching 17 million. Supporting workers in declining fossil fuel sectors must go hand-in-hand with efforts to train the workers needed in clean energy sectors, as skilled labour shortages are emerging as one of the primary risks to energy transitions. But energy job growth also presents one of the greatest opportunities for policy makers to rally public support for the energy transition, and policies can be designed in a way that raises working standards and draws new and diverse people into energy. The IEA continues to deepen its analytical work that supports policy makers in making clean energy transitions people-centred, recognising that workers play an essential role in realising the low-carbon future and that ultimately, the transition must prioritise improving lives and livelihoods to succeed.

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Introduction

In the past few years, the energy sector has undergone a period of remarkable change. First, Covid-19 upended global economies and energy demand. Russia's invasion of Ukraine followed in early 2022, triggering the first truly global energy crisis. Global leaders responded swiftly and strongly by securing alternative suppliers, strengthening policies aimed at fast-tracking the shift to clean energy and providing an unprecedented level of finance to underpin the transformation of the energy market.

Underscoring the dramatic changes underway, for the first time ever, our latest edition of the *World Energy Outlook* foresees a peak in the demand for all three fossil fuels—oil, gas and coal—within this decade. The rapid growth of clean energy technologies combined with the vast ramifications of the global energy crisis are driving the shift away from fossil fuels and accelerating the transition to a low-emissions future. Countries emitting 70% of global greenhouse gas (GHG) emissions today have pledged to decarbonise their energy sectors, pointing to further acceleration on the horizon as new policy and private sector initiatives aim to align with these ambitions.

These developments are having far-reaching repercussions for the energy industry and those who work in it today. Last year, the IEA published its inaugural *World Energy Employment* report, which provided the first comprehensive assessment and benchmark of the global energy labour force. This new edition updates how levels of employment changed throughout the pandemic and the energy crisis to 2022. It also analyses how demand for workers could evolve to 2030 under the government policies in place today and those needed to achieve net zero energy sector CO_2 emissions by 2050.

Recent developments in energy employment trends over the 2019-22 period are drawing increasing attention to the risk of skilled labour shortages hindering the expansion of clean energy sectors. Labour and skills shortages are already translating into project delays, raising concerns that clean energy solutions will be unable to keep pace with demand to meet net zero targets. Accordingly, this report provides in-depth analysis of labour market issues that may negatively impact some of the fastest growing clean energy sectors, highlighting key occupations and skills, looming shortages, education and training requirements, and remuneration levels. It also includes new insights on gender dynamics in training and in the workforce.

Clean energy policymaking today is increasingly intertwined with labour policy. Attracting people to work in burgeoning clean energy industries and managing the transition of workers in fossil fuel sectors are becoming crucial priorities for policy makers, industry, labour unions and civil society. The report aims to provide an objective look at employment trends across the entire energy supply chain, by sector and by region. It also includes first-time estimates on employment in the critical minerals and hydrogen industries and provides examples of successful efforts by governments and companies to prepare their workforce for the clean energy transition.

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Understanding the World Energy Employment report

The *World Energy Employment 2023 (WEE 2023)* report builds on national labour statistics to provide a more comprehensive estimate of the energy workforce today and a forward view to 2030. Most labour statistics do not cover the energy sector in detail, and while some traditional parts of the sector have dedicated subcodes, many emerging sub-sectors do not. 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. Accordingly, this report uses modelled estimates and other data sources to arrive at estimates. A brief description of scope, definitions and approach follows, with more detail available in individual section chapters and in the Methodology section of the Annex.

Scope of energy jobs

The scope of energy and related employment categories and sub-sectors discussed in this report include:

- The supply of energy and related mineral supply includes oil, gas, coal, bioenergy, critical minerals, nuclear fuel supply and hydrogen.
- The power sector includes generation by source (solar, wind, hydropower, fossil fuels and nuclear), power transmission facilities and grids, distribution and storage.
- Key energy end uses include vehicle manufacturing and energy efficiency (buildings, industry, among many other sectors).

The report considers direct jobs related to the activities outlined, including upstream roles that are correlated to energy (e.g. turbine manufacturing, but not production of cement used in the foundation). We exclude other indirect jobs such as workers further upstream in non-energy specific roles and employment in related sectors such as auto mechanics whose positions depend on vehicle manufacturing. It also excludes induced jobs, defined as jobs supported by wages earned in the energy sector but spent elsewhere in the economy. Employment in non-energy businesses owned by energy firms are not included (e.g. workers at hotels owned by enterprises or financial advisory services housed within energy firms). Informal workers are included. Part-time work is normalised to full-time equivalent (FTE) employment for consistent accounting.

Approach

The data presented in the report are modelled benchmarks relying on the IEA's comprehensive databases of national energy systems as inputs for calibration, including investments, capacity additions, existing stock, production, international trade flows of clean energy goods and services, and sales of equipment and appliances. The modelled estimates are then calibrated against data from national labour statistics, corporate filings, company interviews, international

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organisations' databases and academic literature. In addition, other valuable inputs include dedicated secondary surveys and studies on energy employment, such as the U.S. Energy and Employment Report (USEER), Canada's Labour Force Survey (LFS) and the United Kingdom's Low Carbon and Renewable Energy Economy (LCREE).

Prevailing labour costs in each region, industry and occupation are used to benchmark the number of jobs per energy project that would be consistent with the total investment, operating costs and earnings of different energy sub-sectors. Where labour costs are low, such as in India, building a project may employ far more people than it would in the most advanced economies.

For this year's report, the IEA conducted an expansive, in-depth survey of over 160 firms in the energy industry to gain better insight on the issues and problems they are facing in hiring skilled workers, trends in wages, labour needs by occupation and long-term plans. The anonymised findings are presented throughout the report.

Key terminology

The report gives employment broken down by technology or sub-sector (e.g. oil supply, solar PV, etc.), but also presents jobs by region and via different schemas, notably:

- *Economic activity.* This refers to the categorisation of workers and activities as defined by the International Standard Industrial Classification (ISIC) Throughout the report, economic activities are aggregated to five groupings for simplicity: Raw materials, Manufacturing, Construction, Professionals and utilities, and Wholesale and transport.
- *Occupations.* This year's report highlights employment by occupations and skill level, relying on the International Standard Classification of Occupations (ISCO) primarily, but also self-identified occupation titles used by firms in the energy industry today.

Scenario descriptions

The report's focus is predominately on today's energy employment trends, but also includes projections to 2030 for two scenarios used in the World Energy Outlook series:

- *The Stated Policies Scenario* (STEPS), which is based on today's policy settings and considers aspirational targets and pledges only insofar as they are backed by detailed policies.
- *The Net Zero Emissions by 2050 Scenario* (NZE Scenario), which sets out a narrow but achievable pathway for the global energy sector to reach net zero CO_2 emissions by 2050.

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Overview

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A major shift in energy employment worldwide has been underway since the pandemic, with growth coming almost entirely from clean energy jobs in 2019-2022

The global economy has been in a state of flux for the past three years, with energy at the heart of some of the turmoil. The lockdowns at the start of the Covid-19 pandemic gave way to major supply chain disruptions, followed by the global energy crisis, where volatile oil and gas prices contributed to upward pressure on global inflation levels. Central banks countered by sharply raising interest rates to curb inflation, which seem unlikely to abate in the near term.

Labour markets have been directly affected by the turbulence, with economy-wide employment levels in many countries yet to return to their pre-pandemic levels. This issue is especially prominent in emerging market and developing economies, where levels of unemployment remain high, while informal jobs are on the rise. Conversely, many advanced economies continue to experience tight labour markets with unemployment at historic lows.

Energy employment has followed some of the same trends witnessed by labour more broadly as fossil fuel-related jobs contracted, but the global trend toward clean energy remains the driving force shaping the energy workforce. The early lockdowns of Covid-19 led to significant layoffs in the energy industry, especially those employed in construction, manufacturing and extractive industries. Workers operating critical energy infrastructure, such as power plants, utilities, refineries, pipelines and shipping, were much less affected by the pandemic than those in other sectors. As the world gradually emerged from the first phases of the pandemic, many energy jobs returned, however others remained below 2019 levels, notably in fossil fuel supply, where long-term prospects for new investments remained uncertain. On the other hand, total clean energy investment grew by 32% between 2019 and 2022, with over half of that growth occurring in 2022 alone, boosted by a proliferation of government spending packages and rapid expansion of clean energy supply chains. As a result of these trends, global employment in the energy sector is surpassing the pace of the economic recovery and that of general employment. Global economy-wide employment remained around 1% lower in 2022 compared to 2019 levels, while jobs in the energy sector grew by more than 5%, reaching nearly 67 million jobs in 2022. This growth has come almost entirely from the clean energy sector, where employment jumped by over 15% between 2019-22, while fossil fuel-related jobs fell 4%.

Energy employment is on course to increase further in 2023, in tandem with an escalation in investment for both clean energy and fossil fuels. In 2023, total energy employment is set to grow by an estimated 4.5%. Clean energy employment is forecast to reach new highs, while a resurgence in new oil and gas projects, prompted by the energy crisis, will lead to a rebound in fossil fuel jobs in 2023, particularly for the construction of midstream infrastructure.

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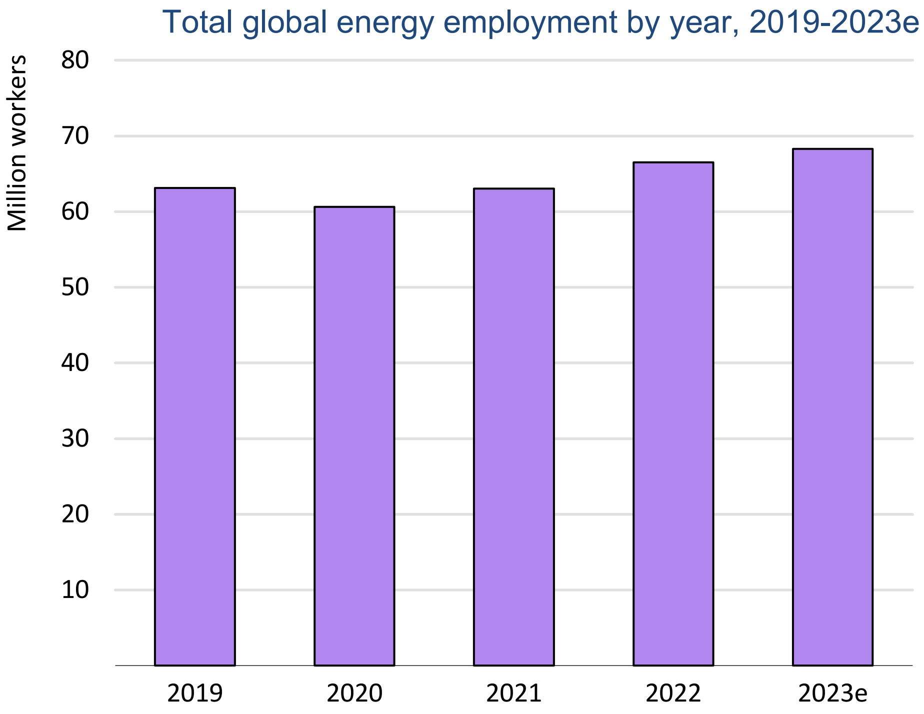
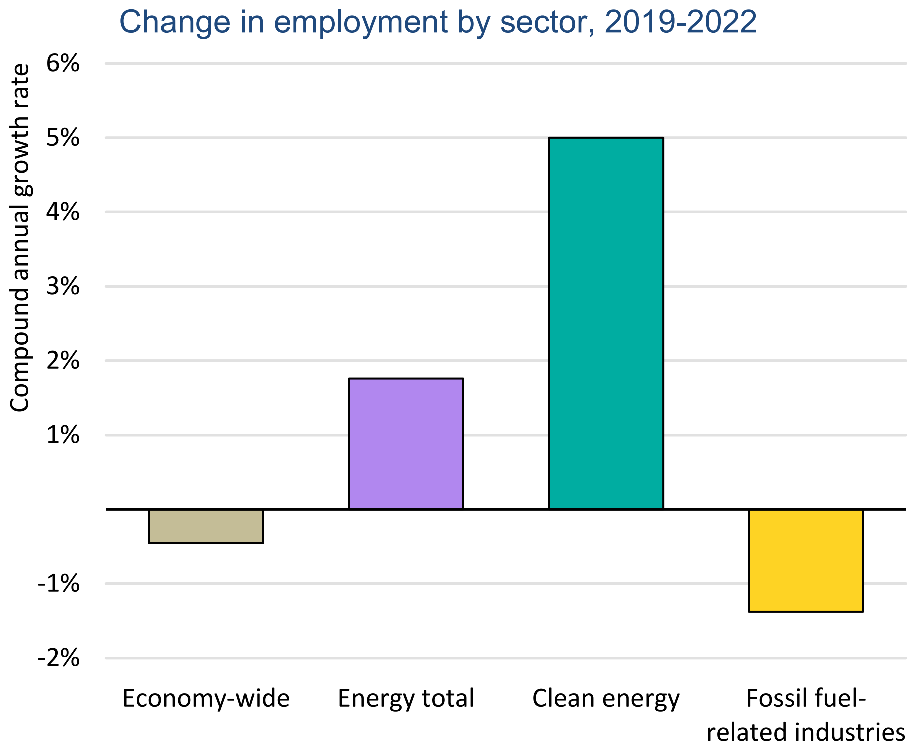
Global energy employment grew by more than 5% over the 2019-2022 period, besting the average for recovery of economy-wide jobs





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Notes: Economy-wide jobs based on the World Bank's World Development Indicators database. Clean energy sectors include low-emissions fuel sources, low-emissions power generation, power grids and battery storage, end-use efficiency, critical minerals extraction, and manufacturing of electric vehicles and their batteries. Fossil fuel sectors includes supply of oil, gas, and coal, as well as unabated fossil fuel-fired power generation and internal combustion engine vehicle manufacturing. Please see the Annex for comprehensive definitions.

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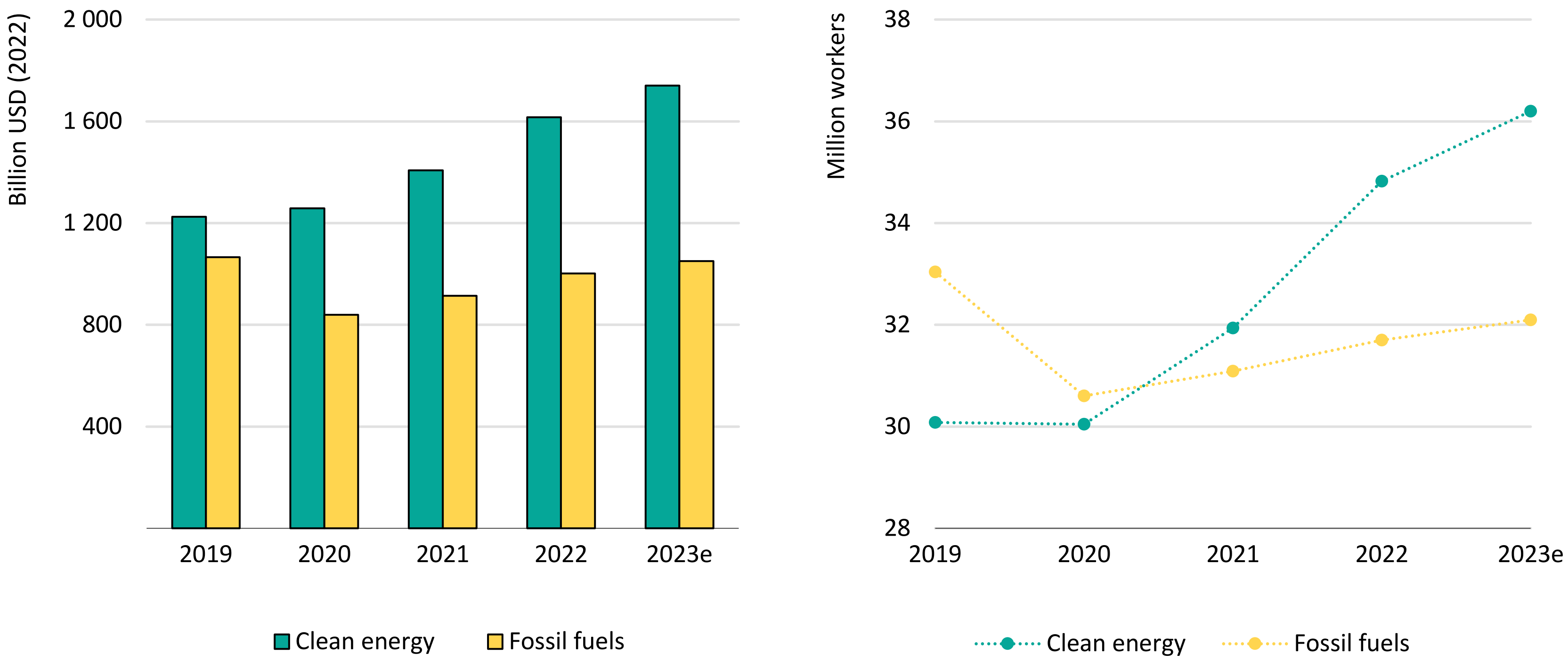
Strong investment growth underpins energy employment trends, with spending on clean energy far outpacing fossil fuels since the pandemic

Global investment and total employment by sector, 2019-2023e



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Notes: For 2023 data “e” indicates estimated total. Clean energy sector includes low-emissions fuel sources, low-emissions power generation, power grids and battery storage, end-use efficiency, critical minerals extraction, and manufacturing of electric vehicles and their batteries. Fossil fuel sector includes supply of oil, gas, and coal, as well as unabated fossil fuel-fired power generation and internal combustion engine vehicle manufacturing. Please see the Annex for comprehensive definitions.

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Clean energy employment surpassed fossil fuel-related jobs for the first time around 2021

Nearly 67 million people were employed in energy and related sectors in 2022, approximately 3% of total formal employment worldwide. Today, around half of the global energy workforce is employed in clean energy – a disproportionate share relative to its contribution to the energy sector, reflecting the higher labour intensity of building new energy infrastructure rather than operating existing assets. Clean energy jobs surpassed fossil fuel-related employment around 2021, led higher by rapid investment growth. In fact, over half of the job growth since 2019 has been within a few key sectors: solar PV, wind, EVs, batteries, heat pumps, and critical minerals.

Energy employment, for the purposes of this report, includes jobs in fuel supply (coal, oil, natural gas, bioenergy, nuclear fuel, low-emissions hydrogen and critical minerals), the power sector (generation, transmission, distribution, and storage), and end-uses (vehicle manufacturing and energy efficiency in buildings and industry). More than 21.5 million people work in fuel supply, having exceeded pre-pandemic employment levels in 2022. The oil industry has the largest workforce in this sector, with 7.6 million workers, followed by coal with 6.2 million, natural gas with over 4.1 million, and bioenergy with 3.6 million. Fossil fuel supply sectors, which saw some of the biggest job losses during the pandemic, have recovered much more slowly than clean energy segments, just reaching pre-pandemic levels in 2022. Coal mining jobs continue to decline, in part due to more mechanised mining in the People’s Republic of China (hereafter, “China”) and other major producers, although this decline was interrupted by the temporary surge in coal during the energy crisis. Oil and gas investments have rebounded amid the crisis, but the pace of re-hiring remained tempered by uncertainty regarding long-term demand prospects in light of increasing climate action. This is particularly the case at international oil companies (IOCs), whereas national oil companies (NOCs) laid off fewer workers in 2020 and are expected to pick up higher market share going forward.

The power sector employs over 20 million workers, with 12.5 million in generation and 7.8 million in transmission, distribution and storage combined. Clean power employment has followed the rapid expansion of renewables, surpassing pre-pandemic levels by 2021, and growing by another 900 000 jobs in 2022, with solar PV and wind providing more than 60% of the growth. Grid expansion projects continue to face delays in many regions, with employment relatively flat despite the proliferation of new projects.

Around 13 million workers were employed in vehicle and EV battery manufacturing in 2022. Employment in vehicle manufacturing still remains below 2019 levels, in line with a decline in sales, but jobs related to the production of EVs and batteries have been growing rapidly in recent years. Over 10.5 million people worked in energy efficiency-related jobs by 2022. Driven by record-high retail electricity and gas prices, employment in building retrofits and heat pumps expanded as homeowners focused on improving energy efficiency and reducing utility bills. But upgrades in industry and households slowed in the second half of 2022 as interest rates rose, impacting project economics.

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Energy jobs span the entire energy value chain: extractive industries, manufacturing key energy technologies, construction of new energy-related infrastructure, and the ongoing operation of systems that deliver energy reliably to end-users. In 2022, more than 8.5 million people, or 13% of energy sector employment, worked in the production of raw materials, including mining and extraction of fuels and critical minerals, and agriculture to produce bioenergy. Manufacturing of energy goods, including vehicles, clean energy technologies and refined petroleum products, employed 21 million workers (one-third of total jobs), with more than half of these in vehicle manufacturing. Construction employed over 14.5 million workers engaged in activities such as building power plants and installing solar panels, which has been the fastest growing segment along the energy value chain. Within clean energy, construction represented 35% of employment compared to less than 10% in fossil fuels. More than 14.5 million workers are employed at utilities and in professional energy services, and other jobs in wholesale trade and transport account for 7.5 million.

Energy is a global industry, yet most jobs are anchored where energy projects are built and operated - around 60% of today's energy jobs cannot be offshored. Jobs in manufacturing and in some professional occupations can be concentrated in particular regions, however many remain proximate to their final market, as is the case for appliances and vehicles. China, the United States, Europe, Japan and Korea are each home to major centres of excellence or manufacturing hubs, which host globally active firms that play a key role in energy supply chains. For instance, China is home to massive solar PV and battery supply chains, North America is the base for a large number of global oil and gas services companies, and Japan, Germany, Korea, and Denmark maintain a high share of manufacturing centres for energy equipment such as turbines, grid-scale power electronics, and vehicles. Producer countries also have a higher share of their economy-wide employment coming from energy, especially in less diversified regions such as the Middle East, Africa and Central and South America.

The leading factors driving the size of each region's energy workforce are population, labour efficiency, wages, and the level of investment in new energy infrastructure. Accordingly, emerging market and developing economies are home to two-thirds of energy jobs, while advanced economies make up only one-third. China has the largest energy labour force, with more than 19 million workers in 2022. China's clean energy supply chains are already a major source of employment, accounting for roughly 60% of the country's energy employment. China witnessed both the largest gains in clean energy jobs from 2019-22 and the biggest drop in fossil fuel employment, reflecting the sheer size of its energy sector. Europe and other Asia Pacific posted the next highest growth in clean energy jobs, followed by India. North America and Europe both witnessed declines in fossil fuel-related employment since 2019, with particularly steep labour cuts in the oil and gas sector. North America's high share of oil and gas jobs meant that pandemic-era layoffs remained the dominant trend in energy employment over the past three years. India and the Middle East were the only major regions to see growth in both clean energy and fossil fuel employment in the 2019-22 period.

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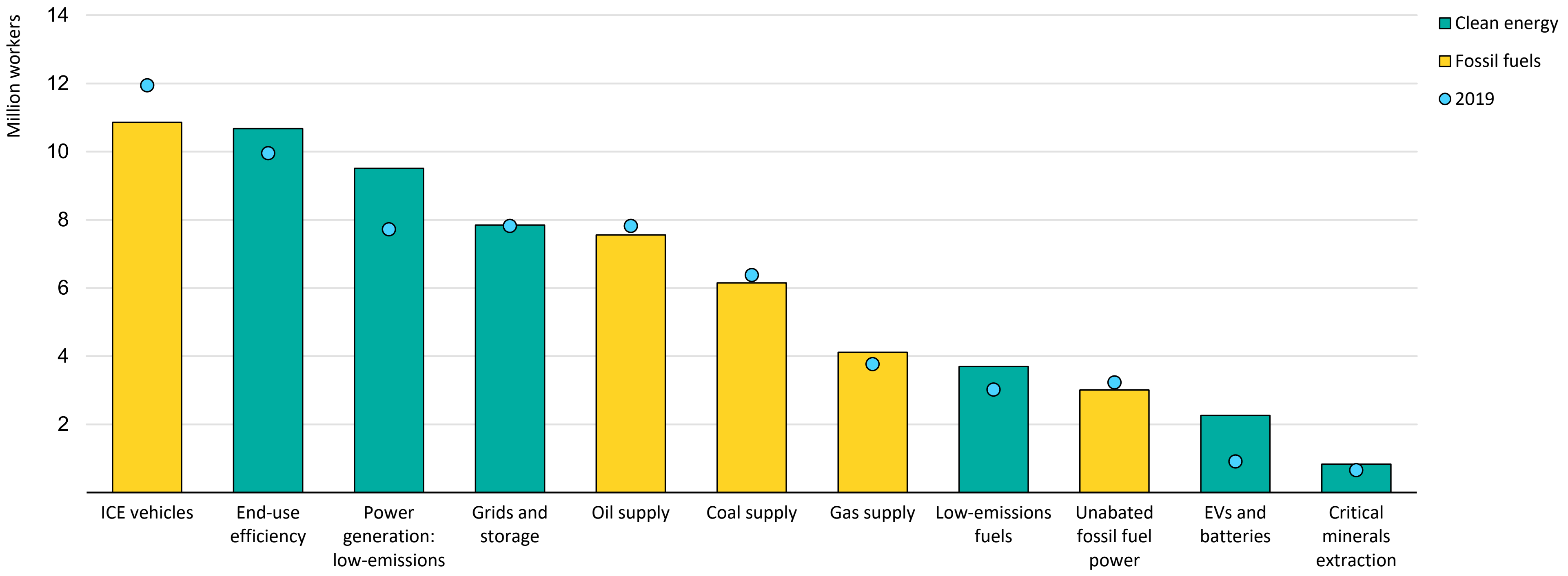
Employment in energy efficiency, low-emissions power and grids is larger than traditional fuel supply sectors, as investment in new clean energy infrastructure continues to surge

Global energy employment in selected sectors, 2022



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Notes: ICE vehicles = internal combustion engine vehicles, EVs = electric vehicles. Power grids include transmission, distribution and storage. Low-emissions power generation includes nuclear and renewables. End-use efficiency includes building retrofits, heat pumps and other equipment, appliances, and industry efficiency. Clean energy sectors include low-emissions fuel sources, low-emissions power generation, power grids and battery storage, end-use efficiency, critical minerals extraction, and manufacturing of electric vehicles and their batteries. Fossil fuel sectors include supply of oil, gas, and coal, as well as unabated fossil fuel-fired power generation and internal combustion engine vehicle manufacturing. Please see the Annex for comprehensive definitions.

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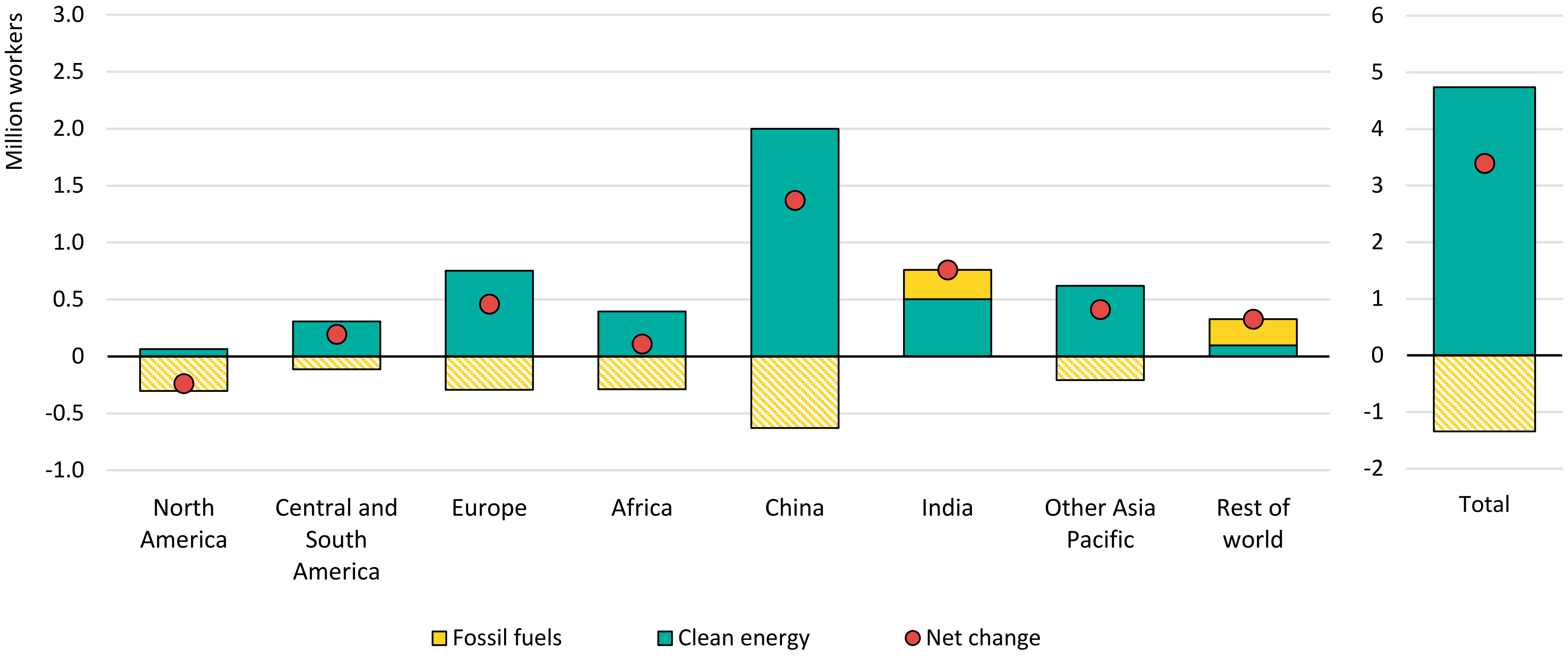
Clean energy is the primary driver of worldwide energy employment growth – and only in a few regions are fossil fuel jobs higher than pre-pandemic levels

Change in energy employment by sector and region, 2019-2022



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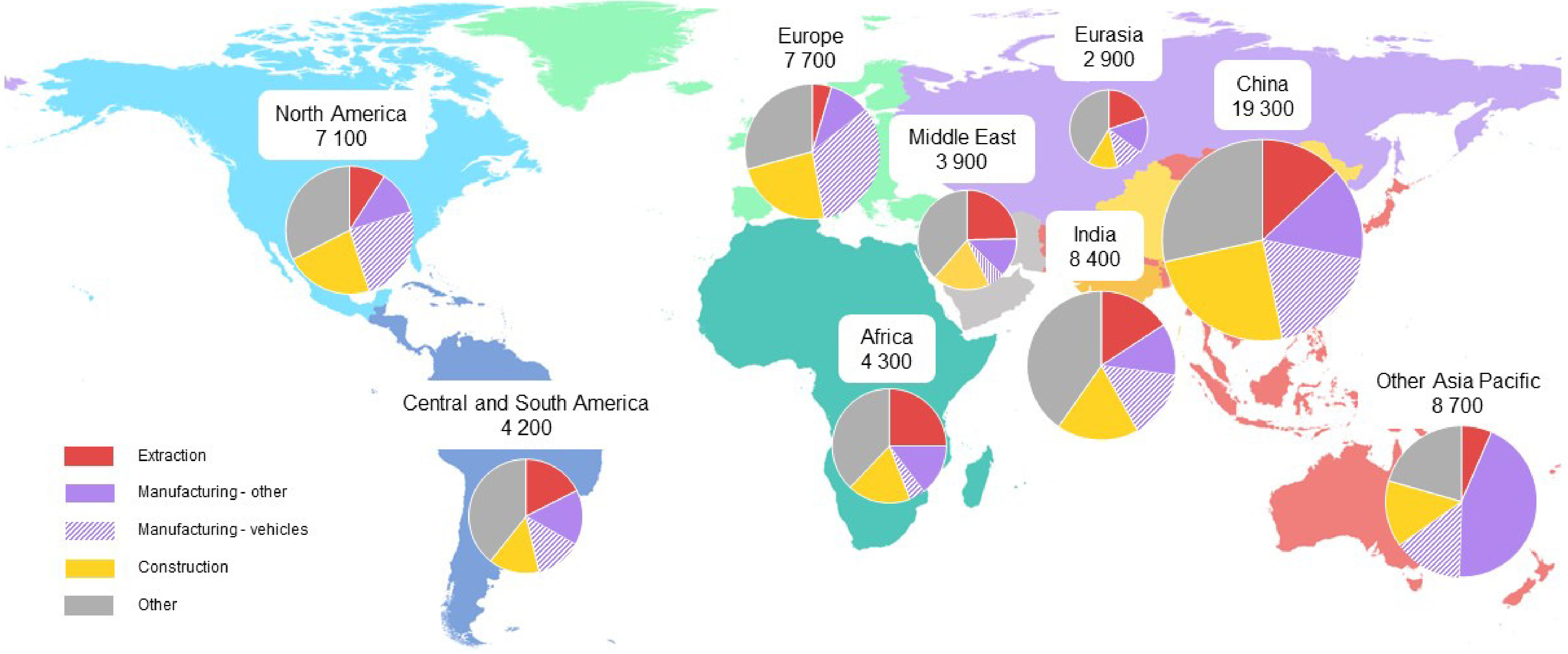
Notes: Clean energy sectors include low-emissions fuel sources, low-emissions power generation, power grids and battery storage, end-use efficiency, critical minerals extraction, and manufacturing of electric vehicles and their batteries. Fossil fuel sectors includes supply of oil, gas, and coal, as well as unabated fossil fuel-fired power generation and internal combustion engine vehicle manufacturing. Please see the Annex for comprehensive definitions.

Asia hosts the world's largest energy workforce owing to its substantial population, lower labour costs, brisk investment and sizable clean energy manufacturing sectors

Energy employment by economic activity and by region, 2022 (thousand workers)



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Notes: This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area. Please see the Annex for definitions of regional groupings. Other includes utilities, energy services professionals, and other jobs in wholesale trade and transport sectors.

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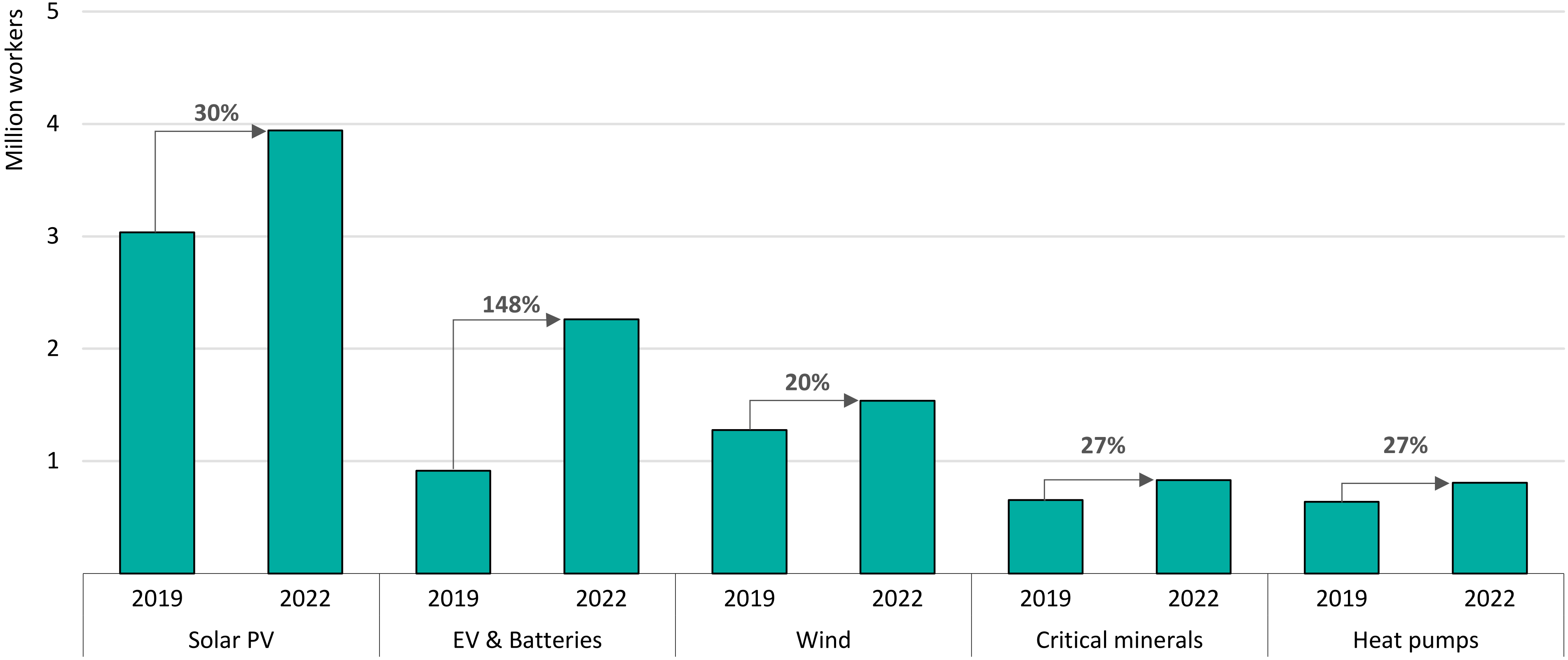
Half of the job growth since 2019 is from solar PV, wind, EVs, batteries, heat pumps and critical minerals, with each sector growing annually by more than 6%

Global employment growth and percent change in selected energy sectors, 2019-2022



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Notes: Overall percent change from 2019-22. PV = photovoltaic, EV = electric vehicle.

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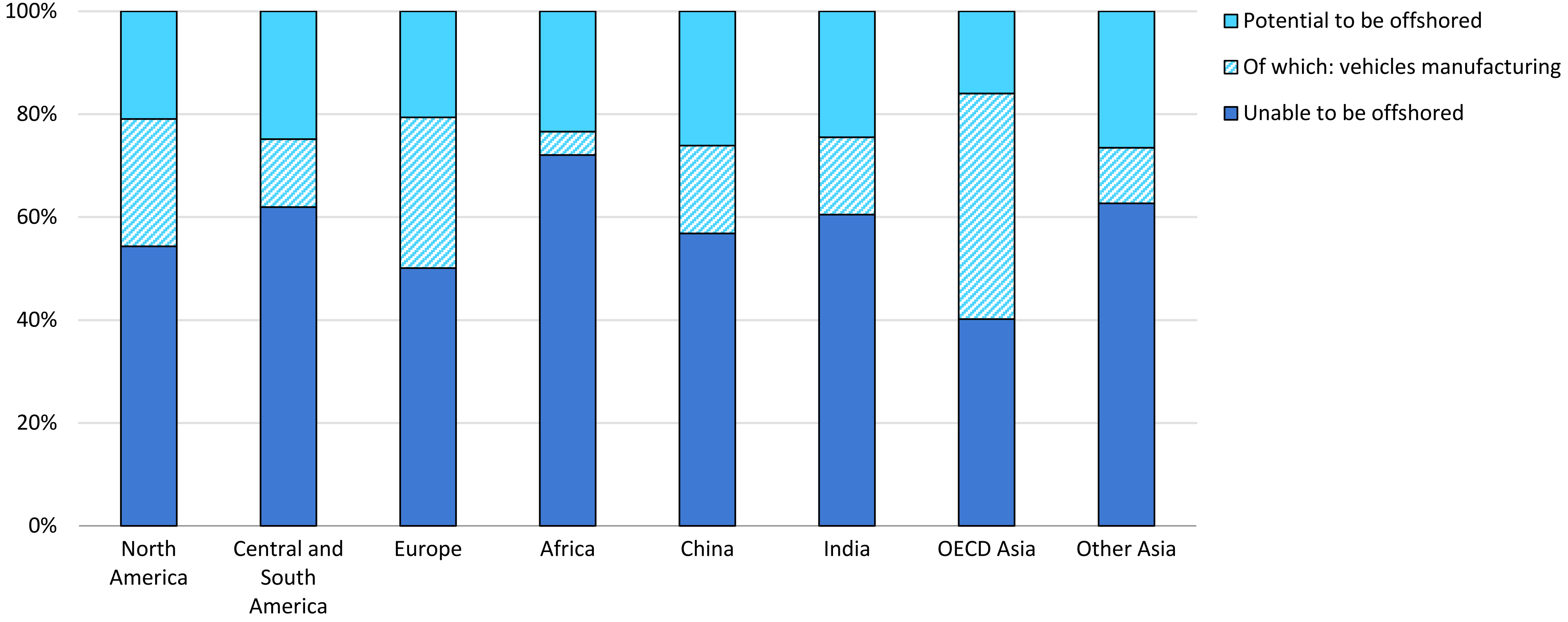
The majority of jobs in the energy sector today cannot be outsourced overseas, a trend that remains true to 2030

Total employment by potential of outsourcing by region, 2022



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Notes: Jobs considered unable to be offshored cannot be relocated outside the region because they are location-bound. Jobs considered to have the potential to be offshored could be performed abroad with little loss of quality.

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

Energy employment by region and sector, 2022 (thousand workers)

	North America	Central and South America	Europe	Africa	China	India	Other Asia Pacific	Middle East	Eurasia	Global
Supply: coal	100	100	100	100	3 100	1 600	700	<50	300	6 200
Supply: oil and gas	1 700	1 000	700	1 300	1 100	800	1 100	2 800	1 300	11 700
Supply: low emissions	200	900	300	600	500	600	600	<50	100	3 700
Power: generation	1 000	800	1 500	600	4 500	1 300	1 900	400	400	12 500
Power: grids	1 000	400	1 000	400	2 200	1 600	800	200	200	8 000
End uses: vehicles	1 800	600	2 400	200	4 300	1 300	2 000	200	300	13 100
End uses: efficiency	1 400	300	1 600	500	3 500	1 200	1 600	200	200	10 700
Critical minerals	100	100	<50	400	<50	<50	100	<50	100	800
All energy	7 100	4 200	7 700	4 300	19 300	8 400	8 700	3 900	2 900	66 500

Notes: Power grids include transmission, distribution and storage. Vehicles include the manufacturing of all road vehicles (two- and three-wheelers, passenger cars, light-duty commercial vehicles, buses and trucks) and batteries for EVs. Efficiency refers to energy efficiency in buildings (covering retrofits, heating, ventilation and air conditioning equipment, as well as appliances) and in industry. Values may not sum due to rounding. Employment estimates for 2019 differ from *WEE 2022* in some instances. These adjustments are largely due to changes in scope of the jobs considered and revisions to input data, such as national statistics. The direction of these revisions varies depending on the technology and geography. Overall, there has been a downward revision of our 2019 energy jobs estimate by approximately 2.8 million worldwide. Please see the Annex for further information on historic revisions.

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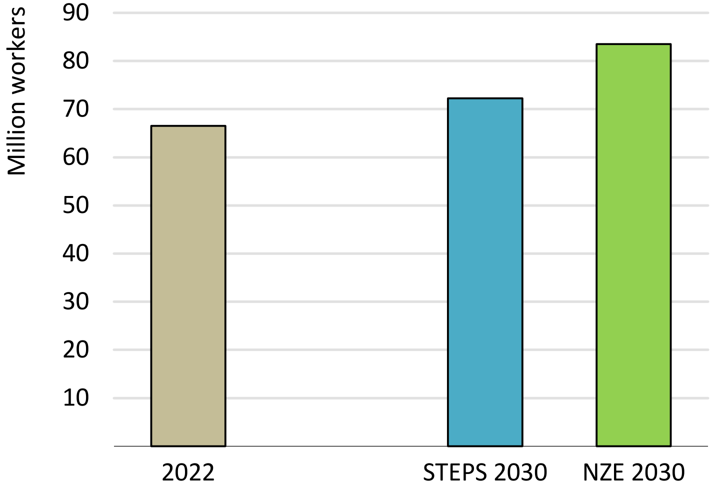
Climbing investment under today’s policies will lead energy sector employment higher to 2030; growth will be even greater on a pathway to net zero

The prospects for employment in the energy sector depend critically on the pace of the clean energy transition. This report sets out projections of the size and make-up of the global energy workforce to 2030 under two scenarios in the World Energy Outlook 2023: the STEPS takes account of current policy settings, and the NZE Scenario sets out a trajectory consistent with reaching net zero emissions by 2050.

Unsurprisingly, the shifts in global energy employment are more pronounced in the NZE Scenario, reflecting the much higher energy sector investment required to accelerate the transition. Yet, in both scenarios, job creation associated with clean energy technologies comfortably outweighs job losses in fossil fuel and related industries through to 2030. More than 5.7million additional jobs are created on a net basis in the STEPS and 17 million in the NZE Scenario.

Meeting rising demand for skilled labour will be one of the primary challenges the energy sector faces in the coming decade. In some cases, the jobs lost in one sector could easily transfer to other roles. For example, workers involved in the assembly of ICE vehicles could switch to manufacturing EVs and batteries. In other cases, new jobs require workers with specific skills that are not widely available in today’s labour market. This is of particular importance for the construction sector that already faces economy-wide labour shortages today, which could threaten the pace of the clean energy transition. Some of the needed skills may exist elsewhere in the energy sector, and workers from energy sub-sectors with falling labour needs, such as oil, gas and coal, could be retrained and redeployed in clean technology sectors. However, these jobs may not be in the same place and may not be a match for all workers. Attention will need to be paid to manage the transition risks in a just and people-centred way. The risks of labour shortages and the challenges posed by worker transitions are explored in -depth in this year’s report in a new chapter on labour and skills.

Global energy employment by scenario, 2022-2030



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Note: STEPS = Stated Policies Scenario, NZE = Net Zero Emissions by 2050 Scenario.

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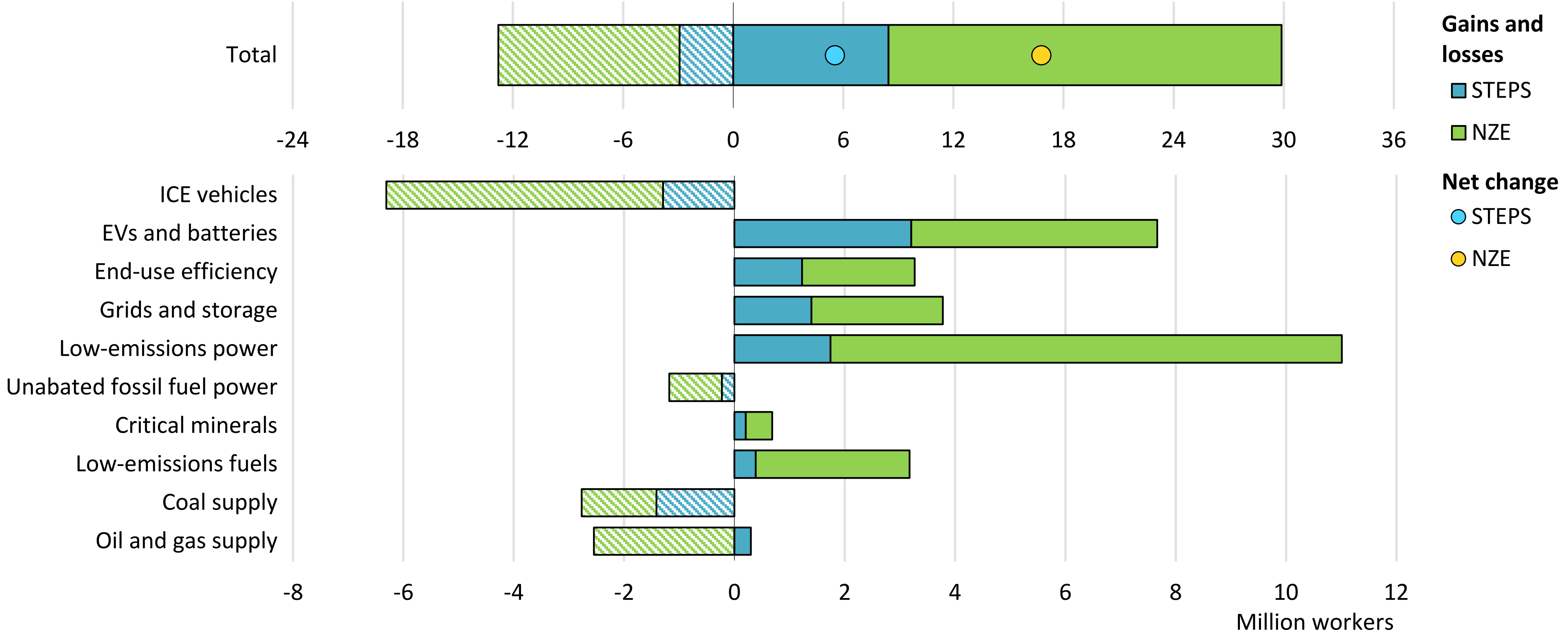
Employment grows as new opportunities in clean energy outweigh job losses in fossil fuels

Changes in global energy employment by sector and scenario, 2022-2030



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Notes: Critical minerals includes only extractive activities. EVs = electric vehicles, ICE vehicles = internal combustion engine vehicles. STEPS = Stated Policies Scenario, NZE = Net Zero Emissions by 2050 Scenario.

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Labour and skills

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Labour and skills shortages threaten to slow the ramp up of clean energy technologies

Worldwide, most countries have yet to return to pre-pandemic levels of employment, with the recovery uneven. Employers in advanced economies are struggling to hire skilled workers in historically tight labour markets. At the same time, structural mismatches between the jobs available and those desired in some emerging and developing economies are contributing to record levels of vacancies despite high unemployment. These realities have converged to create extreme uncertainty for global labour markets.

The energy sector, mid-transformation, is facing an additional, unique set of challenges. Firms in the clean energy sector are starting to report shortages of both workers and sector-specific skills as a result of the recent strong growth in demand. Trends in online job advertisements indicate that energy sectors have some of the highest job vacancy rates, underscoring employers' struggles to fill positions. Most of the jobs in clean energy sectors are in labour-intensive construction and manufacturing, both of which are already facing worker shortages across the broader economy in most parts of the world. These two segments of the value chain account for much of the growth in energy employment through 2030 in all IEA scenarios.

The construction segment is among the worst affected by labour shortages. Many clean energy projects are highly reliant on construction workers for building power plants or installing solar panels. Markets across the globe are already facing shortages of construction workers and other tradespeople, such as electricians, carpenters, concrete workers, welders, and pipefitters. The European Union is facing particularly severe shortages of tradespeople, including electrical engineering technicians, roofers, vehicle mechanics and truck drivers (see table).

Labour shortages in the European Union by occupation and severity, 2022

Occupation	Number of countries with shortage	Percent of shortages that are "high magnitude"
Carpenters and joiners	18	38%
Plumbers and pipefitters	18	38%
Building and related electricians	18	40%
Heavy truck and lorry drivers	18	73%
Welders and flame cutters	17	54%
Building construction labourers	15	38%
Electrical mechanics and fitters	15	22%

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Occupation	Number of countries with shortage	Percent of shortages that are “high magnitude”
Motor vehicle mechanics and repairers	14	33%
Electrical engineering technicians	12	63%
Roofers	11	78%

Note: “High magnitude” signifies “a lack of workers amounting to more than 3% of the current employment in that occupation.”

Source: European Labour Authority, European Employment Services (EURES), Report on labour shortages and surpluses 2022.

In China, the province of Jiangsu recently extended the upper age limit for construction workers to cope with the shortages.

Skills gaps in this segment threaten to limit the pace of the energy transition by impeding the ability of companies to deliver projects on time or take on new work. In many cases, the energy sector is competing directly with other industries for workers. For example, employment in building retrofits, already one of the fastest-growing sectors, is set to soar in the NZE Scenario, with 50% of existing buildings to be retrofitted to zero-carbon-ready levels by 2040. But this sector competes directly with the broader buildings industry for construction workers that are already in short supply, making reaching targets challenging. In other sectors, such as clean power, existing labour shortages are exacerbated by the need for specific skills. Demand for electricians experienced with high -voltage power electronics, for instance, further shrinks the already inadequate pool of potential hires for grid and wind developers.

Manufacturing, another leading segment of clean energy job growth, is also facing difficulties staffing new positions. In China, the world’s manufacturing powerhouse, factories are struggling to fill jobs as the working population shrinks and new workforce entrants increasingly favour white-collar positions over trades or factory work. In 2022, approximately 30% of all energy manufacturing jobs were in China. China’s Ministry of Human Resources and Social Security, along with other departments, estimate that by 2025 the country is liable to face a worker shortage for almost 30 million manufacturing jobs, including over 9 million in power equipment, 1 million in new energy vehicles and over 250 000 in offshore engineering equipment.

The limited availability of adequately skilled workers has intensified competition for staff both within and between different energy industries, including renewables and oil and gas. These shortages are being addressed in multiple ways. For instance, oil and gas firms have been reticent in hiring given the uncertain macroeconomic outlook, making do largely with their existing workforce or relying more on consultancies and outside contractors. Manufacturers of specialty grid equipment and turbines have taken a similar approach. Numerous companies are also offering more generous compensation packages to attract new staff as well as pursuing active reskilling of existing workers. Other businesses have shifted their operations to regions with a bigger pool of skilled labour.

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Policy approaches adopted to tackle skills shortages also vary across industries, regions and countries. The European Union, for instance, has provided financial and organisational support for some key energy industries, including batteries, heat pumps and wind, and creating skills partnerships to identify how to train new workers. As a part of the European Skills Agenda, which includes an ambitious target to upskill and reskill 120 million adults annually over 2020-25, the European Commission launched the European Year of Skills in 2023 to address the skills shortages across the continent. This initiative is designed to empower people and companies, especially small and medium-sized businesses, by promoting the reskilling and upskilling of workers needed to facilitate the green and digital transitions and accelerate innovation and competitiveness. In the United States, the Inflation Reduction Act of 2022 provides financial incentives for apprenticeships in an effort to expand its clean energy workforce. India has set up exchange programmes with the United States and some other countries to develop the curriculum needed to train workers for domestic clean energy firms.

Providing the right regulatory framework to ensure the competitiveness of a net zero industry will be key in meeting climate targets. In Europe, the Green Deal Industrial Plan hopes to help scale up the EU’s manufacturing capacity for net zero technologies through various industrial policies. A pillar of this plan centres on reskilling and upskilling strategic industries by setting up dedicated programmes such as the Net-Zero Industry Academies.

Many national clean energy transition initiatives are tied to efforts to reduce the corporate and geographic market concentration of the manufacturing of critical components and technical expertise for everything from solar PV, wind, and batteries to other key equipment like pumps, compressors, and turbines. Over-reliance on individual suppliers and countries has contributed to bottlenecks in developing new projects in a number of regions, prompting companies to increasingly diversify suppliers and develop local capacity.

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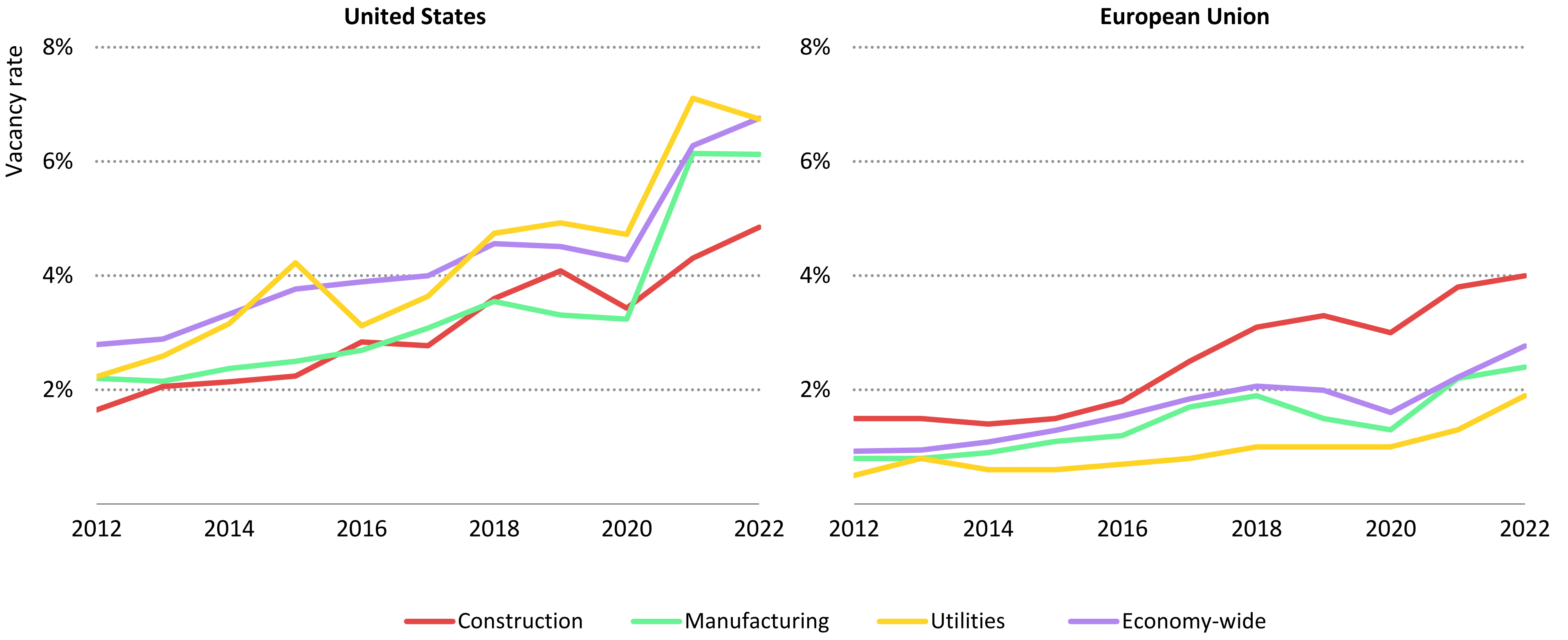
Job vacancy rates, a key indicator for labour shortages, have been rising for years in construction, manufacturing, utilities and other energy-related sectors

Job vacancy rates in energy-related industries in the United States and the European Union



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Notes: Vacancy rates, often used as a proxy for labour shortages, represent the number of job vacancies in an industry as a share of all jobs in that industry, filled or unfilled. “Utilities” differs in scope between regions; US utilities include “transport, warehousing and utilities”, while EU utilities include “electricity, gas, steam and air conditioning supply.”

Sources: U.S. Bureau of Labor Statistics, *Job Openings and Labor Turnover Survey* (dataset), accessed September 2023, and Eurostat, *Job Vacancy Statistics* (dataset), accessed 14 September 2023.

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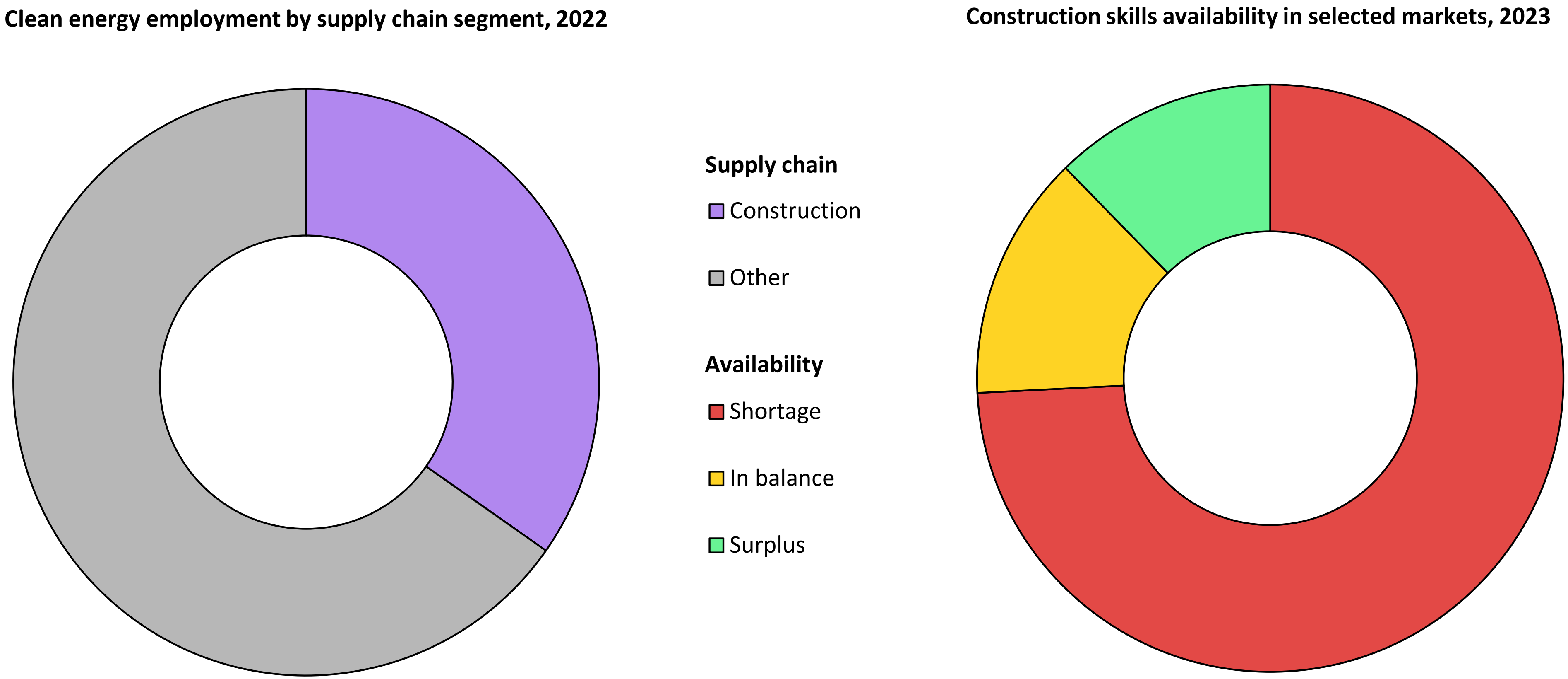
A global shortage of construction workers threatens clean energy installations and efficiency improvements

Clean energy jobs by supply chain segment and skilled labour availability in the construction sector



Clean energy employment by supply chain segment, 2022

Construction skills availability in selected markets, 2023

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Note: Construction skilled labour availability data is drawn from 89 markets across Africa, Asia Pacific, Europe, the Middle East, Central and South America, and North America.
Source: IEA analysis based on data from Turner & Townsend *Global construction cost performance*, 2023.

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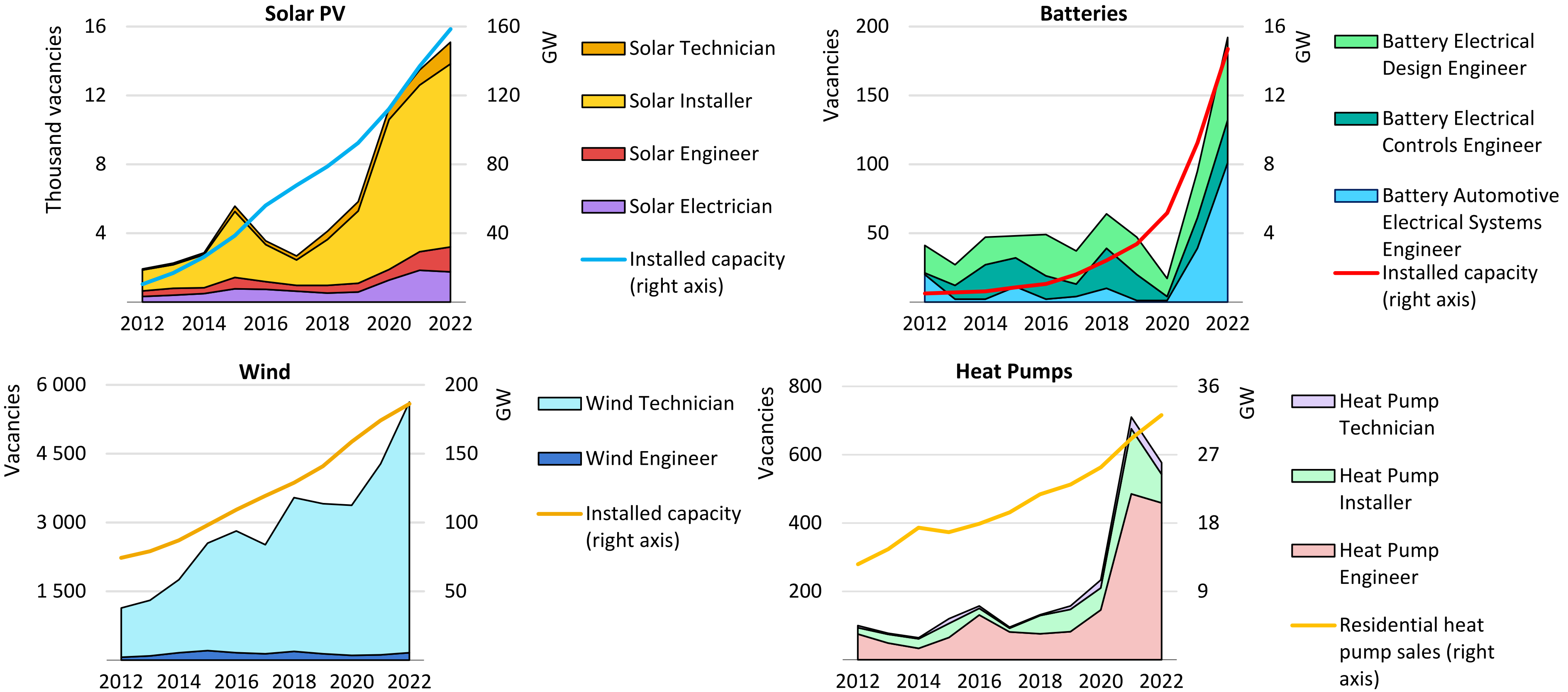
Established clean energy sectors such as solar PV and wind need mostly installers and technicians, whereas newer technologies need more highly skilled workers

Job postings for selected energy occupations in the United States, Canada, and the United Kingdom



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Source: IEA analysis based on data from Lightcast.

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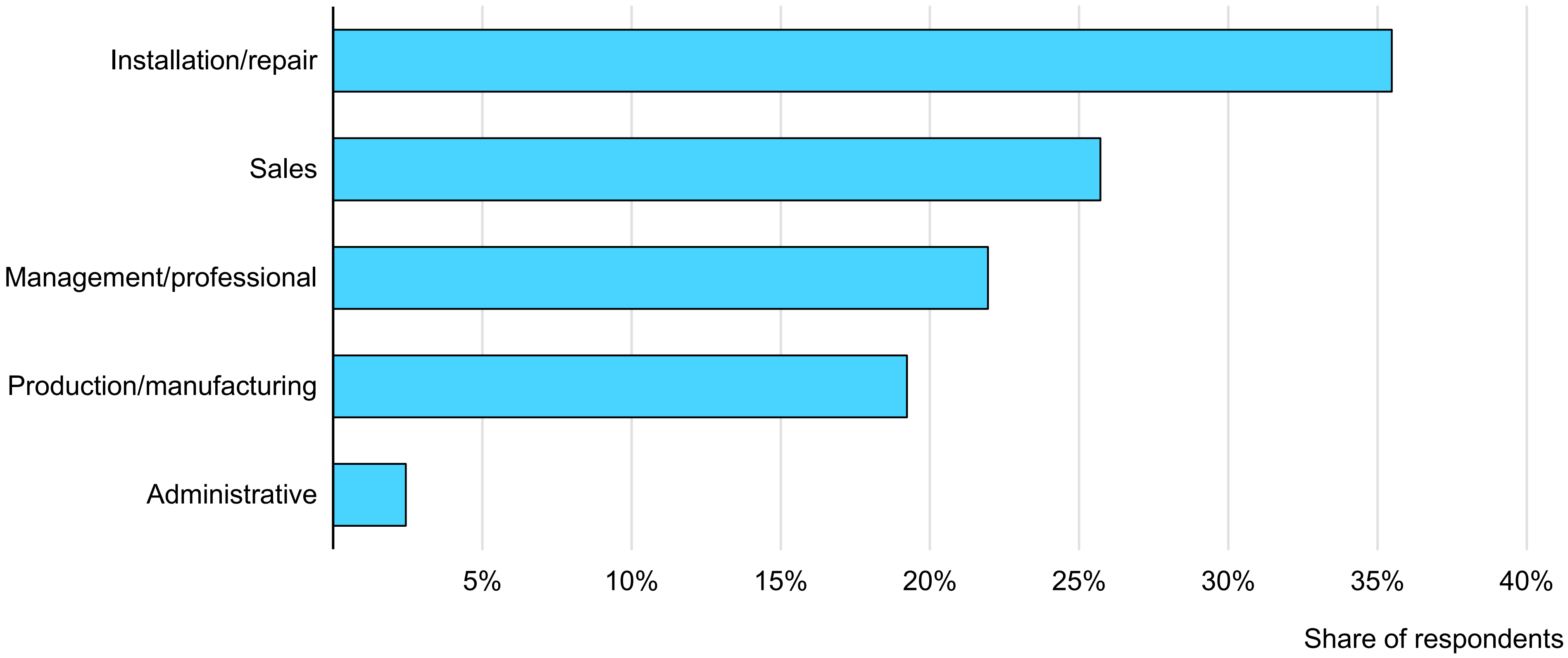
Energy companies are reporting significant hiring difficulties

Share of energy companies reporting perceived greater hiring difficulties than non-energy companies by occupation, 2023



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Notes: Results of the IEA's survey for the World Energy Employment 2023 report. Survey respondents were asked to indicate whether they perceived greater difficulties in hiring than non-energy companies for each occupation. For instance, a respondent might perceive more difficulty in hiring solar panel installers than a roofing company hiring similar candidates.

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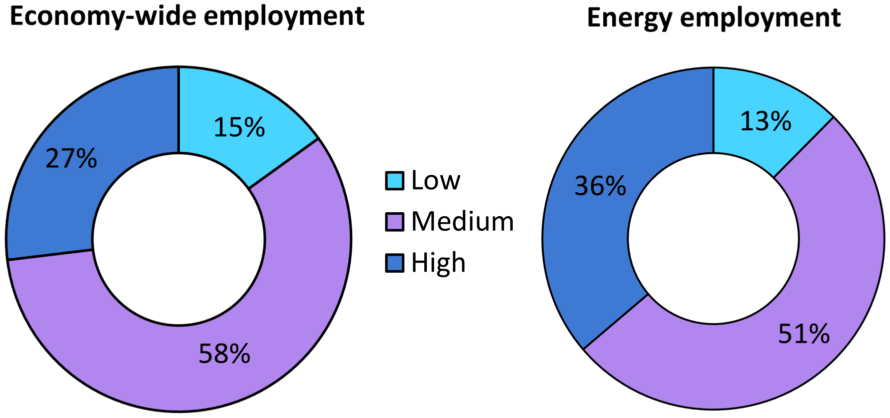
The energy sector requires more highly skilled labour than many other industries

The energy sector requires more highly skilled, specialised energy workers than many other industries, with 36% of the energy workforce typically requiring some form of tertiary education, and 51% some vocational training (see Annex for full explanation of skill levels). Just 13% of energy employment is considered low-skilled, with this labour concentrated in emerging market and developing economies. This estimate likely fails to capture the full extent of informal employment, which is often low-skilled and is also concentrated in those countries. By contrast, most labour-intensive tasks performed by low-skilled workers in advanced economies have been mechanised, automated or outsourced.

Global energy employment by skill level, 2022



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Many of the most prominent skilled labour shortages facing the clean energy industry today are in vocational roles. Most of these medium-skilled energy occupations require further specialisation beyond generic occupations common in energy today. Examples include HVAC specialists, who may retrain to install heat pumps, or electricians who are trained to install batteries or solar PV. Many companies have identified a lack of workers with energy specialisations as a particular barrier for them. In a survey of over 160 energy companies conducted by the IEA for this report, installation and repair positions were the number one occupation segment for which respondents perceived hiring was more difficult for them than for non-energy companies, mostly due to a lack of industry-specific knowledge.

Targeting workers currently in related occupations can reduce the skilling burden. For example, it can take as little as three to five days for a plumber or gas boiler engineer to qualify as a heat pump engineer, while newcomers may require up to four years of training. Additionally, pre-existing certifications should look to integrate new clean energy skills into current curricula to ensure all new conferrals include these needed skills.

There is also a need to create new certifications and curricula to reflect emerging skill requirements, especially for new industries like CCUS and low-emissions hydrogen. Many energy firms have developed in-house training programmes to teach these skills on

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the job, but this comes at an added cost to industry. The time and cost barriers for retraining can be an even steeper barrier to workers themselves. For contractors or self-employed energy workers, time spent retraining may also involve a loss of income. Bootcamps, such as La Solive in France, are targeted to upskill those currently active in the workforce, minimising the time commitments required to pursue the needed reskilling.

Validation of skills, especially those that are not associated with an existing accreditation or formal education, can help improve the efficiency of hiring and improve the liquidity of the labour market for new energy segments. While there is currently no universal skills validation framework specific to energy, over 165 countries have adopted National Qualification Frameworks for the classification and recognition of knowledge and competencies for particular industries and occupations. Identifying new skills needs within the clean energy sector and integrating them within these frameworks will help foster a more efficient approach to upskilling workers.

Many of these initiatives and frameworks are concentrated in advanced economies; the energy transition in emerging market and developing economies will occur in a distinct context that translates into different skilling needs. While moving to codify energy qualifications remains important to minimise the safety and financial risks associated with energy transition work, in many emerging and developing economies these efforts will be secondary to the broader goals of achieving higher youth education levels, formalising the economy, and raising the base skill level of the greater workforce. India's Ministry of Skill Development and Entrepreneurship, for example, aims to build an ecosystem of skill development, with energy as just one component.

Examples of sector-specific occupations by energy technology

Solar	Wind
Photonics technicians	Atmospheric and space scientists
Solar energy systems engineers	Line installers and repairers
Solar PV installers	Wind energy engineers
Solar sales representatives and assessors	Wind energy operations managers
Solar thermal technicians	Wind turbine service technicians
Nuclear	**Batteries**
Nuclear criticality safety engineers	Battery testers
Nuclear reactor operators	Battery maintainers (emergency storage)
Nuclear R&D technicians	Battery inspectors
Nuclear waste process operators	Battery repairers
Radiation protection technicians	Plant and system operators
Heating, ventilation, and air conditioning (HVAC)	**EVs**
HVAC engineers	Automotive service technicians and mechanics
Installers	Electronics engineers
Mechanics	Engine and other machine assemblers
Service sales representatives	Software developers
Sheet metal specialists	Team assemblers

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Degrees and certification programmes may not meet the needs of the clean energy sector

Many companies in the clean energy sector will require an increasing number of workers with degrees in science, technology, engineering, and mathematics (STEM). The conferral of STEM degrees has been rising in some major economies, notably the United States, China and India, as students seek degrees that will help them secure stable work and income throughout their careers. In the European Union, by contrast, the share of university students graduating with STEM degrees has dropped over the last decade, contributing to major shortages in STEM occupations.

Higher education does not capture the full skill needs of the energy industry. For more than half of the 30 million additional clean energy workers on which the energy transition will depend in the NZE Scenario through 2030, vocational education and training (VET) is often a better fit. But despite recognition that VET will be critical to the green transition, these programmes are not expanding fast enough to meet the growing demand in the energy industry. In China, for example, enrolment in vocational education has been falling for years, with the proportion of high school students in vocational schools dropping from 60% around the turn of the century to 35% in 2020. This may in part be attributed to a poor image of VET among students, as well as a lack of understanding of the career and salary options that follow completion of vocational programmes. In addition, training courses tailored to fast-growing energy technologies are not always available. In the wind industry, for example, a lag between technical developments and training content, as well as insufficient training capacity, is contributing to a lack of properly trained workers. Similarly, the electricity sector is facing a shortage of skilled workers for the construction of transmission lines. In Australia alone, 15 000 more workers are projected to be needed by 2025 to build new transmission lines.

To ensure that workers can meet the evolving job and skill needs, close co-ordination between governments, agencies, education institutions and industry will be vital. Governments are best placed to facilitate greater exchange between the education institutions that train energy workers and the industries that need them. A more responsive and inclusive education system would enable existing low-skilled or underqualified workers to more easily receive additional training so that they too can gain the skills required by clean energy companies. As a central point of concern, it is essential that workers be involved in these discussions. Achieving a just transition for workers can be achieved by a tripartite social dialogue among governments, employees and their labour organisations, and employers.

Examples of such collaboration already exist. In Scotland, the Energy Skills Partnership agency connects the university sector with industry as a means of adapting STEM degrees to the needs of the energy transition, particularly in zero-carbon transport and construction. Similar initiatives include the Houston Energy Transition Initiative and the EU Pact for Skills.

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Vocation-specific clean energy technology training courses are available in many major economies, though coverage varies by technology

Training course availability by clean energy technology in selected major economies, 2023

Course Training	Argentina	Canada	Germany	Italy	Russia	South Korea	United States	Australia	China	India	Japan	Saudi Arabia	Türkiye	Brazil	France	Indonesia	Mexico	South Africa	United Kingdom
Wind	✓	✓	✓	✓	⬜	✓	✓	✓	⬜	⬜	✓	⬜	✓	✓	✓	✓	⬜	✓	✓
Solar photovoltaic	✓	✓	✓	✓	⬜	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Ground-source heat pumps	🟨	✓	✓	⬜	⬜	✓	✓	✓	✓	⬜	✓	🟨	✓	⬜	✓	✓	⬜	🟨	✓
Air-source heat pumps	🟨	✓	✓	⬜	⬜	⬜	✓	✓	⬜	⬜	⬜	⬜	⬜	⬜	✓	⬜	⬜	✓	✓
Battery storage	⬜	✓	✓	🟨	⬜	✓	✓	✓	🟨	✓	⬜	⬜	⬜	✓	⬜	✓	⬜	✓	✓
Building retrofits	✓	✓	⬜	✓	⬜	✓	✓	✓	⬜	✓	⬜	⬜	⬜	✓	✓	⬜	⬜	✓	✓

⬜ Not available 🟨 Under development ✓ Available

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Notes: Training courses refer to programmes which offer official certification, including vocational education. University qualifications and HVAC courses (unless specifically referring to heat pumps) have been excluded, as they are available in all the countries displayed. Not available = training courses not available.

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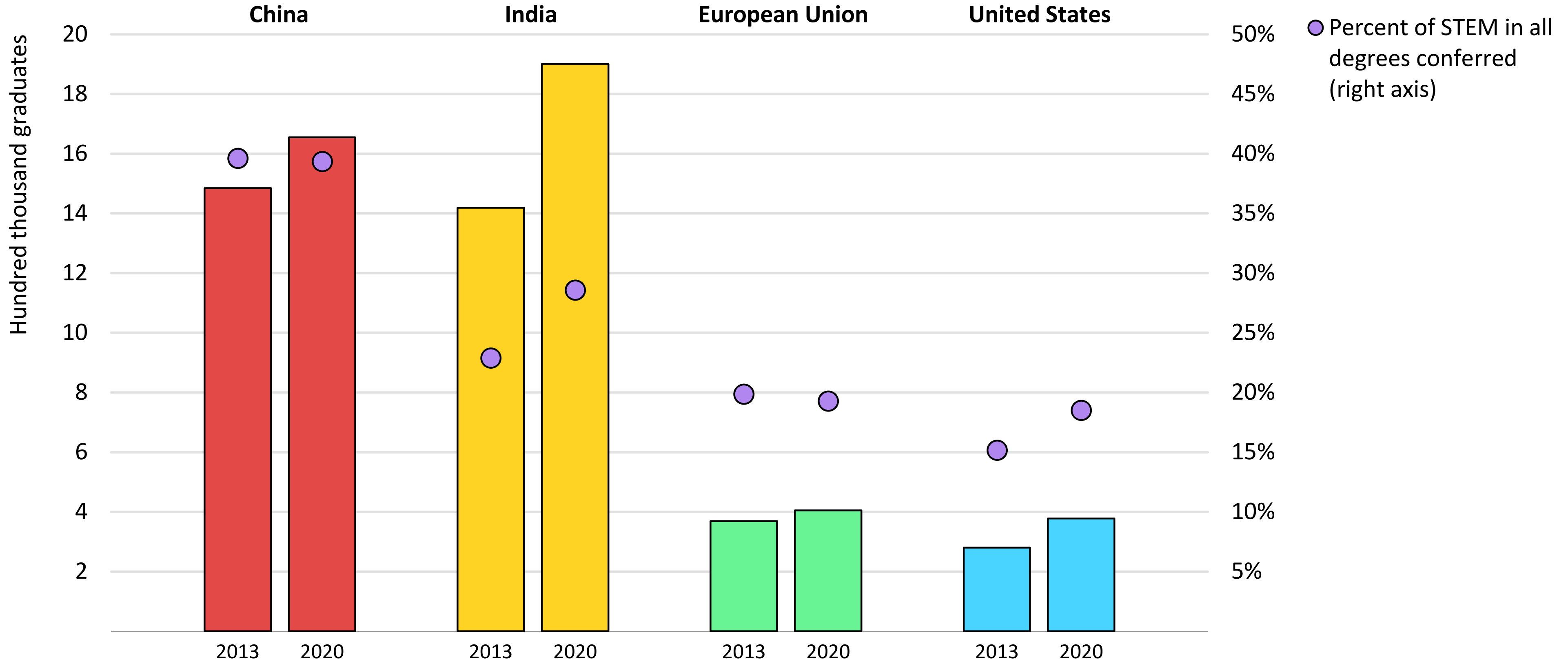
Conferral of STEM degrees has been rising in most major economies

STEM bachelor's degrees awarded in select economies



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Notes: European Union excludes Bulgaria, Croatia, Cyprus[1,2], Malta, and Romania due to data unavailability. Different data sources may create slight discrepancies in scope: China includes sciences and engineering; India includes science, engineering and technology; the United States and the European Union include engineering, manufacturing, construction, natural sciences, mathematics and statistics.

Sources: IEA analysis based on data from Chinese Ministry of Education National Base Statistics (accessed July 25, 2023), Indian Department of Higher Education All India Survey of Higher Education (accessed July 26, 2023), OECD.Stat Education at a Glance (accessed July 26, 2023), and the US Institute of Education Sciences, National Center for Education Statistics, Digest of Education Statistics (accessed July 25, 2023).

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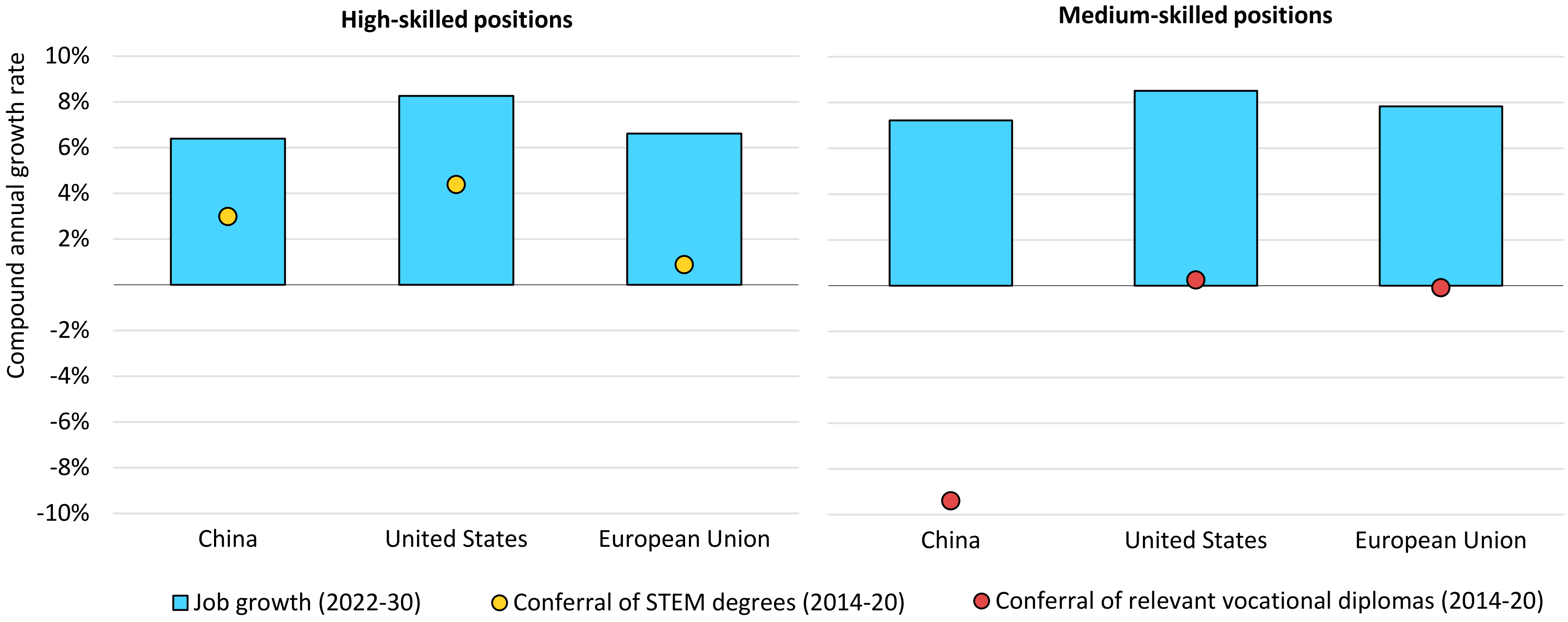
Education in vocational trades relevant to energy has stagnated or declined, despite demand for these workers growing rapidly, including in the energy sector

Job growth by skill level to 2030 in the NZE Scenario and conferral of relevant degrees in China, the United States and European Union



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Notes: European Union excludes Bulgaria, Croatia, Cyprus[1,2], Malta, and Romania due to data unavailability. Different data sources may create slight discrepancies in scope: STEM degrees include sciences and engineering for China; the United States and the European Union include engineering, manufacturing, construction, natural sciences, mathematics and statistics. Vocational data for China includes upper secondary vocational education in energy resources and new energies, manufacturing, and petroleum and chemicals; EU vocational data includes upper secondary vocational education in engineering, manufacturing, and construction and architecture; US vocational data refers to associate degrees and certificates below the associate degree level in construction trades, engineering technologies and engineering-related fields, and mechanics and repair," as upper secondary vocational education is not commonplace in the United States.

Sources: IEA analysis based on data from Chinese Ministry of Education National Base Statistics (accessed July 25, 2023), OECD.Stat Education at a Glance (accessed July 26, 2023), and the US Institute of Education Sciences, National Center for Education Statistics, Digest of Education Statistics (accessed July 25, 2023).

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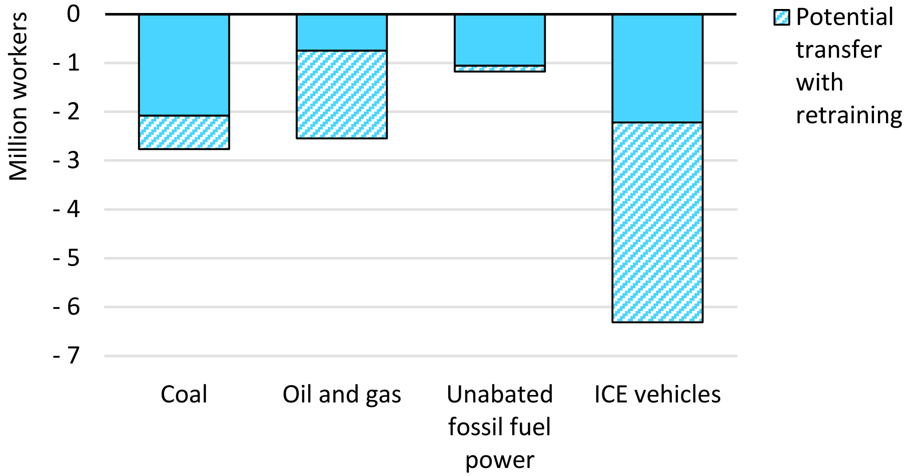
Workers from fossil fuel sectors can help address some of the skills demand, but for others making energy transitions people-centred is vital to their success

The changes in employment ushered in by the clean energy transition need to be carefully managed to minimise the social costs, maintain social license, and ensure labour does not become a bottleneck for the transition. Making transitions just for workers is thus becoming an increasingly important policy consideration, notably in communities intertwined with fossil fuel industries that are set to contract as the energy system is decarbonised. So far, most transition plans target coal communities, with an increasing focus on how best to support the diversification of oil and gas producing companies and their workers.

Fossil fuel-related job losses and potential for inter-industry worker transfer in the NZE Scenario, 2022-2030



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All net job losses in the energy sector through 2030 are in fossil fuels and related industries, with particularly steep cuts in coal supply and a rapid shift from ICE vehicle manufacturing to EVs. In some fossil fuel industries, workers already possess skillsets that can be highly applicable to other sectors: more than half of fossil-fuel related losses from 2022 to 2030 in the NZE Scenario are potentially transferable to other industries with retraining. Oil and gas workers, for example, tend to have skills needed in bioenergy processing, carbon capture, utilisation and storage (CCUS), hydrogen production, and geothermal. The UK's North Sea Transition Deal, for example, includes plans to shift personnel from the oil and gas industry to offshore wind and other clean energy sectors. Similarly, workers in ICE manufacturing may make a relatively straightforward switch to EV manufacturing, which booms in the NZE Scenario.

Workers in other industries, especially coal mining, will be more challenging to transfer. Some highly skilled coal miners working in modern, mechanised mining operations have many of the skills needed to transfer to related mining activities, such as critical minerals, though employment growth in this sector is unlikely to compensate for all coal job losses. However, coal mines in emerging and developing economies are less mechanised and rely heavily on unskilled workers. Coal transition risks are thus highly concentrated in these countries, where 90% of the coal supply jobs lost in the NZE Scenario through 2030 are located. Many of these job losses are set to occur under today's policies already, owing in

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part to efforts to further modernise mining, particularly in China. As a result, the STEPS sees over 650 000 jobs lost in coal mining by 2030. Upskilling workers and helping them identify and obtain commensurate employment opportunities will be essential to ensuring they are not left behind in the energy transition. In South Africa, for example, the Sector Jobs Resilience Plan for coal identifies mine rehabilitation and repurposing, manufacture and maintenance of renewable energy equipment, and beneficiation of coal waste as potential avenues for industrial diversification and skills development among miners.

In all cases, governments will need to comprehensively assess the profiles of workforces in declining sectors to understand their skillsets, compensation expectations, ages, and desire to reskill to determine the most appropriate strategy for reskilling or workforce phasedown. Some industries facing declining labour needs, for example, are working with unions to establish long-term plans and offer early retirement packages to workers who are not ideal candidates for reskilling. The coal transition in Germany's Ruhr region demonstrates how this bottom-up approach with a tripartite dialogue among coal companies, trade unions and governments can minimise the economic and social fallout and achieve a just transition for workers, as well as a successful transformation from a coal-driven industrial economy to a thriving knowledge-based one.

The European Union has recognised skilling as a prerequisite for a successful and just transition, identifying "skills" as one of the four pillars of its Green Deal Industrial Plan. Well-crafted training and reskilling programmes that offer certifications can facilitate career switches for energy workers. Developing effective training benefits from stronger co-ordination among public institutions, private firms, and academia to ensure new curricula and support matches industry's needs. These dialogues should ensure that the workers do not bear the onus of reskilling, and that this responsibility is managed by industry through on-the-job training and other support. This balance influences a range of factors, such as wages, labour market liquidity, and the attractiveness of certain regions to industry.

Creation of well-rounded training curricula is a necessary but insufficient action on its own to achieving a properly skilled workforce; ensuring accessibility and affordability of these programmes is equally important. Facilitating the participation of under-resourced workers can help ensure more equitable access to these new job opportunities. Support measures could include low-cost public transportation to technical schools, online options for training programmes, and reimbursement for the costs associated with upskilling, among others.

Social dialogue with workers, employers, civil society and government must form an important component of decision-making processes related to the design of labour transition plans, collective bargaining agreements, labour standards and measures to promote diversity and inclusion. Large-scale engagement can be time-consuming but tends to save time later and yields more durable outcomes. The International Labour Conference adopted a resolution at its 11th session in June 2023 laying out guidelines for a just transition for affected workers, including the role of governments, employers, and labour representation should play in these multi-stakeholder dialogues.

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Wages in the energy sector are typically higher than pay for similar occupations

Wages vary across the energy sector, but well-established industries such as oil, gas and nuclear still pay more than most newer sectors such as solar PV and batteries. This reflects a higher share of skilled labour in these sectors as well as the ability of established industries to offer more competitive compensation packages. For example, 53% of jobs in nuclear and 46% of jobs in oil and gas typically require at least a bachelor's degree, whereas this share stands at 34% for solar PV. Even vocational roles such as construction may require greater specialisation than in other industries, parlaying into higher pay. This wage gap acts as a barrier to shifting workers from oil and gas to clean energy sectors, especially for late-career workers.

Still, compensation in the energy sector is generally higher than in similar occupations in the broader economy, reflecting a greater degree of specialisation required in most roles. Solar PV installers, for example, can earn around 15% more than roofers and 40% more than telecommunication installers, jobs which require comparable skills. Similarly, HVAC installers can earn much more than average technicians, providing incentives for workers to retrain and gain qualifications for that profession. Still, there are a few clean energy jobs where this is not the case. For instance, battery assemblers earn less than assemblers in other specialised manufacturing sectors.

Wage premiums in energy are playing an important role in attracting needed skilled labour. Around 60% of the companies that took part in the IEA's Energy Employment Survey 2023 reported raising remuneration in the last year to attract staff, in most cases by more than the rate of inflation. For example, in the United States, energy sector pay rose by around 7.5% on average in 2022, compared to just over 1% economy-wide and inflation of 6.5%.

This trend affords opportunities for blue collar workers to upskill and move into higher paying roles. For those workers that require additional skills to enter the energy sector, wage premiums must be sufficiently high to incentivize them to spend the time and money pursuing retraining. Government financial support for retraining can help reduce those premiums. Pay is not the only mechanism to attract workers, who also value other benefits and working conditions such as flexible hours, less travel and a job they view as having a positive impact. In some energy sub-sectors, travel can be a major part of the work, as is the case for teams developing solar PV or wind farms, working on oil and gas rigs or mining critical minerals.

Labour unions can play a role in helping workers negotiate for higher pay and better working conditions, however their prominence in the energy sector varies markedly by sector and region. Labour representation tends to be higher in the well-established sectors such as the power industry, coal mining and oil production, while new energy industries tend to have less union representation. The implications of clean energy transitions are becoming a prominent aspect of labour negotiations, notably in vehicle manufacturing. The IEA's Clean Energy Labour Council brings together key labour representatives to highlight best practices that help ensure just and equitable labour outcomes through the clean energy transition.

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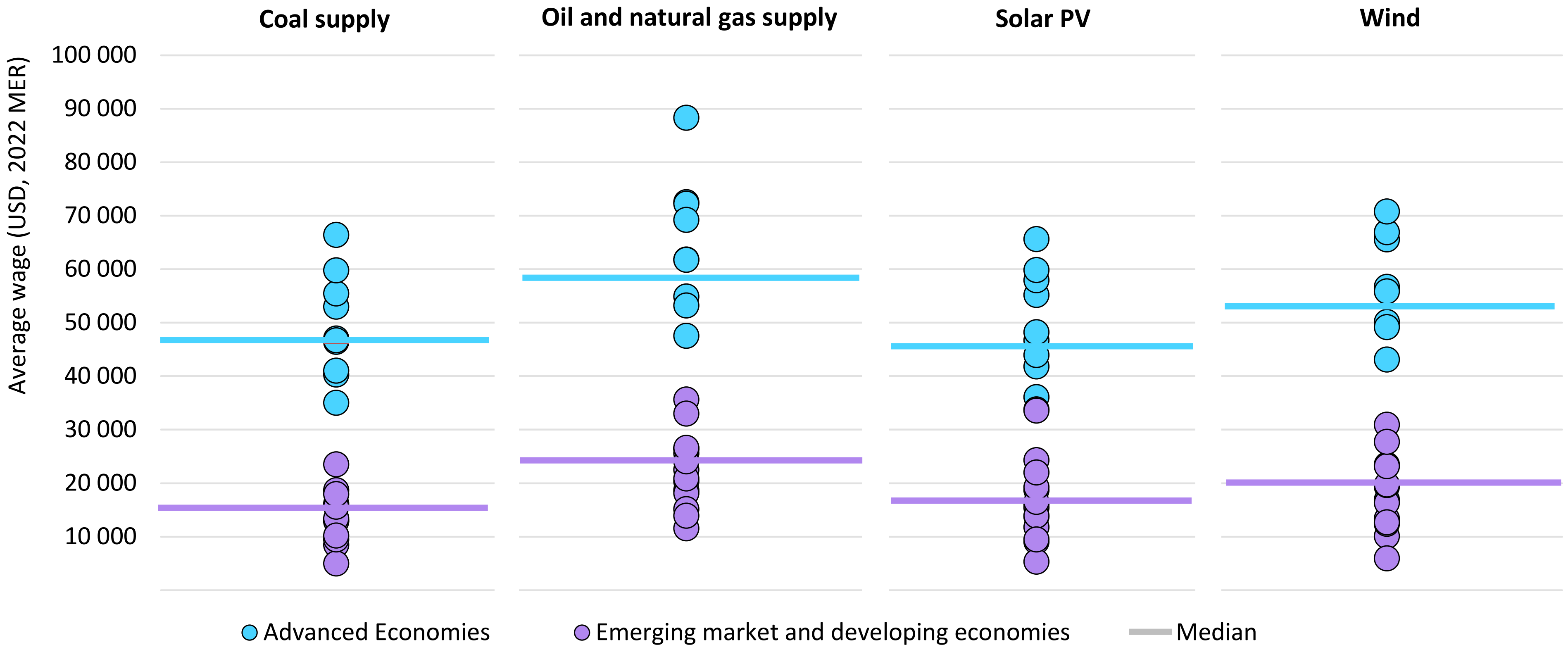
Workers in oil and gas supply generally earn more than in other energy industries, creating a barrier for those who may need to switch sectors because of the transition

Average annual earnings per worker in selected energy sectors and regions, 2022



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Source: The IEA developed this figure based on data from the Economic Research Institute (ERI). This figure includes only the countries available in the ERI database.

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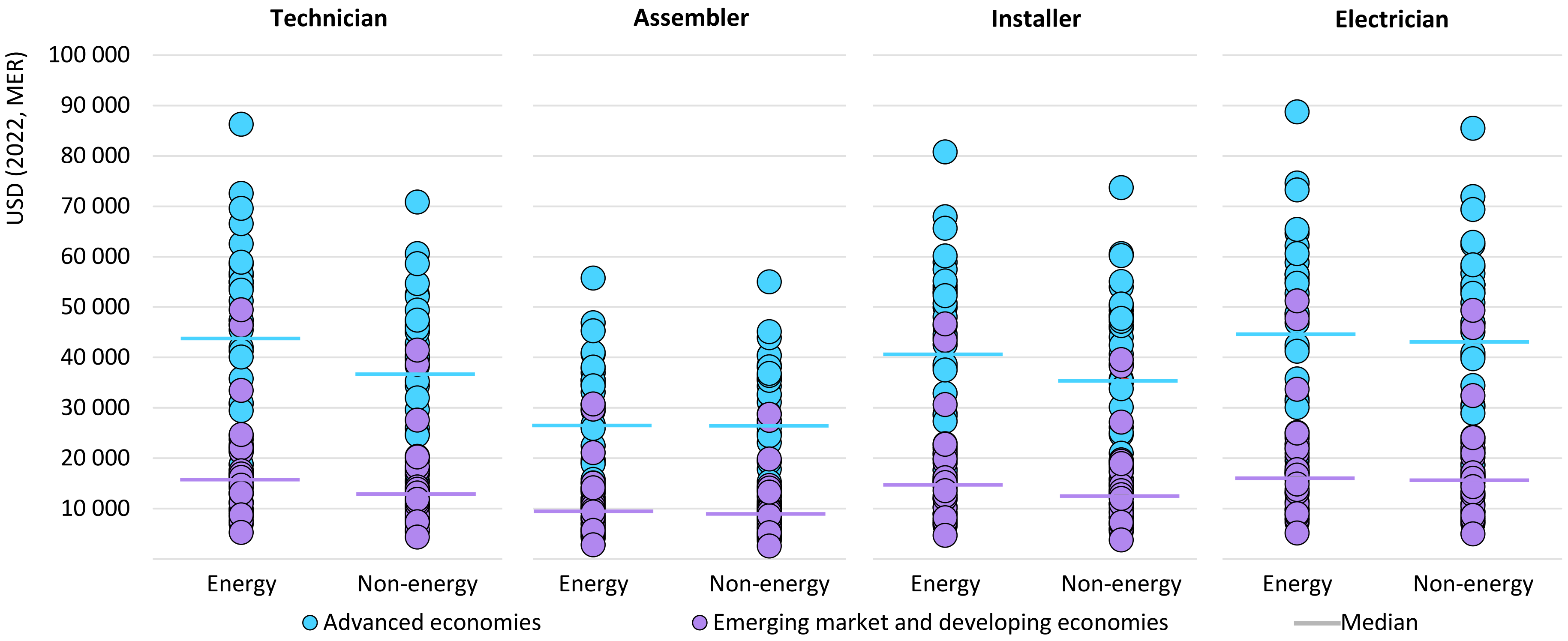
Jobs in the energy sector tend to pay more than comparable occupations in the broader economy, rewarding the additional skills they demand

Annual salaries compared in selected energy and non-energy occupations, 2022



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Notes: Technician refers to trained workers that perform general, complex and advanced assembly of products according to established specifications and instructions, and undertaking high precision calibration using testing instruments. Installer refers to workers that perform installations, repairs, inspections, reassembly, replacements, and refits products as required. Assemblers refers to a worker that utilises tools and machines to assemble parts and fabricate products. Reads and follows a bill of materials. Handles and manipulates small parts. Ensures that parts and finished products pass quality control checks.

Source: The IEA developed this figure based on data from the Economic Research Institute (ERI). This figure includes only the countries available in the ERI database.

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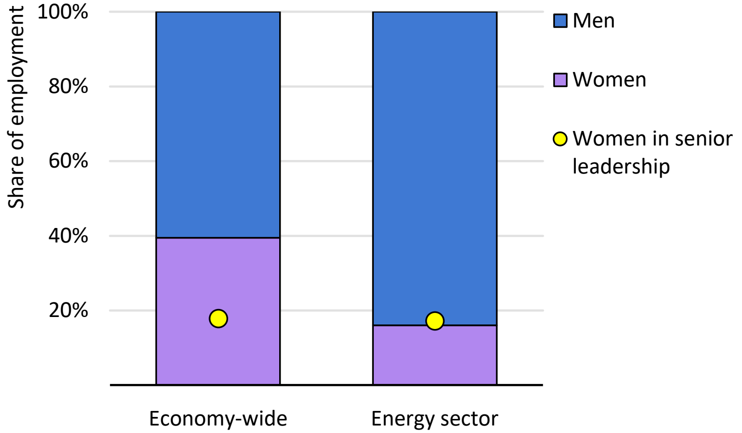
Women make up less than one-fifth of the energy workforce

Women have historically been underrepresented in the energy world. With net growth in energy employment exclusively in the clean energy sector through 2030, the transition offers an opportunity to redress this trend with more inclusive policies, at both the company and government levels. Currently, women make up less than 20% of the global energy workforce – well below the global economy-wide average of 40%. The share of women in senior management positions in major energy firms is similar to that of the broader economy, at around 18%, according to the IEA's Gender and Energy Data Explorer.

Narrowing the gender imbalance depends, in part, on increasing the number of women entering vocational or educational programmes relevant to energy, which continue to be dominated by men. In the United States, the number of women graduates in these fields is rising slightly, while the share of women awarded STEM bachelor degrees is gaining more significant ground, at over 40% in both India and the United States as of 2020. This is in stark contrast to the European Union, where the share of STEM degrees awarded to women has remained relatively flat at around 15% since 2013. Closing the gender employment gap also requires raising participation levels of women in construction and manufacturing, which account for a significant share of energy jobs and remain dominated by men.

The IEA's Gender Diversity Initiative has developed a set of indicators in an attempt to assist efforts to narrow the gender divide. Data indicators include the rates of gender balance in decision-making, entrepreneurship and innovation, and whether men and women have similar opportunities through wage-gap analysis.

Global employment by gender, 2022



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Notes: Employment shares are from the International Labour Organization (ILO) covering 48 countries for the energy sector. Senior management shares are IEA calculations based on the Refinitiv PermID database.

In emerging and developing economies, skilling programmes targeting women can help expand the available labour force and support growing local businesses. In 2019, the Kenyan Ministry launched a Gender Policy mechanism to raise the level of gender awareness in the energy sector, while international programmes in partnership with Bhutan, Nepal, and Sri Lanka also provide examples of potential policies to address the gender gaps in these regions.

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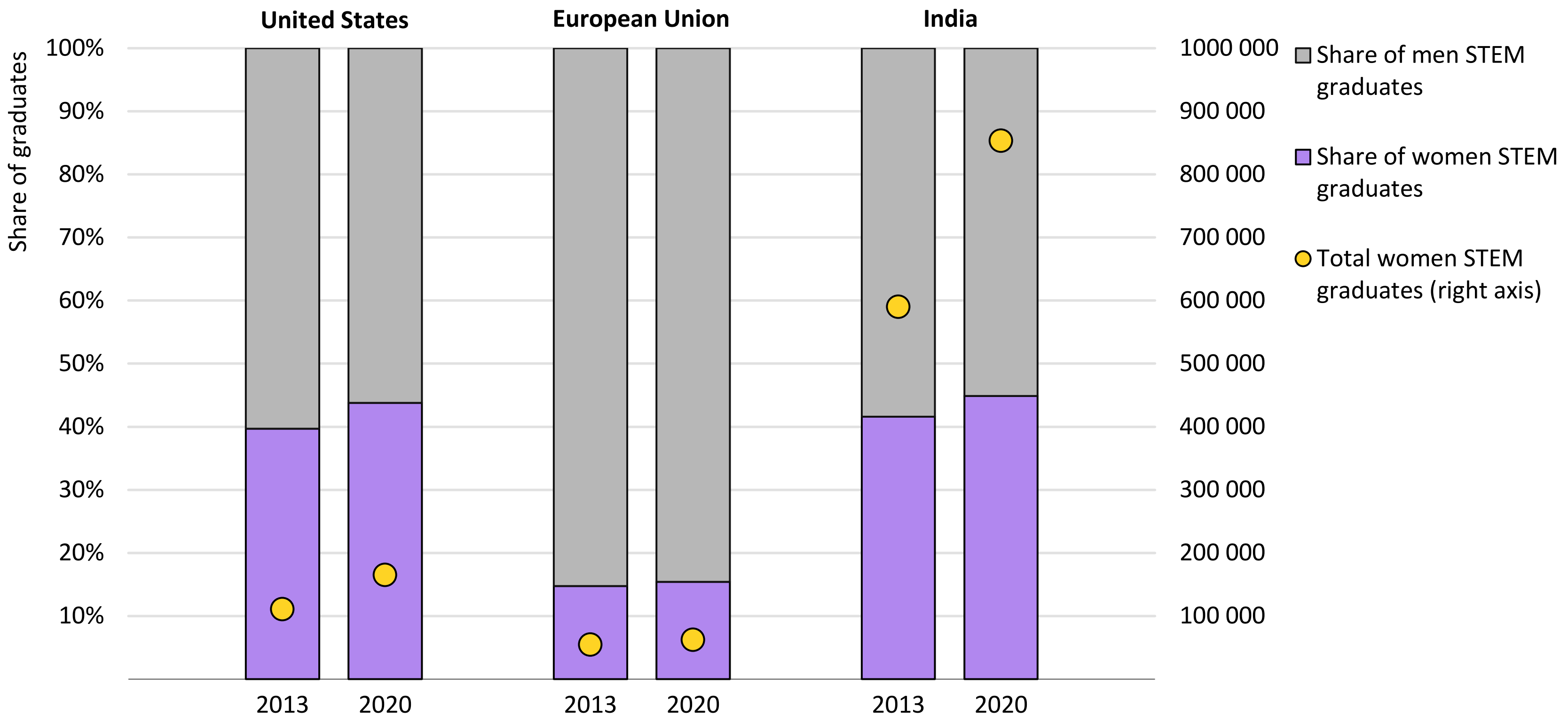
The number and share of women STEM graduates is rising, but remains well below half

Share of STEM bachelor degrees awarded to women in selected countries/regions



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Notes: European Union (EU) data excludes Bulgaria, Croatia, Cyprus[1,2], Malta, and Romania due to data unavailability. Different data sources may create slight discrepancies in scope: India includes science, engineering and technology; the United States and the EU include engineering, manufacturing, construction, natural sciences, mathematics and statistics. Sources: US National Center for Education Statistics, OECD, and Indian Department of Higher Education.

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Fuel and minerals supply

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Oil and gas jobs are back above pre-pandemic levels, thanks to strong growth in LNG

The global oil and gas industry employed over 11.5 million people in 2022, with around 7.6 million associated primarily with oil and 4.1 million with natural gas. Though total employment has recovered to above pre-pandemic levels, largely due to increased investment in midstream activities and liquefied natural gas (LNG), the number of workers focused primarily on oil remains below 2019 levels.

The global trend masks important regional differences which help explain why employment in oil and gas has returned to pre-pandemic levels before a recovery in investment, now expected in 2024. A third of the growth in oil and gas employment between 2019 and 2022 occurred in the Middle East – the only region where upstream oil and gas investment surpassed pre-pandemic levels. NOCs, which dominate the industry in the region, tend to have lower per-worker productivity than IOCs. As such, the average number of workers per dollar invested in upstream oil and gas in NOCs is about three times higher than those in IOCs.

Upstream investment remained below pre-pandemic levels in other regions in 2022, though this did not always result in lower employment. Most regions with major NOCs saw fewer layoffs during the pandemic than IOCs, with the notable exception of China, where ongoing efforts to improve productivity of its oil majors continued to reduce headcount. Many IOCs have been reticent in rehiring alongside the economic recovery from the pandemic. Some firms had already started to cut oil investments and staffing from their peaks around 2015, with the plunge in oil prices at the start of the pandemic accelerating this process. Despite a rebound in oil and gas revenues to record highs and an increase in investment in 2021-22, IOCs have not increased hiring, possibly due to lingering uncertainty around long-term employment needs. Instead, many IOCs have increasingly relied on oil field service companies and other contractors, which largely consist of lower-quality jobs. Rehiring has remained particularly limited in North America, which accounts for about 70% of upstream oil and gas employment in advanced economies.

As in the Middle East, South America has also seen the launch of several large new oil projects, led mainly by IOCs, which has fuelled job growth. They include ExxonMobil's USD 10 billion Yellowtail project offshore of Guyana and the USD 2.5 billion installation of Mero 4, the floating production, storage and offloading unit led by Petrobras in Brazil. New investments in refining have also contributed to an increase in oil jobs in Africa, with major refineries such as Dangote in Nigeria coming online.

A growing share of jobs in the gas industry are in LNG. Investment in LNG projects jumped in 2022, reaching USD 37 billion – an increase of almost one-third since 2021. Russian Federation (hereafter "Russia")'s invasion of Ukraine triggered a number of new LNG projects, including an increase in floating storage and regasification units (FSRUs): Germany alone has received three FSRUs so far, with three more expected online ahead of the 2023-24 winter. Additionally, about 60 liquefaction and regasification terminals are currently under construction or coming online worldwide. This led to an overall 18% increase in LNG-related jobs in 2022, with

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construction alone supporting nearly 150 000 jobs out of a total of 560 000 in the LNG sector.

The oil and gas industry is now facing a hiring crisis, exacerbated by the layoffs made at the beginning of the pandemic. Concerns about career security and the impact of the energy transition have made new workforce entrants hesitant to commit to a career in the oil and gas sector, especially in advanced economies. In the United States, for example, the number of petroleum engineering graduates fell by over 80% between 2017 and 2022. In addition, a growing number of oil workers have expressed interest in moving out of the industry. The skills shortage is further exacerbated by an ageing-out of workers.

Retaining and recruiting the skills needed in the oil and gas industry is further complicated by uncertainty about the pace of the energy transition and its impact on the sector. Employment in oil supply, which includes exploration, development, production and other jobs related to the upstream sector, grows by around 120 000 jobs worldwide, or 2%, to 7.7 million by 2030 in the STEPS, while the number of jobs in gas supply rises by 180 000, or 4%, to 4.3 million. The Middle East accounts for half of that increase. By contrast, worldwide, the oil and gas sector sees a decline of more than 2.5 million jobs, or around 20%, over the same period in the NZE Scenario.

These uncertainties highlight the importance of building a flexible workforce. Employers may need to expand their oil and gas labour forces in the coming years to accommodate short-term growth in fossil fuel demand, but they must also be prepared to retrain and upskill their existing labour forces to shift to other, cleaner energy sectors and more diverse project portfolios. The outlook for the demand for labour also varies across regions. In 2022, producers in emerging and developing economies employed around 80% and 75% of all oil and gas supply workers, respectively. These shares are likely to grow over 2023-30 as advanced economies seek to curb their production and consumption of fossil fuels more quickly than in emerging and developing economies, shifting labour demand to clean energy sectors.

The mobility and skills of oil and gas workers have already made them highly sought after by employers in other parts of the energy sector and non-energy industries. For example, chemical engineers in refineries can make use of existing skills for making hydrogen, biofuels and synthetic fuels. Similarly, engineering skills such as seismic interpretation, drilling, reservoir mapping and flow assurance are highly applicable to the carbon capture and storage (CCS) and geothermal industries. In 2022, the US Department of Energy granted more than USD 160 million to establish a consortium of experts with the aim of identifying labour needs in geothermal energy and drawing insights from best practices in the oil and gas industry.

There are limits on the transferability of skills to clean energy sectors. Not all the clean energy jobs that are created will be co-located or share the same skills as those lost. Late-career workers may also be reluctant to switch industries as they likely earn more in oil and gas than the wages in most clean energy sectors: oil and gas workers are among the highest paid workers in any sector thanks to their high level of skilling, well-established labour representation, and the need to compensate for occupational hazards and mobility requirements.

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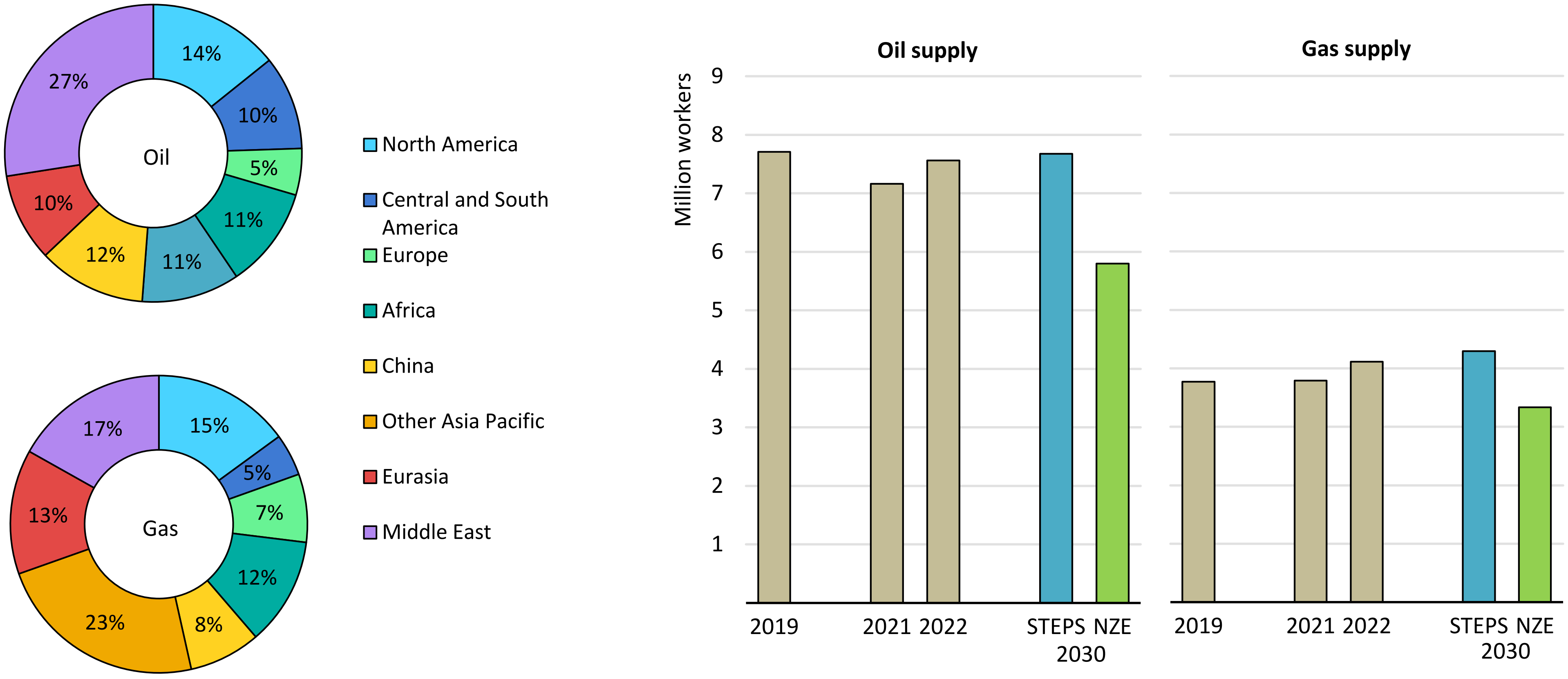
Not all the oil jobs lost during the pandemic have been replaced, with international companies reluctant to rehire, while gas sector employment continues to expand everywhere

Employment in oil and gas supply by region in 2022 and by scenario in 2030



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Notes: The gas supply chart includes employment in natural gas production, transportation and LNG. STEPS = Stated Policies Scenario, NZE = Net Zero Emissions by 2050 Scenario.

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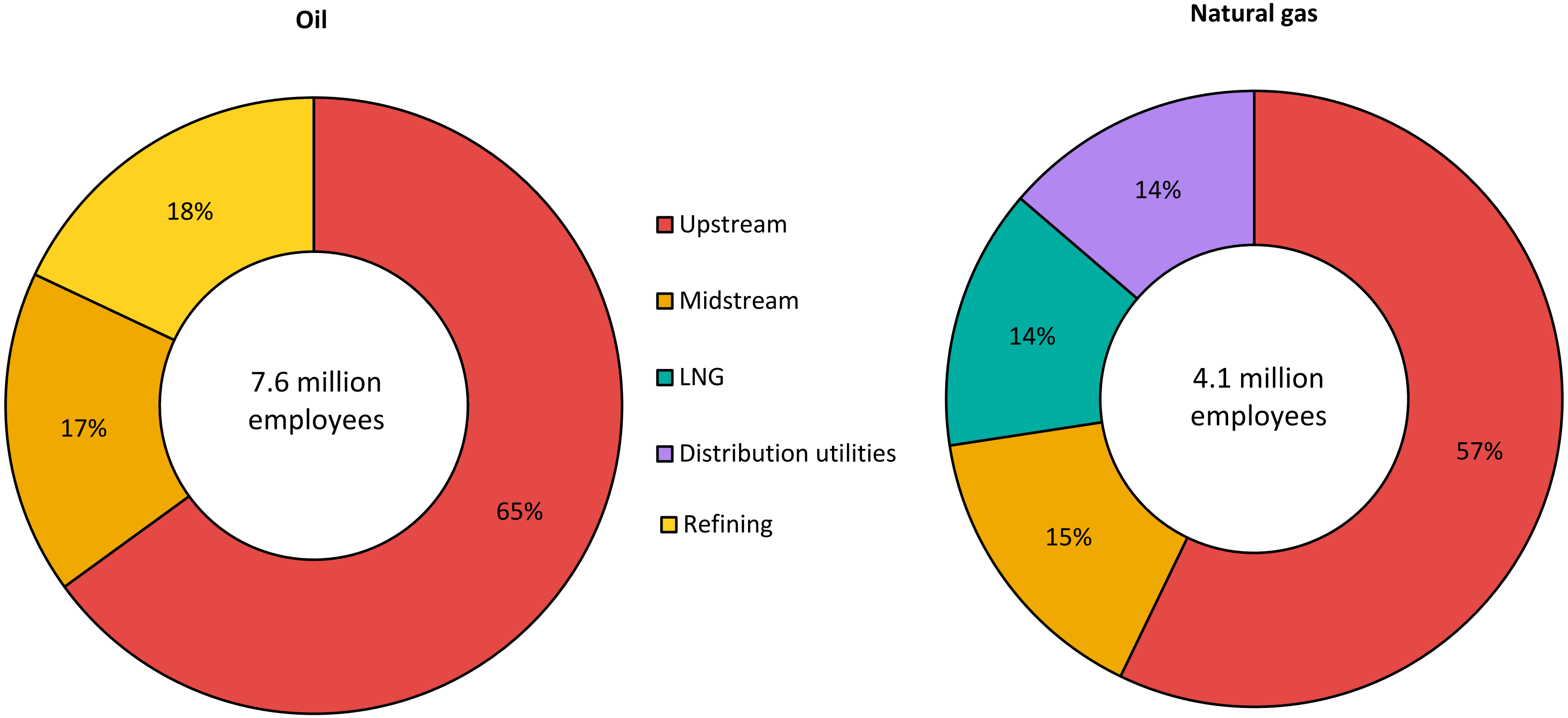
The majority of oil and gas workers focus on upstream projects, but the share of midstream activities and LNG is rising

Employment in oil and gas supply by supply chain segment, 2022



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Notes: These figures include employment in oil production, transportation, and refining. Midstream excludes all LNG-associated employment, including LNG transport. 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, CNG and electric charging service, as well as an array of other items).

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Global coal supply employment continues to fall, even as production rose by 7%, largely due to efforts to improve productivity

Global employment in the coal industry continues to contract, with the total number of jobs down to 6.2 million jobs in 2022. The decline of coal supply employment in China slowed in 2022, while employment in India continues to climb slowly, with labour productivity gains partially offsetting rising demand as the sector increasingly opens to private sector players. Increased coal production in advanced economies during the energy crisis did not translate into more jobs, though it did momentarily slow the fall in coal employment.

Coal supply employment remains concentrated in Asia, with China, India, and Indonesia together accounting for nearly 85% of all coal supply jobs worldwide in 2022. Coal mining in these three countries is less mechanised than in advanced economies. In China and India, for example, around ten times more workers are required per tonne of coal produced than in Australia or the United States. This highlights the potential for massive gains in labour productivity, which can allow employment to remain stable or even decrease as production rises. For example, for each coal mining job created in China between 2000 and 2022 due to increased production, 1.5 jobs were rendered redundant by productivity improvements. As a result, approximately 2.6 million jobs were lost while Chinese coal production grew by over 3% per year on average. These regions also have a much larger informal coal workforce than in advanced economies. Informal workers, included in the estimates, often earn far less than formal workers and face poor working conditions.

Of the fossil fuel supply sectors, coal employment is set to decline the most. In the STEPS, employment worldwide decreases by over 20% to 4.7 million jobs in 2030, a drop of 1.4 million. Part of this decline is due to improvements in labour productivity and mechanisation, as well as declines in coal production. Job losses are much bigger in the NZE Scenario, with employment plunging by 45%, or by 2.8 million jobs, to 3.4 million in 2030.

Helping redundant coal workers find alternative employment and dealing with the social impact of mine closures will become increasingly urgent as energy transitions advance. China's experience with scaling back coal employment offers lessons in this regard. In 2013, China instituted reforms to shut down illegal mining, consolidate coal mines, and improve competitiveness that halved coal mining employment in the country by 2020. In 2016, the Ministry of Finance allocated CNY 100 billion (USD 15 billion at a 2016 exchange rate) to an Industrial Special Fund, which was set up to support newly-unemployed coal mine workers through direct welfare payments, job creation, early retirement benefits and help with finding other work. By the time the fund closed in 2020, it had helped 1 million former coal workers find new jobs. Additional aid from the provinces was also made available. Nonetheless, a calculation of assistance per worker helped indicates that the financial aid was likely insufficient to support all coal mining workers who lost their jobs. Moreover, today around 90% of workers live within 400 km of a critical mine or deposit, potentially offering new opportunities.

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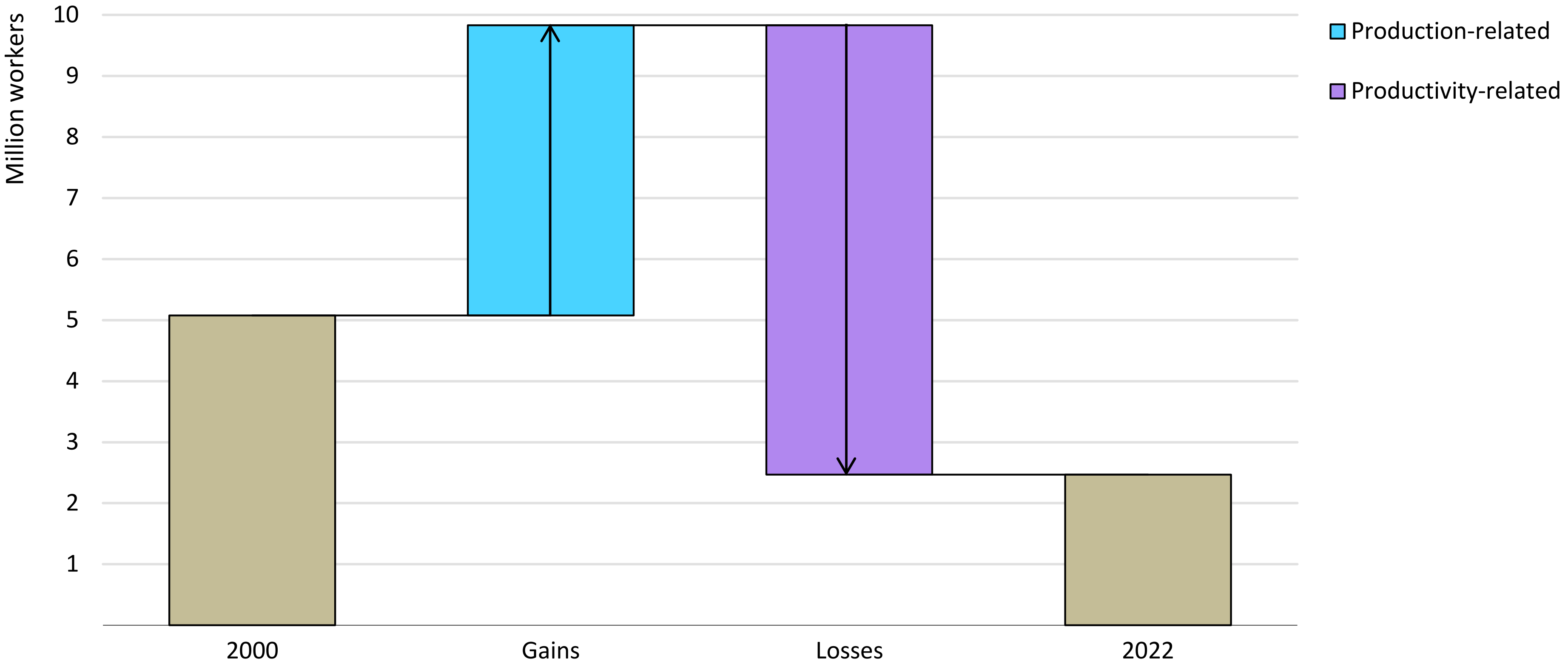
Labour productivity increases, driven primarily by mechanisation and automation, are the main causes of declining coal employment

Changes in coal mining employment in China, 2020-2022



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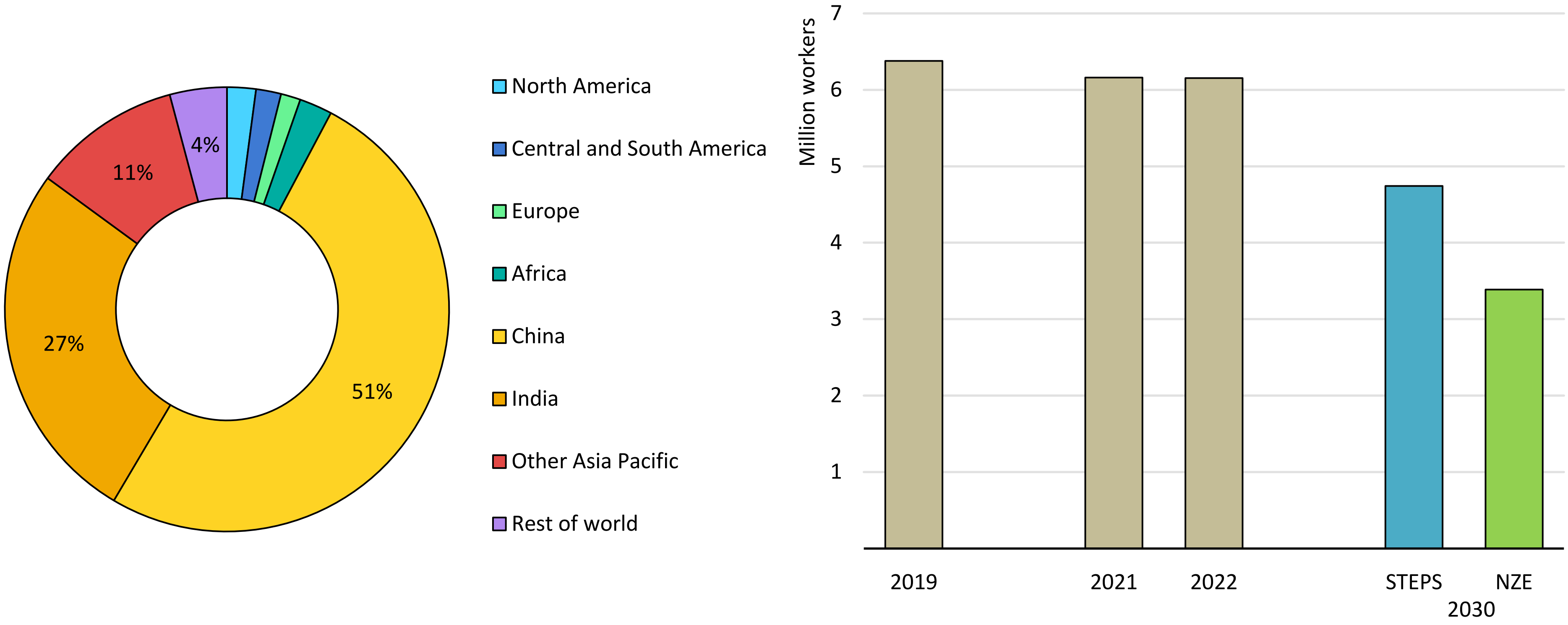
Coal jobs, which are concentrated in China and India, are set to continue their decline as labour productivity rises

Employment in coal supply by region in 2022 and by scenario in 2030



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Notes: Includes coal production and transportation, but excludes coal transformation for blast furnaces and coke ovens. STEPS = Stated Policies Scenario, NZE = Net Zero Emissions by 2050 Scenario.

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Biofuel and biogas employment is set to grow as fuel blending targets ratchet up

Brazil, Indonesia, and the United States together account for just over 30% of the 3.6 million people working in the bioenergy industry globally in 2022. This includes growing feedstocks, processing them, building and operating biofuel and biogas production facilities, and delivering those fuels to market. However, producing biomass pellets, processing crop residues and waste, and producing charcoal are excluded. Around 40% of all the jobs in this sector are related to growing and processing feedstocks.

Biofuel demand worldwide rose by 5% to just over 2 million barrels of oil equivalent per day (mboe/d) in 2022, equal to 4% of transport sector oil demand. The gains largely reflect a rebound in oil demand from lower pandemic levels, but also efforts in some countries to increase production for use of locally produced biofuels in the wake of the energy crisis. The outlook for demand growth is projected to be about 40% lower in 2022, while at the same time some countries, including Brazil, China and Indonesia, saw important increases in liquid and gaseous biofuel investments from the previous year. Moreover, a number of countries with flexibility to increase blending rates, notably Argentina, India, and Indonesia, did so to reduce oil imports.

Biogas production relies on a large number of small facilities reliant on crop residuals, manure, municipal solid waste and wastewater. China was the largest producer in 2022, followed by Europe and the United States. A large number of new facilities around the world were completed in 2022, with more slated to come online in 2023, contributing to growth in new construction-related jobs. In the United States alone, over 120 biogas facilities were under construction or brought online in 2022, while about 300 new plants came online in Europe over 2022.

Employment in the bioenergy sector as a whole is poised for further expansion. The total number of jobs globally reaches approximately 4 million by 2030 in the STEPS, based on a projected 50% increase in global fuel production. Biogas and biomethane production also increases around threefold, with most of the gains occurring in Europe, with an additional USD 18 billion of investment in the pipeline through the end of this decade. Most of the employment growth in this sector is in feedstock production and processing. In the NZE Scenario, bioenergy use grows much more quickly, boosting employment to almost 6 million by 2030.

While solid bioenergy is not considered in our estimates of total employment, it can be sizable, especially where charcoal is used as a primary cooking fuel in the developing world. Those jobs are typically informal, covering the harvesting, processing and distribution of charcoal and fuelwood. Some estimates show that nearly 7 million people work in the charcoal trade in sub-Saharan Africa alone.

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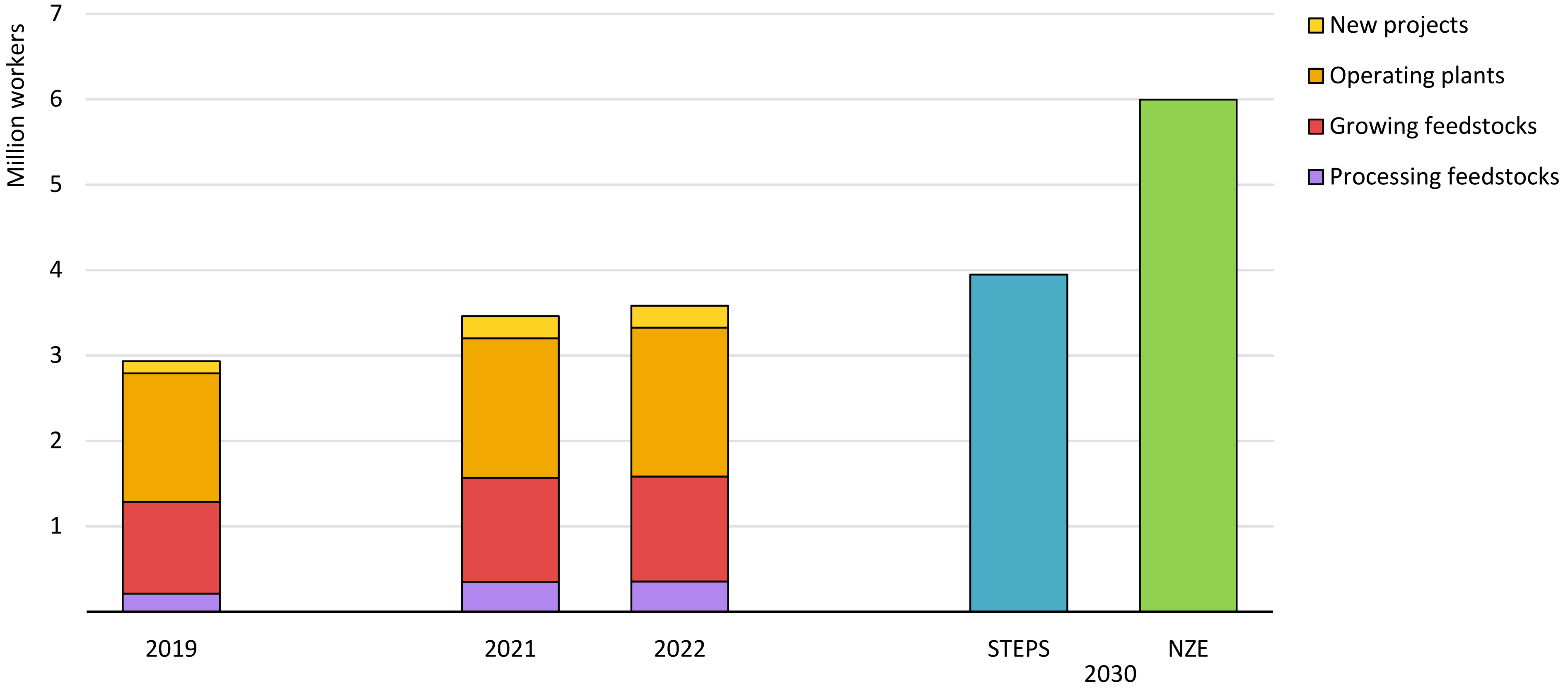
Ambitious new policies for biofuels and biogas point to significant growth in the workforce to 2030, but getting on track for net zero by 2050 would require a much bigger increase

Employment in bioenergy supply by value chain step, 2019-2030



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Notes: STEPS = Stated Policies Scenario, NZE = Net Zero Emissions by 2050 Scenario.

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Mining critical minerals for clean energy technologies currently employs over 800 000 workers, and could double by 2030 on a pathway to net zero emissions

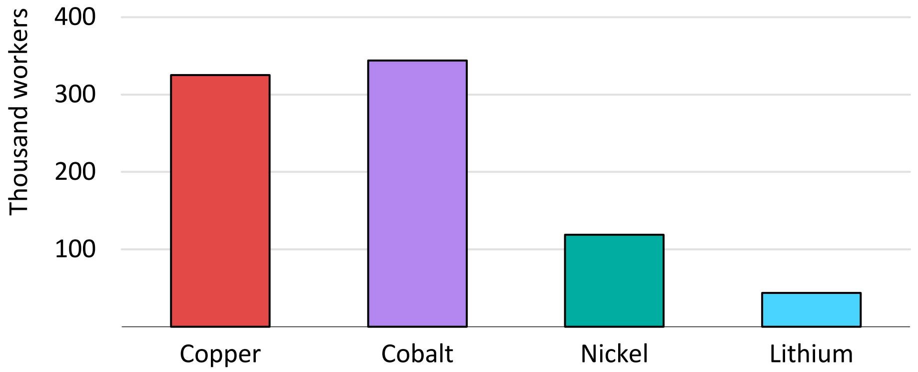
Global demand for critical minerals, which includes copper, cobalt, nickel and lithium in this report, has grown rapidly in recent years, driven in large part by clean energy technologies, especially batteries for EVs, wind and solar PV. In total, demand for lithium tripled, cobalt jumped 70% and nickel rose 40% between 2017 and 2022.

Worldwide employment in mining critical minerals – included for the first time in this report – has risen in line with growing production. On average, the workforce grew at a rate of 8% per year between 2019 and 2022, to reach an estimated 800 000. Growth was particularly strong in 2022, up by more than 25%, due to a record jump in demand from battery manufacturers. Employment in critical minerals processing is not included here due to insufficient data.

Mining jobs for these critical minerals are concentrated in a handful of countries where larger mines operate, notably Indonesia and major producers in Africa and South America. Copper and cobalt mining currently employ the largest number of workers in almost equal numbers. While the volume of cobalt produced is much smaller than that of copper, it has much higher employment, owing to the presence of a number of small, largely unmechanised artisanal mines. Lithium requires less labour per tonne produced than other critical minerals as it is also extracted using brining techniques, which can be highly mechanised.

Most mining-related jobs are in the operation of the mine and transport of materials to processing facilities, requiring skilled miners able to operate heavy machinery safely. This represents the vast majority of mining operations globally today that are typically owned or operated by large mining multinationals. However, in developing economies, low-skilled labour, often informal, does play a role, as is the case with cobalt extraction in the Democratic Republic of the Congo. Informal workers there typically lack adequate safety training and equipment, having also the worst working conditions and lowest salaries compared to formal workers. The total number of workers in cobalt extraction in the country is hard to assess, yet estimates can be as high as 250 000, with child labour making up around one-fifth of the workforce.

Global employment in selected critical minerals extraction, 2022



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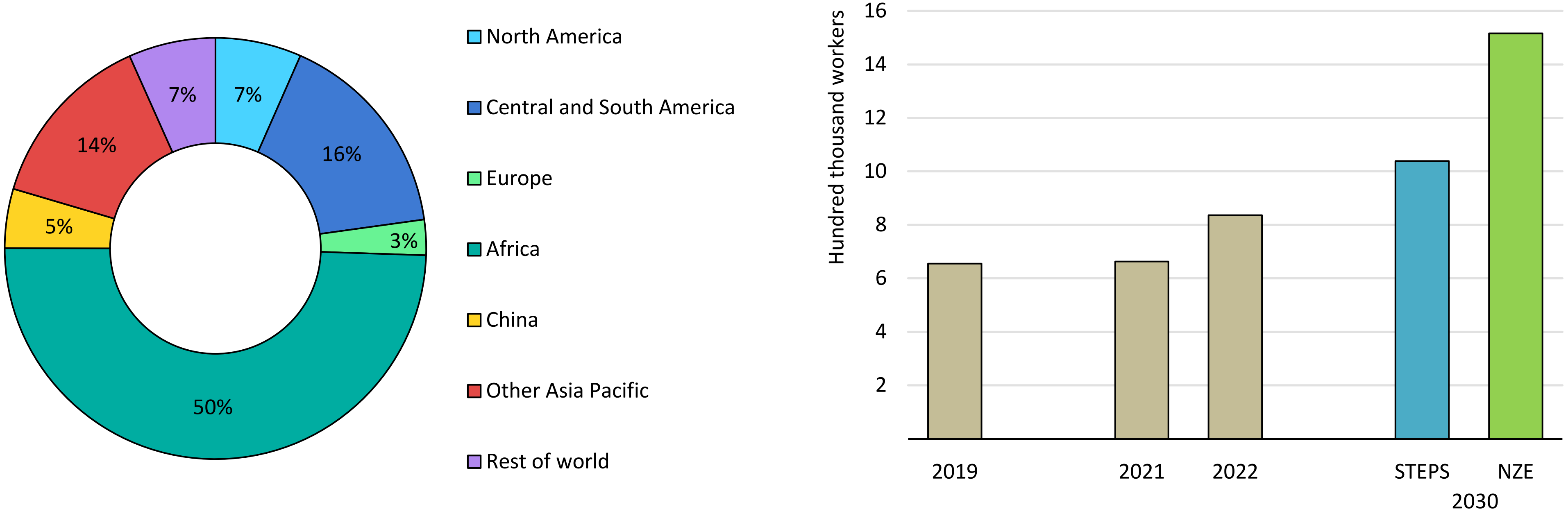
Jobs in exploration and development of new mines require more professionalised skill sets. They represent a small share of total mining employment, but companies cited challenges in hiring for these positions as fewer students pursue education relevant to mining, in part due to negative perceptions of the industry in advanced economies. This challenge is set to get worse as global exploration spending rose by 20% in 2022, led by Australia and Canada.

Continued strong growth in demand for critical minerals used in clean energy technologies is set to further boost the need for workers, though a push to increasingly mechanise new and existing mining operations is expected to temper labour demand growth in the coming years. In the STEPS, the global mining workforce expands by 25% between 2022 and 2030, driven primarily by growth in battery production for EVs and stationary storage.

Employment in critical mineral extraction by region in 2022 and by scenario in 2030



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Notes: Critical minerals include cobalt, copper, lithium and nickel. STEPS = Stated Policies Scenario, NZE = Net Zero Emissions by 2050 Scenario.

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The hydrogen supply and CCUS workforce is small today, but would expand in a net zero world

The number of people currently employed in key low-emissions innovative technologies, such as low-emissions hydrogen and CCUS, is estimated at around 50 000 workers globally. In addition, many more workers are involved in other sectors essential to clean technology innovation which are not captured in this report.

Clean hydrogen employment, in the context of this report, includes hydrogen from electrolysis as well as steam-methane reforming with CCUS. This represents only a small share of the total workforce connected with today's hydrogen supply chain, most of which is produced using unabated fossil fuels and is mainly associated with industrial processes such as fertilizer production and petroleum refining. Total production of low-emissions hydrogen was less than 1 Mt in 2022, virtually all of which was produced via steam-methane reforming with CCUS.

Low-emissions hydrogen production is set to grow strongly in the coming years. Over two dozen countries around the world, including Japan, Oman, South Africa, Australia, and Germany, have adopted national hydrogen strategies. In 2022 alone, nearly USD 3.5 billion of hydrogen production projects were approved worldwide, more than a 750% increase from 2021. Major companies are establishing strategic partnerships to secure future supply, and the world's first international shipment of liquefied hydrogen occurred in 2022.

Countries seeking to become hydrogen hubs must plan and cultivate a skilled hydrogen workforce. The industry is still at an early stage of development, involving considerable amounts of research and development as well as construction of demonstration projects. As such, there is strong demand for highly skilled positions, such as engineers and experienced generalists. As the industry scales up, the skillsets required will increasingly resemble those in oil refining, gas processing and chemicals, including knowledge and experience of safety protocols, operations and process control. A number of oil, gas and chemical companies, such as Shell, BP, and Sinopec, are working on early electrolytic hydrogen projects.

Employment related to CCUS, including workers in industry, power, and direct air capture (DAC), is difficult to dissociate from other sectors as it overlaps with other employment categories in this report such as power generation, oil and gas, and hydrogen. Still, employment is set to steadily increase with the growing number of CCUS projects announced, thanks to a host of new incentives for pilot carbon sequestration projects, notably as a result of the US Inflation Reduction Act. The announced pipeline for new CCUS capacity is more than 100 000 t/yr as of 2022 (and 1 000 t/yr for direct air capture facilities).

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Given CCUS's strong interconnection with other parts of today's energy system, most CCUS workers must possess knowledge and skills that span both industries. For example, those involved in enhanced oil recovery must have knowledge of oil and gas extraction and CCUS. Similarly, many skills essential to the CCUS industry can be found in parallel industries, which can be drawn upon as employment grows. For instance, some DAC technologies rely upon well-established equipment used in chemical industries, and workers with skills in process engineering or operational knowledge of chemical plants are valuable to local DAC facilities. CCUS-focused skills can thus be integrated into broader curricula relevant to the oil, gas, and chemicals industries. Industry is already engaging with educators and retraining programmes to develop relevant curricula and highlight opportunities for job transfers.

Uncertainty about the pace of the development of these innovative industries and the insufficient stock of experienced personnel are complicating efforts to prepare training programmes. Extensive on-the-job training is common within the industry, but educational institutions are wary of building new programmes around a technology for which labour demand is still uncertain. That uncertainty is reflected in our different scenarios. In the STEPS, global employment in low-emissions hydrogen supply and CCUS see only modest growth. By contrast, in the NZE Scenario, employment increases twenty-fold to almost 800 000 jobs, partially compensating for the job losses in the oil and gas industry. When considering employment in hydrogen, CCUS and other growing sectors which share skill requirements with oil and gas, total employment stays roughly the same at today's levels in the NZE Scenario 2030, highlighting the opportunity for these firms to diversify their portfolios and reapply their current workers' skills to new technologies.

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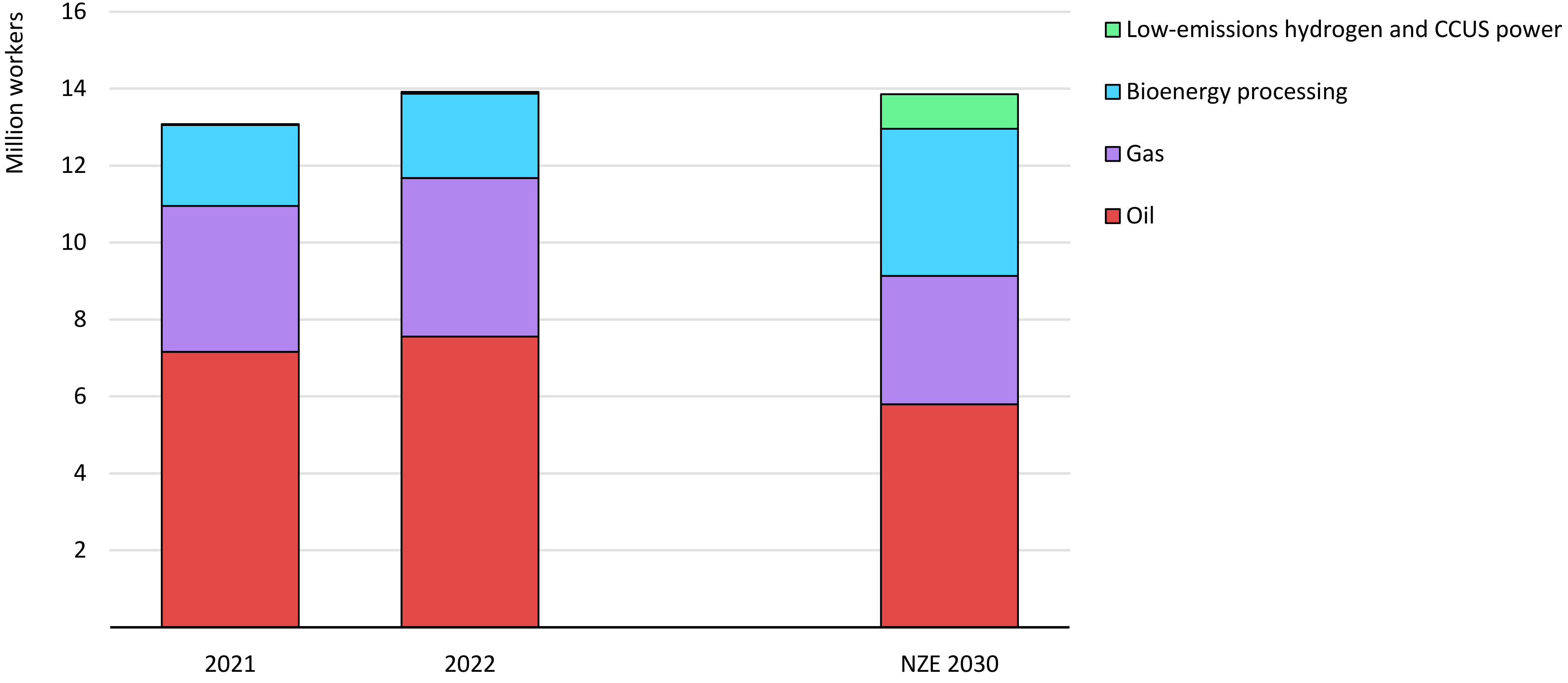
Low-emissions hydrogen, CCUS, biofuels, and other jobs in clean innovation jobs grow in the NZE Scenario, nearly compensating for losses in oil and gas

Global employment in fuel supply by type in 2022 and in the NZE scenario by 2030



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Note: NZE = Net Zero Emissions by 2050 Scenario.

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Power sector

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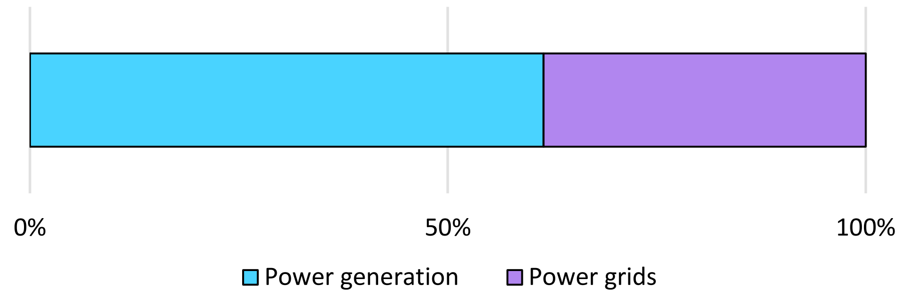
Power sector jobs total more than 20 million, with the overwhelming majority in clean energy

Global power sector employment, including generation and grids, exceeded 20 million in 2022. Power sector investment increased by around 12% in 2022, to USD 1.1 trillion, and 2023 is expected to see further growth.

Global power sector employment by segment, 2022



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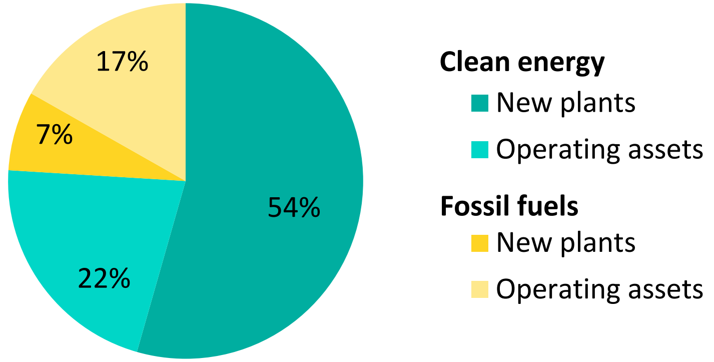
Notes: Power grids include transmission, distribution and storage. Storage refers only to battery storage, including both on grid and distributed batteries. Pumped storage hydro is included in hydropower.

More than half of power sector jobs, or around 11 million, are in the operations and maintenance of existing capacity. Manufacturing power system equipment totals approximately 3 million jobs. Building power plants, dams, grids and mounting systems for solar PV panels employs just above 6 million jobs. Global power generation accounted for an estimated 12.5 million jobs in 2022, of which 3.9 million worked in solar PV, 2 million in hydropower and 1.7 million in coal power. Wind power, including onshore and offshore, employed slightly over 1.5 million and nuclear power 1 million. Employment in hydropower surpassed that in coal power generation in 2022, ranking second only to solar PV. Clean energy accounted for more than 75% of all the jobs in power generation.

Global employment in power generation by sector, 2022



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Note: More than 75% of employment associated with operating clean energy assets is in hydropower, nuclear and solar PV.

Power generation employment has been growing steadily in recent years in line with rising installations of new clean power generation. Capacity has grown at an average of more than 4% per year over the past decade, to 8 600 GW in 2022, with more than 75% of new additions being renewables. Building new power generation facilities is the largest driver of employment in the sector, representing over 60% of jobs. Accordingly, the number of jobs rose by 14% between 2019 and 2022.

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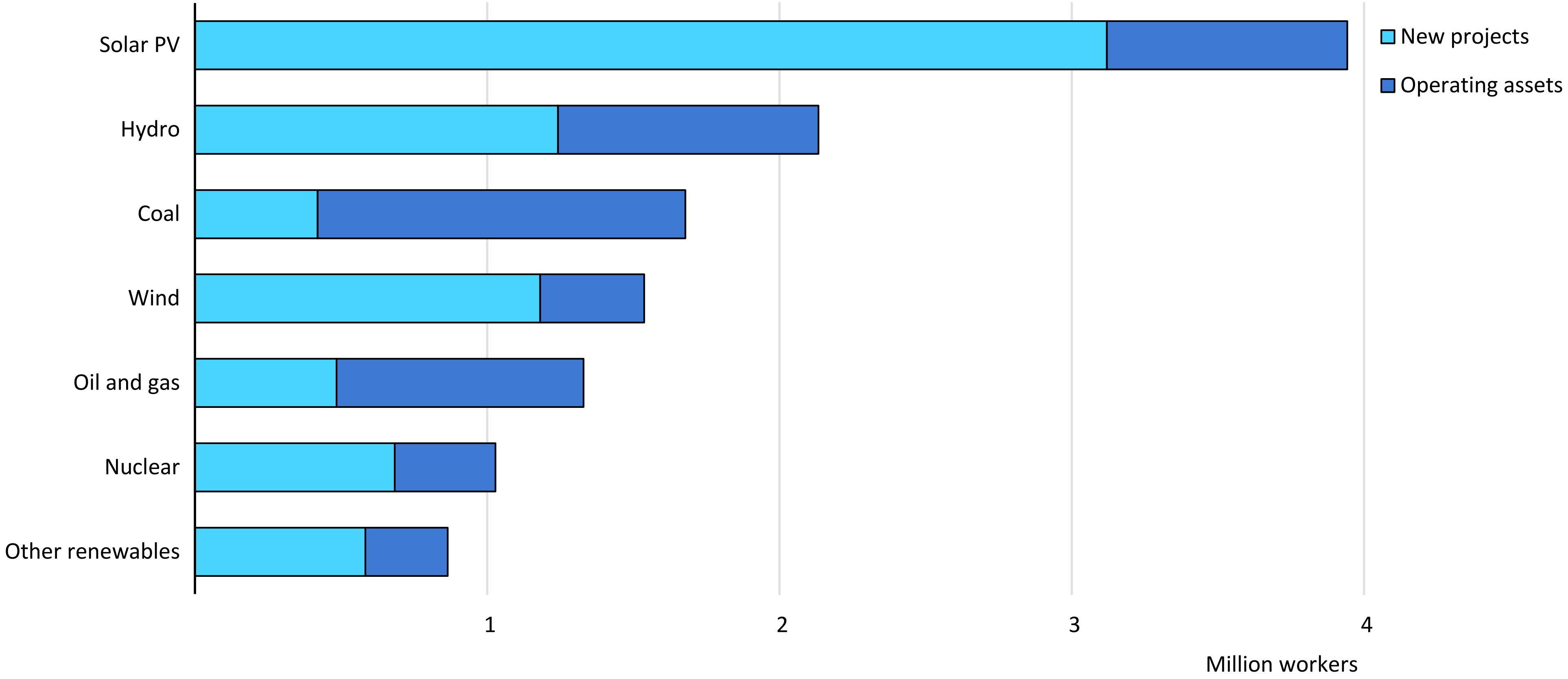
The power generation sector workforce is just over 12.5 million people worldwide, with more than 60% employed building new projects

Global employment in power generation by technology, 2022



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Note: Other renewables include geothermal, concentrating solar power (CSP), marine and bioenergy.

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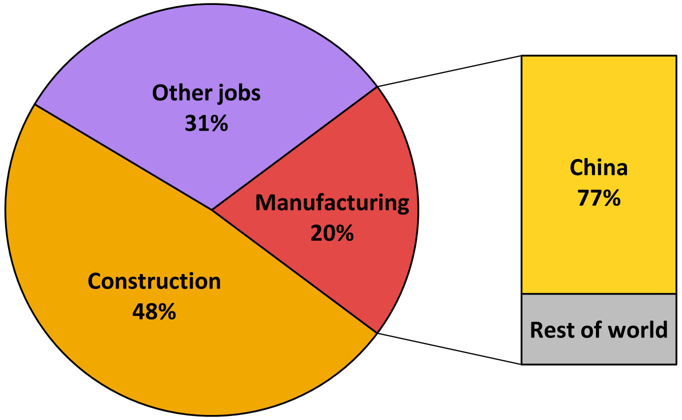
Solar PV employs 3.9 million workers, mainly engaged in installing new capacity

Employment in the solar PV sector worldwide exceeded 3.9 million jobs in 2022, an increase of more than 13% over the previous year. This increase was nonetheless smaller than that of installations, which grew by almost 24%, reflecting a significant improvement in productivity and an easing of problems in hiring enough workers to keep pace with demand. Around two-thirds of PV jobs today are associated with distributed solar (rooftop and other small-scale installations), which is more labour intensive per unit installed than utility-scale projects.

Construction, which encompasses the installation of solar panels in both individual homes and utility-scale solar farms, is by far the largest contributor to employment in the solar PV sector, representing nearly half of all PV jobs worldwide. Manufacturing, which covers production of polysilicon, wafers, cells, modules, and inverters, as well as racking, mounting, and other components, represents around 20% of total employment. Over 75% of these jobs are concentrated in China where the vast majority of the world's solar panels are manufactured. The shift to larger production lines continues to improve labour productivity and lower the cost of key solar components. The five main components listed above represent around 70% of total solar PV manufacturing employment. In 2022, solar PV manufacturing capacity grew by nearly 40%, with almost all of that growth occurring in China.

Off-grid solar home systems sales are playing an increasingly prominent role in regions without universal electricity access today, mainly in sub-Saharan Africa where around 8% of households with access to electricity rely on these systems. Rapid growth in this sector has boosted the number of solar PV jobs in Africa to an estimated 115 000 in 2022.

Shares of solar PV jobs by economic activity and region, 2022



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The global prospects for solar PV employment hinge on the strength of policies to boost installations, as the announced pipeline of new manufacturing is already sufficient to supply solar deployment levels consistent with the NZE Scenario. In the STEPS, the solar PV industry adds over 1.1 million jobs by 2030, taking the total workforce to 5.1 million. In the NZE Scenario, the workforce grows much faster, with more than 2.5 million new jobs boosting the total to 6.6 million.

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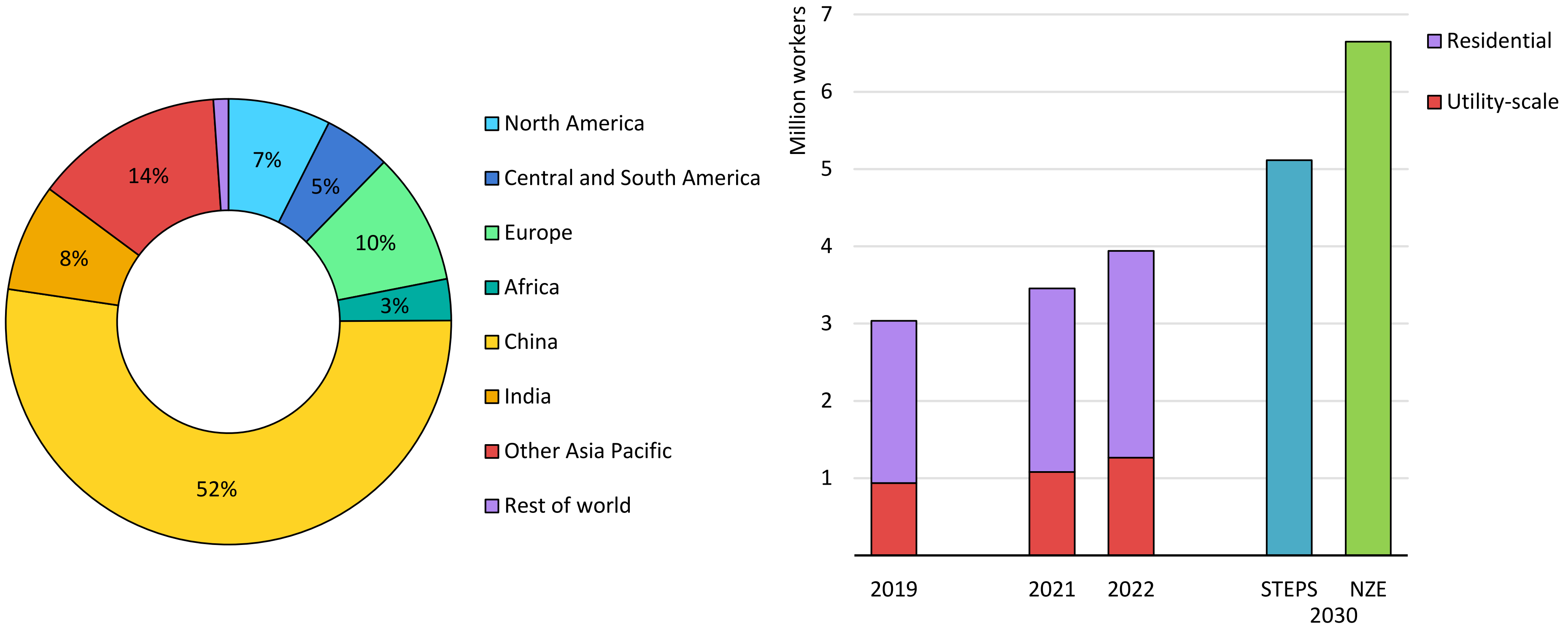
The growth in solar PV employment to 2030 hinges on policies to accelerate energy transitions

Employment in solar PV by region in 2022 and by scenario in 2030



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Notes: STEPS = Stated Policies Scenario, NZE = Net Zero Emissions by 2050 Scenario.

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Wind power employs over 1.5 million people, with onshore projects providing 80% of jobs

Employment in wind power generation exceeded 1.5 million people worldwide in 2022, an increase of over 100 000, or 7%, compared with 2021. This represents a recovery in the rate of wind employment growth, which had slowed to less than 5% in 2021. That deceleration reflects the global slump in the wind energy sector in 2021 and 2022, as project developers and manufacturers faced rising input costs and the expiration of major government incentives in China and other countries. Due to the contract-based nature of wind power projects, turbine suppliers and developers saw their margins shrink as they were bound to previously agreed-upon prices, despite ballooning inflation and supply chain pressures that pushed up costs. As a result, global wind power capacity additions dropped 14% in 2021 and another 21% in 2022, but have since recovered strongly in 2023.

More than half of wind power jobs are in the Asia Pacific region, with China alone accounting for 40% of the world total. Outside of Asia, Central and South America are experiencing rapid growth in wind energy employment, with over 20 000 onshore jobs added in 2022 as the region prepares to add over 25 GW of new capacity in the next five years, mostly in Brazil, Chile, and Colombia. The workforce in Africa is also expanding fast, by more than 75% in 2022, supported by several projects in South Africa.

Onshore projects account for approximately 80% of all wind jobs, though offshore employment is growing at a similar rate. China and Europe dominate offshore wind, together representing more than two-thirds of global employment in 2022. China leads onshore wind employment with more than 40% of total jobs worldwide, followed by Europe with 20%, then North America and Central and South America with roughly 10% each.

Around two-thirds of workers in the wind sector work in manufacturing or in the construction of wind farms. Construction in wind requires more specialised skill sets than in other sectors, including in erecting turbines, assembling them, and transporting materials (which require specialised equipment). These skills are even more specialised for offshore developments, where a lack of skilled technicians and insufficient training capacity is starting to hold back new projects. The development of a widely recognised and transferrable training framework is of particular importance to the wind power industry, where the geographic limitations of wind farm localisation generate the need for a significantly mobile workforce that should not have to engage in constant retraining.

Wind energy jobs reach nearly 2 million in the STEPS in 2030 and just under 5 million in the NZE Scenario, fuelled by capacity growth of over 1 100 GW and 1 800 GW, respectively. Onshore wind remains the primary employer in both scenarios, though the share of offshore jobs rises to 25% in the NZE Scenario and over 30% in the STEPS in 2030, compared with 20% today.

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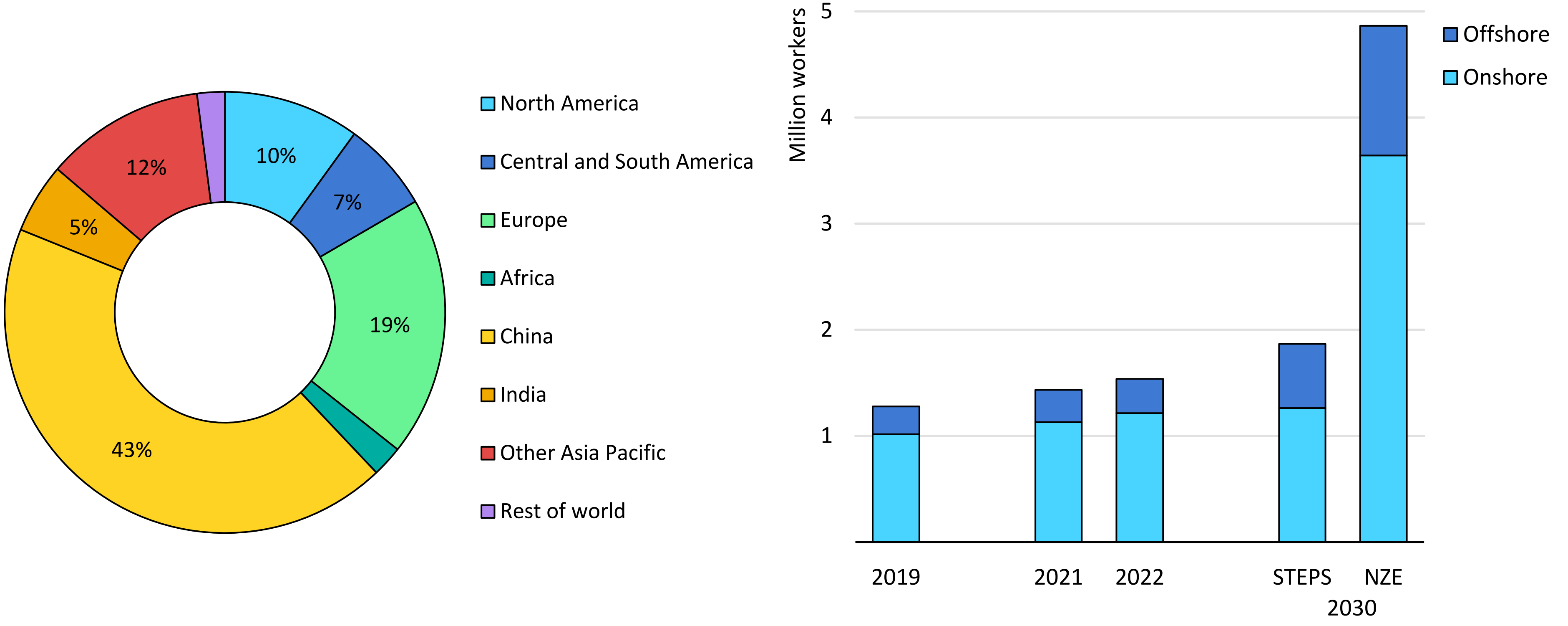
Employment in wind energy is concentrated in China, which is responsible for the bulk of both manufacturing and installations

Employment in wind energy by region in 2022 and by scenario in 2030



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Notes: STEPS = Stated Policies Scenario, NZE = Net Zero Emissions by 2050 Scenario.

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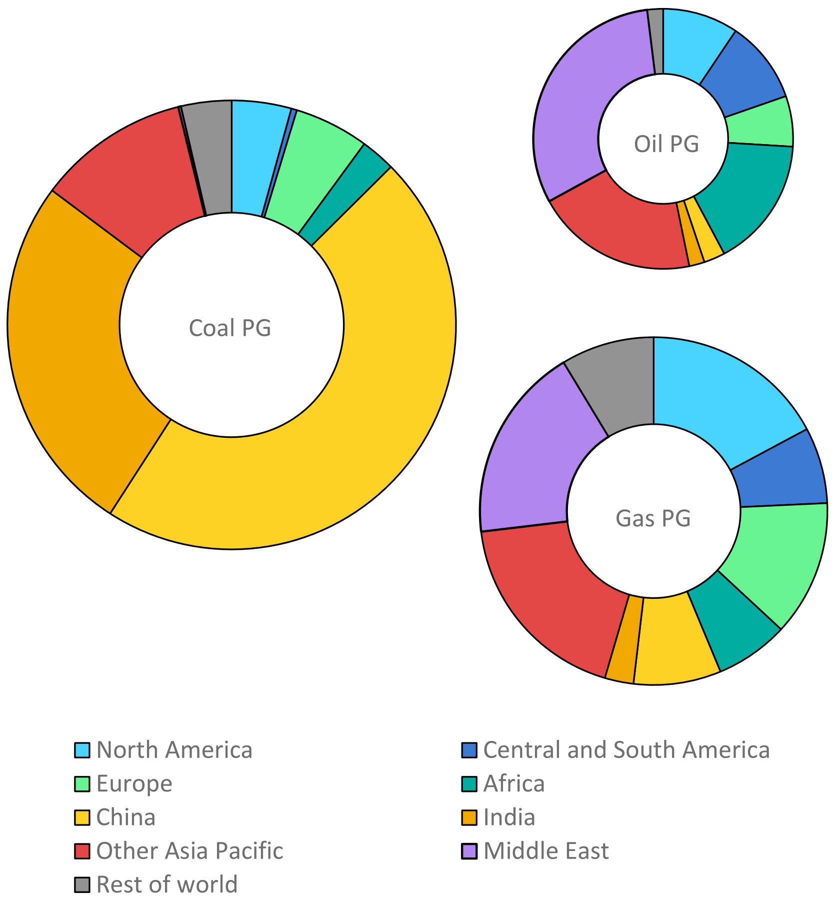
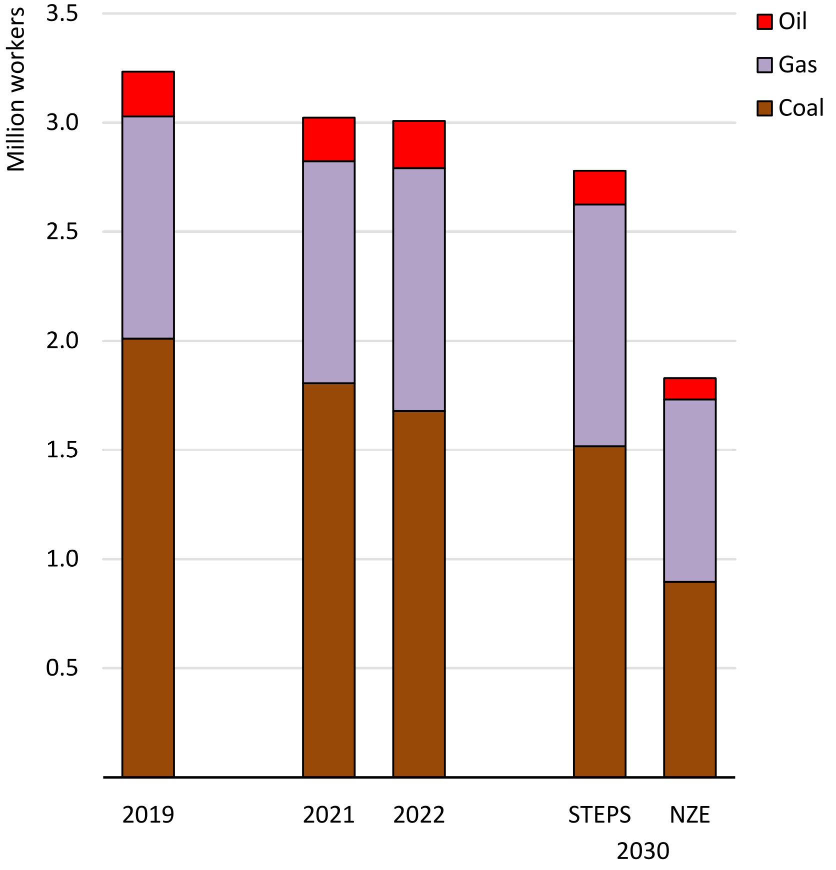
Employment in fossil fuel power plants has declined since 2019, led by coal

Employment in fossil fuel power generation by region, 2022



Global employment in fossil fuel power generation by fuel 2019-2022 and by scenario in 2030



Notes: STEPS = Stated Policies Scenario, NZE = Net Zero Emissions by 2050 Scenario.

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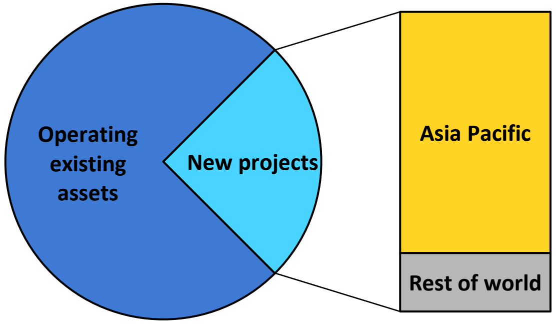
Employment in coal-fired power has fallen sharply as the pipeline for new projects dries up

Nearly 1.7 million workers worked in coal-fired power generation in 2022. Coal supplies just over one-third of global electricity generation and is the third largest source of employment in the power sector. Jobs in coal power have been declining in both advanced economies and emerging market and developing economies in recent years. The pipeline for new coal power plants continues to decline, halving since its peak in 2015. The slowdown in the construction of coal plants has led to job declines of more than 15%, or 330 000 jobs, compared with 2019. Steady retirements of coal power plants, largely in advanced economies, are contributing to the global decline, though they are partially offset by new plants in emerging and developing economies. The delayed closure of some plants amid the energy crisis momentarily slowed the rate of job losses in advanced economies, but they resumed in 2023. A marginal increase of coal power plant utilisation in Europe in 2022 did not significantly impact employment.

Coal power employment today is concentrated in Asia, with China and India together accounting for over 70% of all coal power generation jobs. New coal power projects are still coming online in China, India and Indonesia where electricity demand continues to rise, though many of the new plants in China are planned to operate primarily to balance renewables and provide essential reserves, rather than as baseload plants. The slowdown in new construction is nonetheless causing the workforce to contract. Some of the job losses in manufacturing the turbines and other equipment used in coal plants have been compensated for by increased demand in other sectors, which employ many of the same workers.

Unabated coal power generation employment decreases in most regions in the STEPS and in all regions in the NZE Scenario through 2030. Employment in unabated coal power falls by 10% to 1.5 million jobs in 2030 in the STEPS and by nearly 50% to fewer than 900 000 jobs in the NZE Scenario. The speed of job losses is sharpest in North America and Europe in the NZE Scenario, where policies to move rapidly away from coal are strongest. CCUS projects offer some opportunities to limit job losses in coal power generation, but their impact on total employment is small even in the NZE Scenario. Today, employment in coal power with CCUS is minimal as only three plants are in operation. Jobs are concentrated in research and development. New projects boost global employment in the sector to over 75 000 jobs by the end of the decade in the NZE Scenario. Almost all these new jobs are in China, India, and Indonesia, where retrofitting newer coal-fired power plants may help to avoid stranding of assets and allow continued exploitation of domestic coal reserves.

Employment in coal power generation by asset and region, 2022



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Approximately a million people work in gas-fired power generation, mostly in the Middle East, North America and Asia Pacific

Employment worldwide in gas-fired power generation bounced back to above pre-pandemic levels in 2022, reaching more than 1 million jobs. Around 29 GW of new capacity came online – less than in recent years as soaring prices in the wake of Russia's invasion of Ukraine prompted many countries, in particular in Europe, to curtail investments in gas power plants.

Around 40% of natural gas power employment is in building new plants and their components – a higher share than for coal as gas plants require fewer workers for onsite operations and maintenance. Gas-fired power generation employment remains concentrated in Asia Pacific, the Middle East and North America, where new projects continue to move ahead. Upstream manufacturing of generators and turbines is concentrated in advanced economies, with turbine manufacturing dominated by a small number of companies, including GE Power, Siemens and Mitsubishi.

The slowdown in new gas-fired capacity additions is set to keep global employment in the sector stable in the coming years in the STEPS. However, this stability masks divergent regional trends. Notably, Europe and North America are expected to witness a decline in job opportunities within this sector, while jobs in Africa, India and the Middle East grow as they install additional capacity. Employment falls by 25% in the NZE Scenario as very few new gas plants are built.

Oil power generation, which accounts for a small share of total capacity, employed less than 220 000 workers in 2022. Installations of central power units slowed and countries with oil plants continued to switch to other, cheaper forms of power. Oil power generation employment is concentrated in the Middle East, Africa and Asia Pacific. The Middle East alone represents almost one-third of all oil power generation jobs in 2022.

Diesel generators continue to see sales climb, in part due to increased demand for a dependable backup power source in regions where grid power supply is unreliable, and for use in critical facilities such as hospitals and data centres. Diesel generators are also in high demand for use in remote locations and at construction sites, providing essential support for uninterrupted operations. Sales growth has tapered in recent years as solar plus storage systems are beginning to claim some of this market.

As countries continue to replace oil generation with cheaper and cleaner forms of energy, jobs in the sector worldwide decline by slightly over 28% in STEPS and by nearly 55% in the NZE Scenario by 2030.

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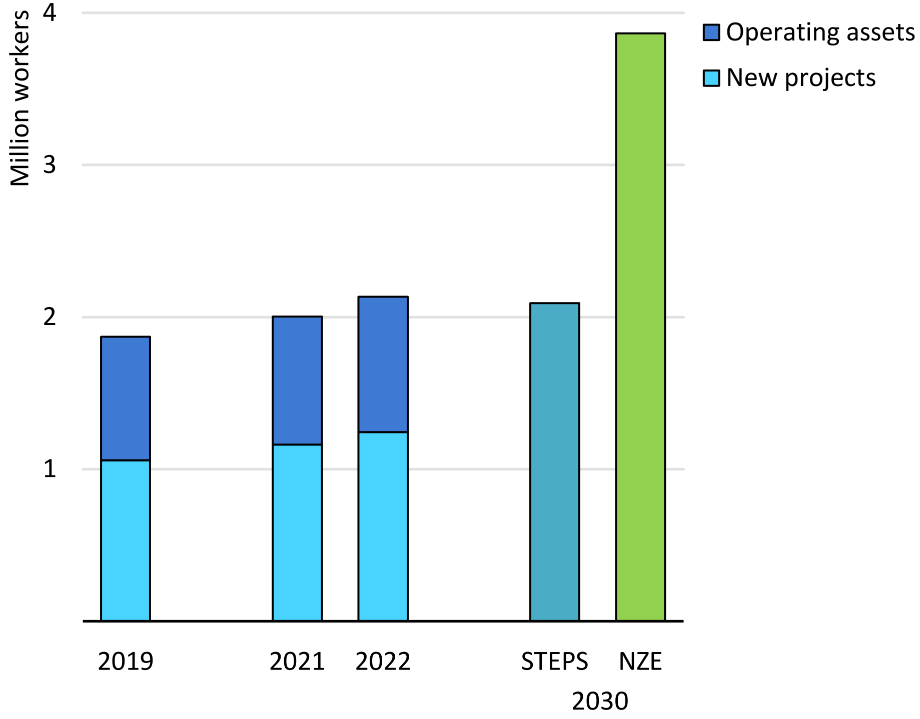
Employment in hydropower exceeds 2 million workers, second only to solar PV, but job prospects hinge on policy support

Global employment in the hydropower sector amounted to 2 million in 2022 (including pumped storage hydropower), accounting for 17% of total power generation employment – the second-largest contributor after solar PV. More than half of the jobs were in Asia Pacific, with China alone accounting for around one-quarter. One-third of hydro jobs are associated with the construction of new projects.

Employment grew by 6% year-on-year in 2022, driven by new project construction, including a 9 GW hydroelectric plant in Indonesia and the 3.6 GW Fengning pumped storage power station in the Hebei Province in China. China remains the largest hydropower employer globally and accounted for three-quarters of additions in 2022. A number of major hydropower developers in China also play a significant role in international project developments, as is the case for other major hydropower firms globally.

Global employment is flat to 2030 in the STEPS, as capacity additions stay relatively stable in this decade. A number of new projects have been hindered by environmental permitting barriers, negative public perception, weather volatility and long construction times, which limits growth in the STEPS. Employment increases by more than 80% in the NZE Scenario with several projects in development today moving forward, boosting jobs in construction and manufacturing. Small run-of-river hydro and pumped storage hydroelectricity also grow much more rapidly.

Employment in hydropower by asset type and scenario in 2030



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Notes: STEPS = Stated Policies Scenario, NZE = Net Zero Emissions by 2050 Scenario.

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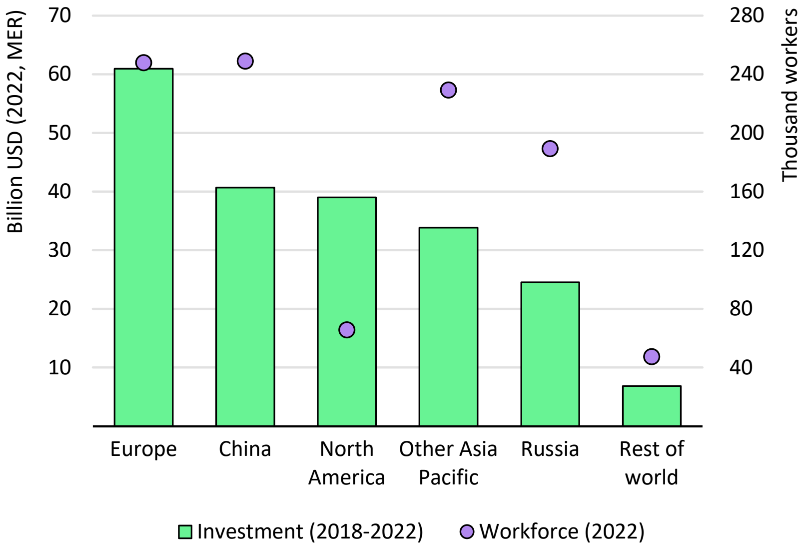
Employment in nuclear energy continues to grow, but remains concentrated in a few countries

Employment in nuclear power is expanding slowly but steadily worldwide, surpassing 1 million jobs in 2022. Countries with existing nuclear fleets are reinvesting in the technology while others are venturing into nuclear power for the first time. Most jobs are in countries with a well-established industry, reflecting the large numbers of staff needed to run nuclear plants. Job losses in the European Union associated with plant closures have been more than offset by growth in China and Russia, which together account for over 40% of all jobs. Both countries are pursuing export strategies for nuclear power plants and services, resulting in a relatively high share of manufacturing roles in total nuclear power employment.

The remainder of nuclear energy employment is spread over a wide range of countries. Turkey, Egypt, and Bangladesh, for example, are currently building their first nuclear reactors, while other countries such as Japan, Belgium, and South Korea have recently opted to restart or reinforce their civil nuclear programmes, in some cases reversing past decisions to phase out or phase down the technology.

Policy support will determine the prospects for employment in nuclear power, though the speed with which it can grow is limited by the technology's large up-front costs, long lead times and highly specialised skill requirements. Global nuclear power employment is broadly flat through to 2030 in the STEPS but grows by 750 000 jobs to reach 1.8 million in the NZE Scenario. Growth in the latter scenario is primarily fuelled by China, which adds over 240 000 jobs. The United States adds 130 000 jobs, supported by a tax credit under the Inflation Reduction Act, which has drastically improved the economics of maintaining existing reactors and boosted new builds. India also sees significant growth, as the expansion of its largely indigenous nuclear power programme translates to an increase of nearly 70 000 jobs by 2030 in the NZE Scenario. Massive new investment in the French nuclear programme is not enough to sustain nuclear power employment in Europe, which loses jobs in the sector through 2030 in both scenarios as several countries progress towards phasing out the technology.

Investment and employment in nuclear power by region



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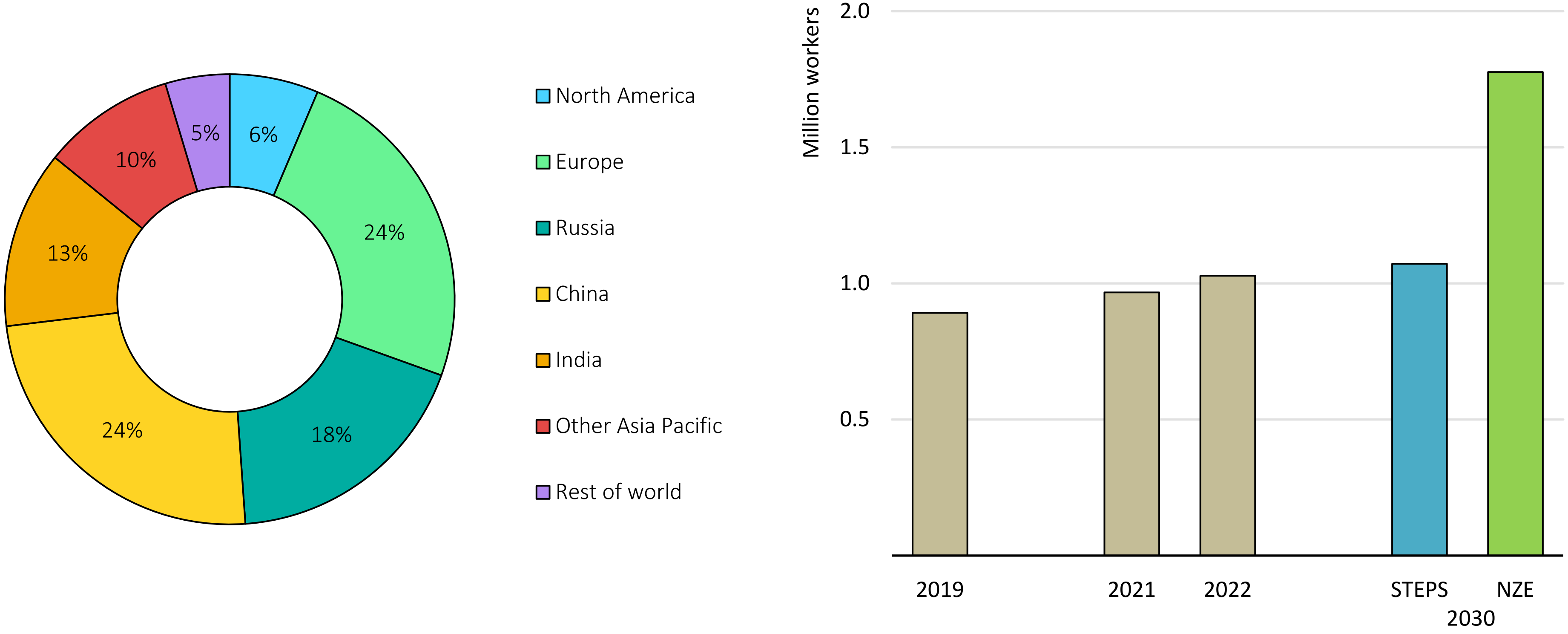
Nuclear power employment is dominated by a handful of countries with well-established nuclear energy programmes and firms

Employment in nuclear power by region in 2022 and by scenario in 2030



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Notes: STEPS = Stated Policies Scenario, NZE = Net Zero Emissions by 2050 Scenario.

Lessons from nuclear skills shortages in France

The nuclear power industry is facing a serious skills shortage, which not only underscores the problems of an insufficient qualified workforce needed to keep pace with clean energy transitions, but also impedes the development of the technology itself.

After extensive hiring in the 1970s and 1980s to facilitate the initial nuclear build-out in Western Europe and North America, the industry in these regions slowed down and took on relatively few new workers from the late 1980s to the early 2000s. Postponing retirement helped avert earlier skills shortages, but now the ageing-out of the original workforce is revealing the extent of the skilled labour gap for younger employees.

Skilled labour is of particular importance to the nuclear industry, as it represents a significant share of the cost to build a new plant. A high level of certification is required across essentially all nuclear assembly, construction, and operation occupations. For example, specialist welders in the nuclear sector require three additional years of training vis-a-vis similar roles, which are already undersupplied. This is reflected in the higher salaries in nuclear versus most other energy sectors. Still, uncertain contract timing, political turbulence and the often-negative public perception of nuclear power all impede the industry's ability to recruit.

The French experience with local skill availability while building the Flamanville 3 reactor illustrates the severe consequences that even niche skills shortages can generate. Among other issues, a lack of properly trained local nuclear welders resulted in errors that contributed to delays in delivery and project cost overruns as overseas labour was contracted at a premium to repair the welding. Unexpected technical issues across the rest of the French nuclear fleet in 2021-22 further strained the supply of skilled labour and led to the import of more foreign specialists. The lack of sufficient staff translated into ballooning costs for fleet operator Electricité de France (EDF), intensifying its financial challenges. Years of political uncertainty about the future of nuclear in France made it difficult historically to manage hiring and to attract workers and students to related studies and certifications. In turn, the skills shortage has contributed to a damaged public perception of nuclear energy.

The challenges faced by the French nuclear industry reflect a broader story among advanced economies: the supply of industrial and trade labour has declined amidst the pivot to service-heavy economies, and political uncertainty further discouraged new workers from entering the nuclear industry. Meanwhile, countries like China and India established clear programmes to build expertise and expand the sector. Unclear policy direction can thus impair an industry or technology from cultivating the needed workforce to rapidly scale, making clear that the costs incurred in training a skilled workforce are likely to be far outweighed by the costs of failing to do so.

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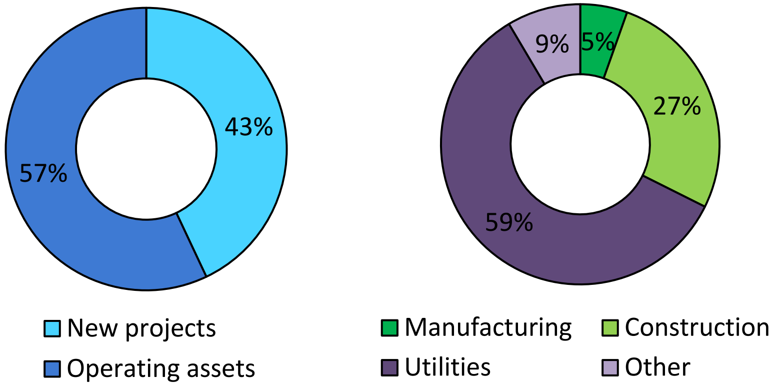
New projects are boosting employment in power grids, especially in advanced economies, China and India

Employment in electricity transmission, distribution and storage worldwide rose to around 8 million in 2022, climbing slightly above its pre-pandemic level, largely due to projects to expand and upgrade assets. The number of workers at utilities working on operating and maintaining the grid has changed little since 2019, representing around 60% of total employment in the sector. But new jobs have been created in manufacturing equipment and construction of additional facilities, which had slowed at the start of the pandemic, boosting total employment by over 3% in 2022 compared with 2021. Most of the growth was in China and advanced economies. A growing share of investment and associated jobs is related to renewables integration. Jobs in battery energy storage have also been rising rapidly, reaching around 150 000 in 2022. Employment in other emerging and developing economies has been hit by a decline in investment, with utilities weighed down by high debts from the energy crisis.

Most jobs in transmission and distribution relate to the operation and maintenance of the grid, responding to outages and customer connections, including meter reading. The growing uptake of smart metering and broader grid digitalisation reduces the labour needed for these tasks but is demanding greater digital skillsets among utilities personnel. For instance, drones can help operators with maintenance activities by identifying potential issues with real-time, high-resolution data on the condition of the grid. Countries with low levels of smart grid deployment can have three times more workers than regions heavily invested in smart grids, especially smart meters.

The prospects for employment in electricity networks depend on policies to advance electrification of end uses and the deployment of clean energy technologies. The number of jobs in the sector climbs to around 9 million in 2030 in the STEPS. Approximately 80% of this increase is concentrated in China, India and advanced economies; while low grid investments limit job growth in other emerging and developing economies. Globally, jobs related to storage nearly double. In the NZE Scenario, grids employment climbs to 11.6 million by 2030, as investments increase rapidly to keep pace with rising levels of renewables, universal access to electricity and more spending to improve system reliability.

Global employment in grids by type of asset and activity, 2022



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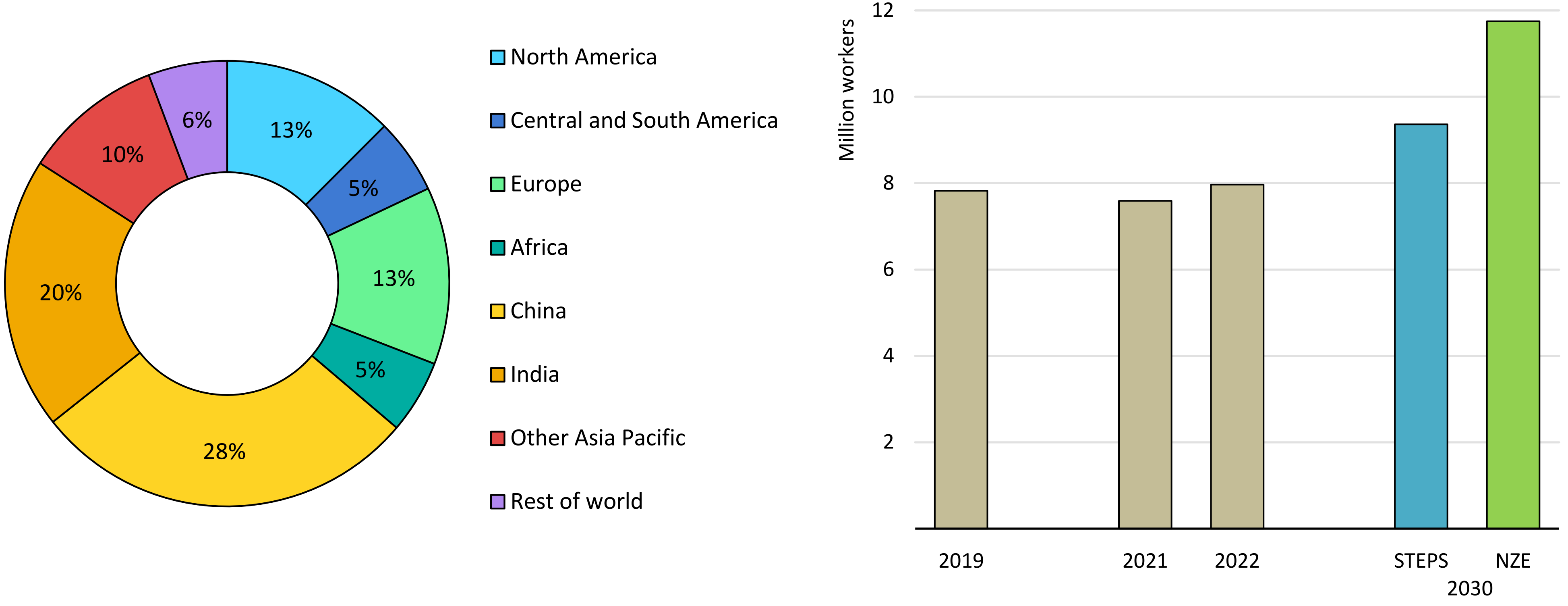
Job prospects in power grids depends on policies to accelerate electrification of end uses and the deployment of clean energy technologies

Employment in power grids by region in 2022 and by scenario in 2030



Notes: STEPS = Stated Policies Scenario, NZE = Net Zero Emissions by 2050 Scenario.

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Digital skills are key to the clean energy transition

Digitalisation of the power sector is crucial for clean energy transitions, with deployment of digital technologies a key enabler for the integration of variable renewables. Equally, adoption of digital technology at scale will significantly improve the management, operations and reliability of grids, while for end-users it can improve co-ordination with utilities and could unlock options for demand response and smart EV charging that can help consumers optimise their energy use and capture cost savings.

The success of the power system digitalisation will crucially depend on a scale up of digital skills in the energy workforce, including training current employees and attracting higher skilled employees. The digitalisation of energy has generated new vocation-specific roles within the energy labour workforce, such as smart-grid planners, network engineers, energy modellers, and expanded software and IT-related roles, and cybersecurity specialists.

Certain digital skills are of particular importance to the power sector. They are increasingly being used in traditional segments — such as power plant operation and network design, automated operations and remote maintenance — but also are enabling the development of new tools for planning and managing the electricity system. Those skills will be especially vital to optimising the development and secure operation of distribution networks, embedding by response or energy storage to improve efficiencies and resiliency. Guarding against rising cybersecurity risks will also be a critical area to attract new talent, in light of cybersecurity attacks on a wide range of energy infrastructure such as grids, nuclear power plants, pipelines, or dams.

Policy makers, local governments, industry and educators are working to address these skilling needs. In Europe, an estimated four out of ten adults lack basic digital skills. IEA analysis indicates that dedicated digital skill certifications related to the power sector are available across most major economies, but they are less likely to be available in emerging and developing economies. Greater digital skills will also be required beyond the power sector. As of 2022, there are 25 national coalitions in the European Union focused on improving digital skills in the energy industry more broadly.

Developing a digital competent workforce has become a strategic imperative for energy companies. In nurturing a digitally-skilled workforce, companies must provide consistent, frequent and effective internal training programmes for both existing staff and new hires, while promoting collaboration with universities to help prepare students for the new digital needs of the sector, coupled with a well thought-out and forward-looking recruiting policiesdesign flexibility services from providers of distributed generation, demand

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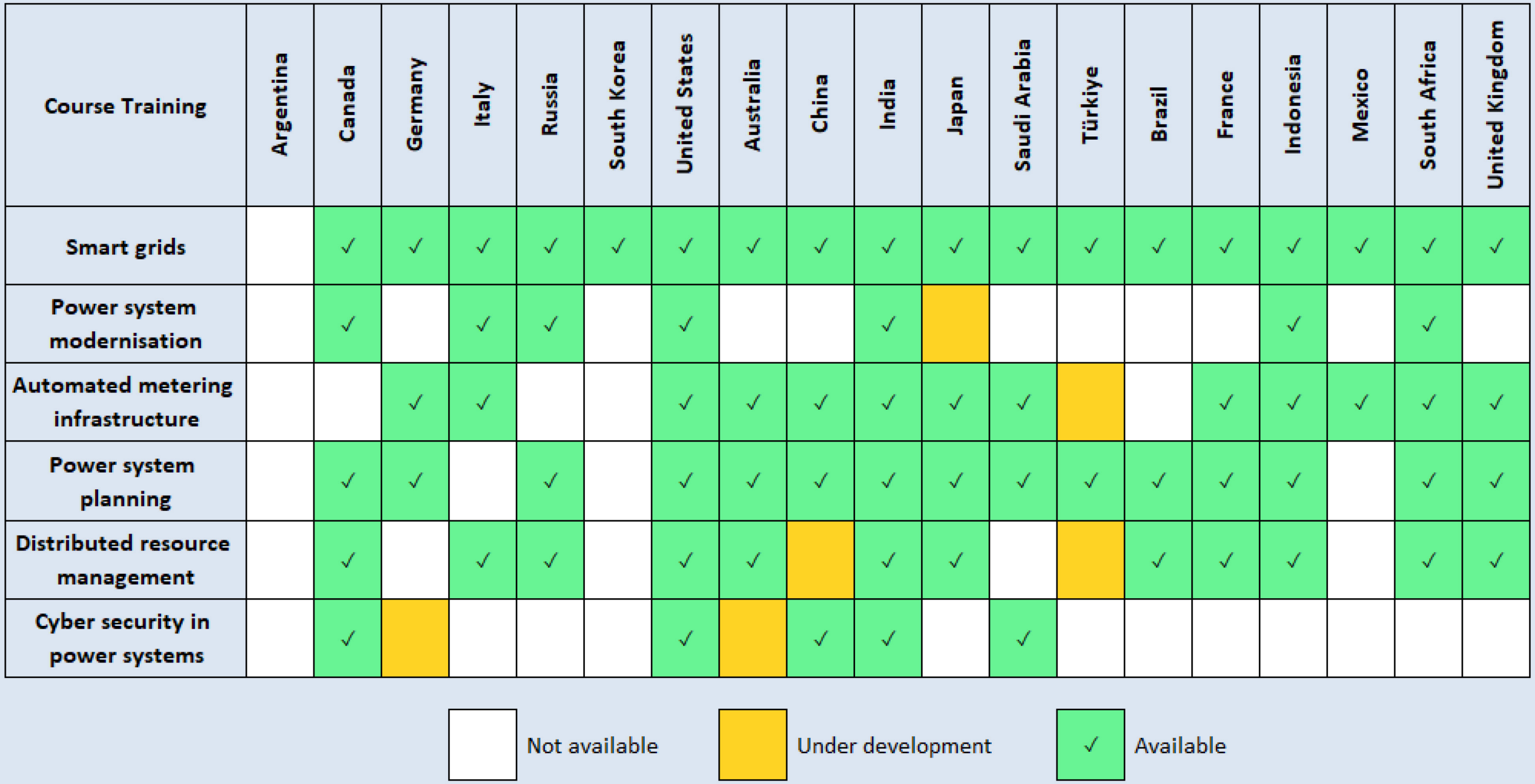
Training course availability by digital technology in selected major economies, 2023



Course Training	Argentina	Canada	Germany	Italy	Russia	South Korea	United States	Australia	China	India	Japan	Saudi Arabia	Türkiye	Brazil	France	Indonesia	Mexico	South Africa	United Kingdom
Smart grids		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Power system modernisation		✓		✓	✓		✓			✓	🟨					✓		✓	
Automated metering infrastructure			✓	✓			✓	✓	✓	✓	✓	✓	🟨		✓	✓	✓	✓	✓
Power system planning		✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
Distributed resource management		✓		✓	✓		✓	✓	🟨	✓	✓		🟨	✓	✓	✓		✓	✓
Cyber security in power systems		✓	🟨				✓	🟨	✓	✓		✓							

☐ Not available 🟨 Under development ✓ Available

Notes: Training courses that are available at higher education institutions, and/or vocational education and training (VET) schools.

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Vehicles and end-use energy efficiency

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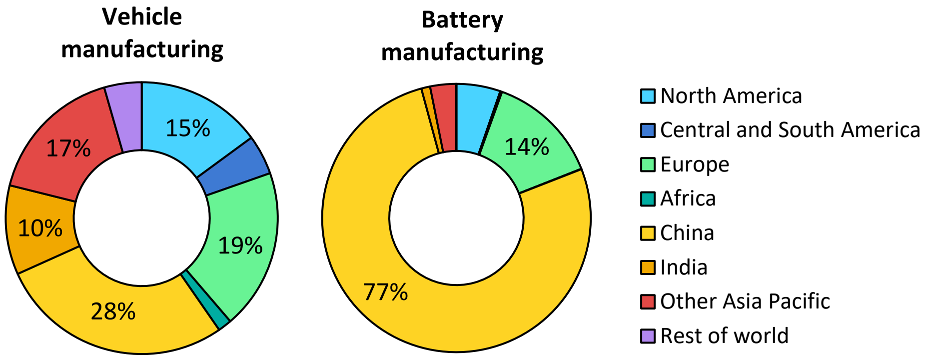
Vehicle sales are on the rise again, with EVs increasing their share of sales globally, and by 2030 one-third of the manufacturing workforce will be dedicated to EVs and batteries

The number of jobs in global automotive manufacturing plunged during the Covid-19 pandemic alongside plummeting vehicle sales, and in 2022 employment had only partially recovered to 11.8 million as sales remain below 2019 levels. Assuming continuation of current trends, the workforce is likely to return to pre-pandemic levels in 2023. This overall growth masks important regional dynamics: while jobs in advanced economies remain lower than pre-pandemic levels, emerging and developing economies have continued to gain market share. Today, the largest vehicle producers are China, Europe, other Asia Pacific and North America.

The rapid growth in EV sales is reshaping the vehicle manufacturing workforce. EVs represented nearly 15% of global vehicle sales in 2022, around double the share of just two years ago. Excluding batteries, EV workers account for 8% of the total automotive manufacturing workforce, up from 3% in 2019. The ratio of EV workers to EV sales is relatively high today, as the sector builds up the labour force that it needs to design, engineer and produce the vehicles that will be sold in subsequent years.

The shift to EVs has far-reaching implications for upstream vehicle component manufacturers, which are included in these employment totals. EVs have fewer mechanical components than ICE vehicles but require batteries and other related systems. New battery facilities are under development around the world, with vehicle battery manufacturing capacity increasing by 50% in 2022 and battery manufacturing jobs climbing by nearly 20%. While China continues to dominate the battery supply chain, investments of more than USD 73 billion in battery manufacturing plants was underway in the United States in 2022, boosted by IRA measures.

Share of workforce by region, 2022



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Up until now, growth in battery manufacturing jobs has offset declines in other parts of the automotive manufacturing chain. But firms that manufacture components for ICE vehicles are not the same as those that make EV batteries, nor are their production facilities always located in the same regions. For that reason, some regions with large employment bases focused on ICE upstream

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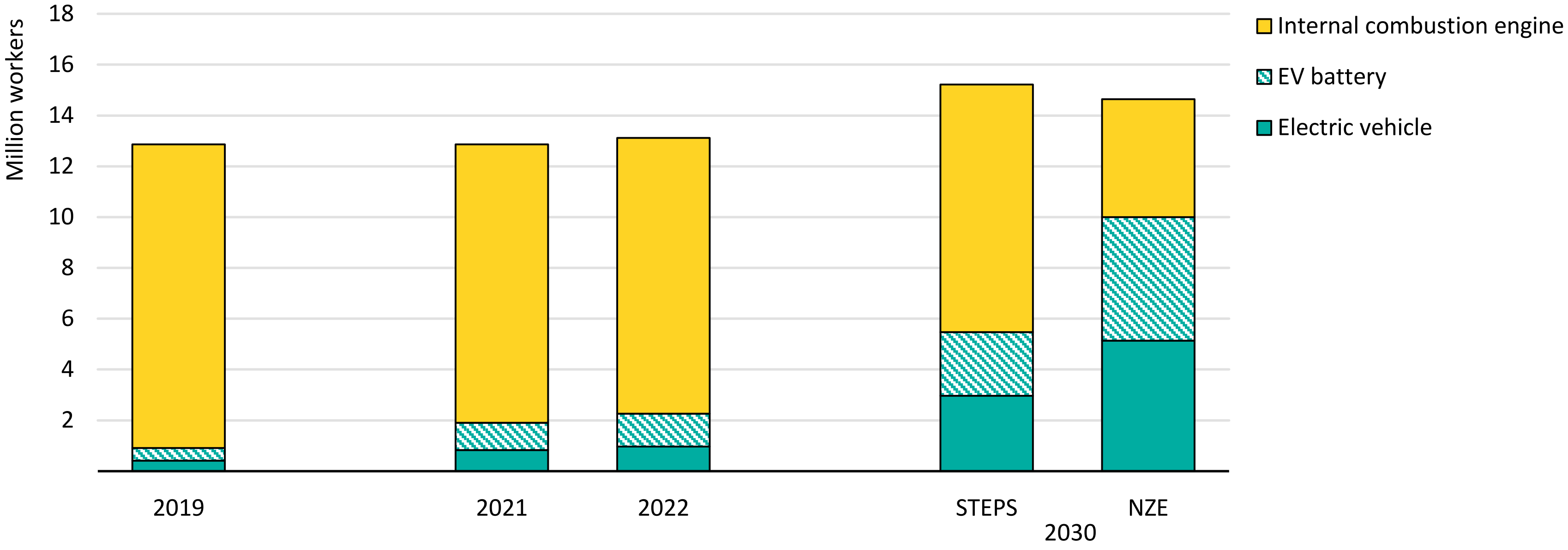
manufacturing are set to lose jobs on a net basis unless large-scale investments in electric vehicle supply chains are made.

New battery manufacturing companies in Europe are struggling to hire qualified employees locally, often recruiting personnel from Asian countries to join their workforces. Well-established players in the industry are also now facing difficulties in staffing new facilities. Major firms often rely on transferring existing workers to recently built plants to help with training and upskilling new recruits: up to 30% of staff in a new plant often comes from existing manufacturing facilities.

In the STEPS, jobs in vehicle manufacturing continue to grow, to 12.7 million in 2030, buoyed by rising sales. The share of workers dedicated to manufacturing electric vehicles and their components will rise in tandem, reaching to around one-third of all vehicle manufacturing jobs in 2030. In the NZE Scenario, vehicle jobs are lower in 2030, primarily attributed to market stagnation in Advanced Economies as countries adopt additional measures to encourage increased ridesharing, mass transit use, and other alternative transit options. In the NZE Scenario, EV and battery manufacturing overtake ICE vehicles to account for over two-thirds of the sector's workers by 2030.

Global employment in vehicle and EV battery manufacturing by type in 2022 and by scenario in 2030



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Notes: In this figure, Electric vehicles include workers in batteries supply chains. STEPS = Stated Policies Scenario, NZE = Net Zero Emissions by 2050 Scenario.

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Energy efficiency jobs remained relatively flat in 2022, bolstered by high energy prices and government incentives on one hand, but hindered by high interest rates on the other

Energy efficiency plays a key role in achieving our climate and energy security objectives. Efficiency delivers around 10% of the emissions reductions needed by 2030 in a pathway in line with the NZE Scenario. There are a substantial number of people working in energy-efficiency related fields today, although it is difficult to assess the size and scope of the workforce as there is no universal definition of end-use energy efficiency jobs. This report attempts to draw bright lines around workers whose daily focus is on implementing energy efficiency measures or improving the energy efficiency of devices or processes. Accordingly, the report accounts for those working in the following activities:

- Efficient building retrofits and weatherisation.
- The production and installation of heat pumps, and other clean heating and cooling equipment (e.g. solar heating, other geothermal).
- The production and installation of energy management systems.
- The design and manufacture of efficient appliances and building materials.
- The operation of community, utility, and regional energy efficiency programmes.
- Energy service companies (ESCOs) and other energy management activities in buildings and industry.
- Implementing energy efficiency upgrades in industry.

A number of these categories infer a threshold to delineate efficient from non-efficient products and projects. Efficient appliances and materials are defined by top-tier performance for each region, which are reflected by standards and labelling schemes, which the IEA tracks and uses in its modelling each year. Efficient retrofits are defined as meeting the minimum performance standard for near-net-zero or net-zero ready buildings.

Beyond these jobs, many others include a strong focus on energy efficiency in their day to day, such as architects, builders, contractors, and equipment manufacturers. As the pace of clean energy transitions quickens, the number of jobs that need skills related to efficiency and clean energy increase and should be considered in broader efforts to cultivate a skilled workforce to deliver on energy and climate objectives.

The energy crisis and increased government incentives bolstered the economics of energy efficiency projects, but high interest rates are acting as a brake on this growth, especially those dependent on financing to cover upfront costs. Jobs climbed by around 10% in 2022, reaching over 10.5 million, slightly above the level of 2019, amid higher investment. This is putting additional strain on the existing labour force in many markets as they contend with increasing difficulties in hiring the needed employees, especially for

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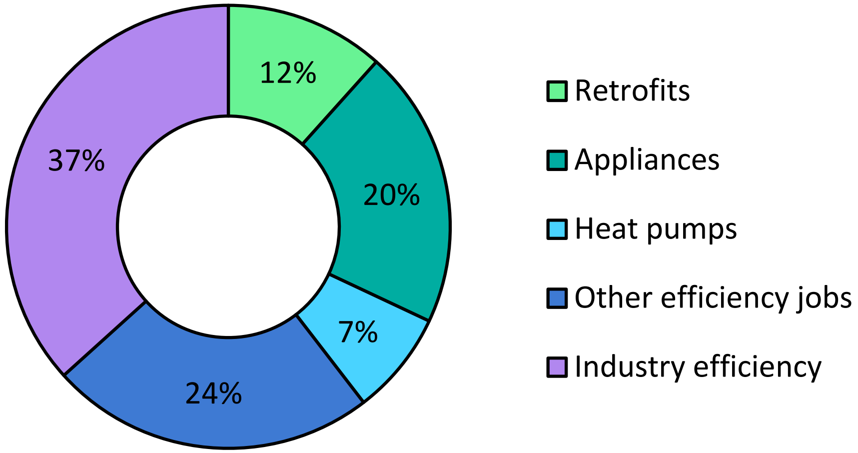
construction workers and HVAC technicians. This is leading to long wait times for retrofit projects and heat pump installations.

Despite the hiring difficulties, employment in retrofits and heat pumps still rose. Building retrofits witnessed the fastest job growth within the energy efficiency category in 2022, growing by over a third. Around half of these jobs are in Europe, where high natural gas prices and government efforts encouraging efficiency and fuel switching saw substantial uptake. Heat pumps also saw fast growth in 2022, with employment expanding by over 15%. Heat pump manufacturing and installation employs 800 000 people globally. Skilled installers are presenting real bottlenecks in Europe, which saw its second year of over 40% growth in heat pump sales. Industry remained tenuous in adopting new major energy efficiency projects with uncertain cash flows and a focus on operational measures that could more immediately guard against high energy prices. As a result, industrial energy efficiency jobs remained rather flat in 2022.

Jobs in end-use energy efficiency worldwide grow to nearly 12 million in 2030 in the STEPS and 14 million in the NZE Scenario as governments target doubling energy efficiency progress by 2030. Employment in building retrofits and heat pumps again see the largest gains, both more than doubling in the NZE Scenario, while jobs in industry efficiency also see notable growth.

Some of this job growth implies a pivot for those working in manufacturing and installing other standard appliances, construction materials, and heating systems, as well as those in construction working on other building types. The skilling requirements for workers needing to shift vary but can be less than four weeks for medium-skilled workers. For example, most HVAC technicians in the United States and China who currently install traditional heating and cooling units have some training on heat pump installation already integrated in their basic credentials. However, in higher-skilled positions working on building retrofit designs, developing more efficient appliances and industrial processes more substantial upskilling is required.

Share of global employment in end-use energy efficiency by sub-sector, 2022



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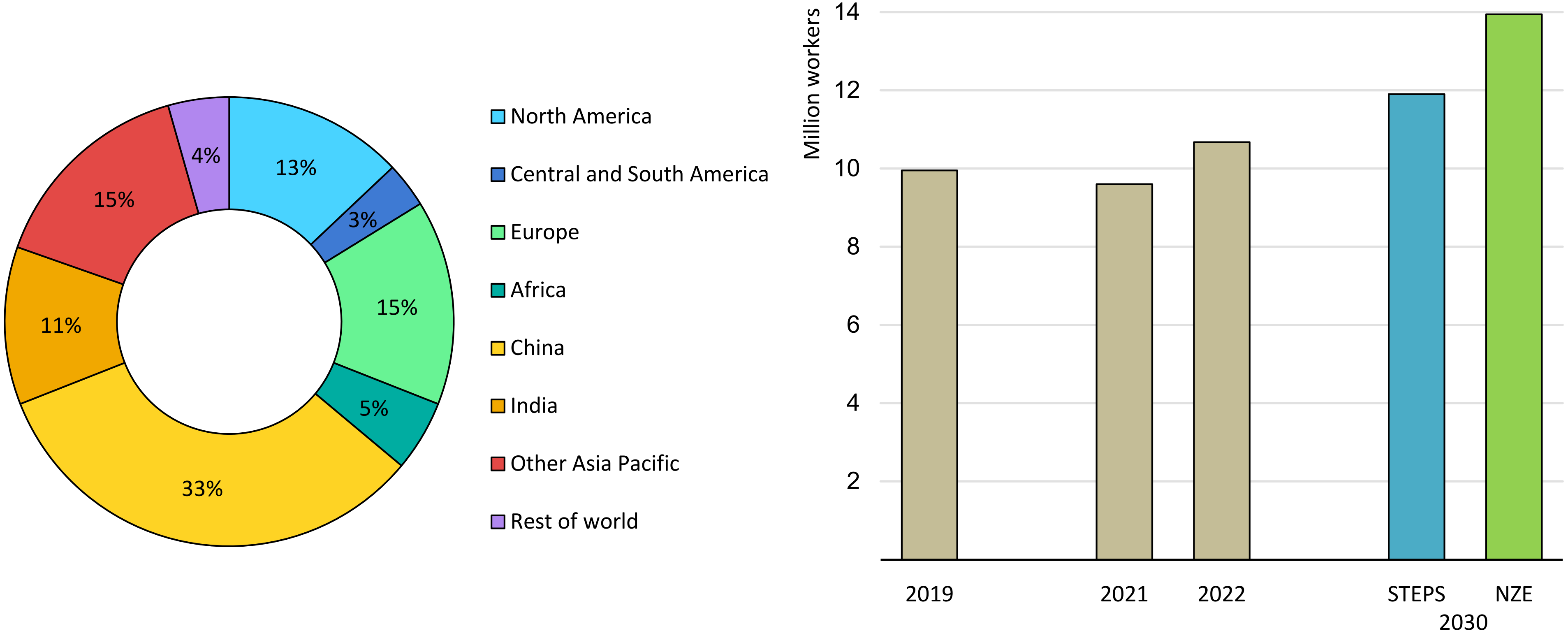
Energy efficiency jobs have yet to recover to pre-pandemic levels, but are forecast to grow steadily through 2030

Employment in energy efficiency by region in 2022 and by scenario in 2030



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Notes: STEPS = Stated Policies Scenario, NZE = Net Zero Emissions by 2050 Scenario.

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Annexes

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Methodology

A note on historic revisions

Data for 2019, used as the pre-Covid-19 pandemic baseline year, have changed slightly compared with WEE 2022. These adjustments are largely due to changes in scope of the jobs considered and revisions to input data, such as national statistics. The direction of these revisions varies depending on the technology and geography. Overall, there has been a downward revision of our 2019 energy jobs estimate by approximately 2.8 million worldwide. These changes include:

- Global employment in **transmission and distribution** has been revised downward, due to a reallocation of jobs within utilities to the appropriate sub-sectors, and an update of country-level data in some regions. Jobs previously in transmission and distribution were reallocated to other energy sectors, such as power generation and energy efficiency, and a few outside the energy sector. There has also been a revision to the number workers based on new country-level data and updated estimates on informal workers. Substantial downward revisions include China, Asia Pacific, and Europe.
- Employment estimates for **vehicle manufacturing**, including batteries, have been revised downward in China, Japan and Korea and upwards in Mexico in light of new data.
- The scope of **energy efficiency** employment has been redefined to include efficient appliances. Additionally, we have revised the efficiency thresholds that affect which jobs are counted as working on efficient equipment and processes. This reduced the number of jobs in industry efficiency and excluded many workers associated with traditional heating, ventilation and air conditioning (HVAC) equipment that did not meet new efficiency thresholds. Notable effects include a revision upwards in Europe and downwards in North America, China and India.
- The employment estimate for **coal mining** in Central and South America has been revised upward considering new national statistics.
- Energy employment estimates have been expanded to include critical minerals mining, nuclear fuel supply, and low-emissions hydrogen supply.

Modelling

Modelling is based on the IEA's energy balances as well as energy investment data, and calibrated based on a rich collection of employment data from the following sources:

- National statistics for all major countries.
- EUROSTAT data.
- ILO's employment database.
- UNIDO's IndStat and MinStat databases.
- Reports by international organisations and industry associations.
- Academic literature.

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- Annual reports of major companies in each sector.
- Company surveys.

The data provided in this report represent our best estimates of employment across the energy sector based on the most recent available data. They are published to help governments and other stakeholders to understand the magnitude of the impacts of energy policy and investment on workers, but given the uncertainties that exist, they are clearly not the last word. We will update these estimates as new and improved data become available.

Where data was missing for certain years, energy sub-sectors, or countries, employment multipliers were applied based on the corresponding volumes and investment values in IEA energy balances. Regional multipliers were constructed based on wage differences. The steps included:

- **Identifying the cost contribution breakdown** for USD 1 million spent on new projects or products for regions with existing multipliers (e.g. 10% labour, 50% materials, 10% equipment costs). The breakdowns were derived using detailed manufacturer surveys, primarily from the US Annual Survey of Manufacturers data which provide information on the contribution to costs of average wages, labour and materials. Industry evaluation was used to confirm breakdowns or provide more granular detail for specific technology types.
- **Adapting the cost contribution breakdown** to each region, taking specific account of how differences in wages and material costs shift the relative shares of labour and material. Average wages and basic material costs were indexed on the basis of US costs, and these were applied to the labour and material costs for a USD 1 million project or purchase to calculate how much that same purchase would cost to produce in a low-wage economy. We utilised local wages, average cost differential of input materials, share of imports in production and the costs of those imports to arrive at adjusted cost contribution breakdowns for various regions.
- **Finding average wages for relevant jobs** in a region by using national average salary information specific to a sub-sector. Where information on wages specific to a sub-sector was not available, average wages from salary reporting websites were used, splitting the labour costs to distinguish between those associated with production and manufacturing and those associated with overheads (e.g. research and development, procurement and marketing).
- **Calculating jobs per million dollars for the expenditure** by dividing the portion spent on salaries by average salaries. The indirect multiplier for advanced economies was used as a basis for indirect jobs, and the rectification multiplier for each country was applied to calculate indirect jobs.

The final employment multipliers were integrated with the IEA's Global Energy and Climate Model by applying the multipliers to the appropriate sector and regional investments.

Definition and scope of employment

The definitions used in this report are:

- Direct: Jobs created to deliver a final project or product. These are counted in this report.

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- Indirect: Supply chain jobs created to provide inputs to a final project or product. Only inputs that are predominantly demanded by the energy industry are counted in this report.
- Induced: Jobs created by wages earned from the energy sector and spent in other parts of the economy, thereby creating additional jobs. These jobs are not counted in this report.

In this report's accounting, employment encompasses all direct jobs and the indirect jobs from suppliers providing immediate inputs to the sector considered. Induced jobs and jobs that may be created from re-spend are not included. This sets a clear boundary around the jobs that the upfront investment would pay for to deliver the project.

Jobs are normalised to full-time equivalent (FTE) employment for consistent accounting. An 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). Where data is available for hours worked, we calculate part-time workers with a proportion. Otherwise, part-time employment is assumed as 0.5 FTE.

Employment numbers include informal workers, with the hope that our numbers reflect the scope of energy policy impact more completely. In alignment with ILO definitions, informal workers comprise own-account workers and all those employed in informal sector enterprises; contributing family workers; workers holding informal jobs; members of informal producers' cooperatives; and own-account workers engaged in the production of goods exclusively for own final use by their own household. Estimates are based on a literature review of informality rates by region and sector.

This report does not address employment in the following energy sectors, among others, which will be covered in forthcoming reports:

- Coal transformation for blast furnaces and coke ovens.
- Fossil fuel downstream distribution, for example workers in petrol stations and workers in gas utilities.
- End-use renewables such as geothermal or solar heating for buildings or biomass boilers.
- Efficiency jobs related to appliances and lighting in buildings.
- Manufacturing of non-road vehicles, as well as the servicing and maintenance of vehicles.

Economic sectors

Employment in this report is presented not only by energy sectors, but also by economic sectors (as defined by the ISIC Revision 4 classification system), with significant numbers of workers in the following sectors:

- Agriculture (code A), in particular for bioenergy production
- Mining and quarrying (code B)
- Manufacturing (code C)
- Electricity, gas, steam, and air conditioning supply (code D)
- Construction (code F)
- Wholesale and retail trade (code G)

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- Transportation and storage (code H)
- Professional, scientific, and technical activities (code M)

Throughout the report, the economic sectors are aggregated into five groupings for simplicity:

- Raw materials (codes A and B)
- Manufacturing (code C)
- Construction (code F)
- Professionals and utilities (code D and M)
- Wholesale and transport (codes G and H)

Sample of ISIC codes referenced in employment modelling[1]

Code	Name
0510	Mining of hard coal
0520	Mining of lignite
0610	Extraction of crude petroleum
0620	Extraction of natural gas
0892	Extraction of peat
0910	Support activities for petroleum and natural gas extraction
1920	Manufacture of refined petroleum products
2710	Manufacture of electric motors, generators, transformers and electricity distribution and control apparatus
2720	Manufacture of batteries and accumulators
2731	Manufacture of fibre optic cables
2732	Manufacture of other electronic and electric wires and cables
2733	Manufacture of wiring devices
2815	Manufacture of ovens, furnaces and furnace burners
2824	Manufacture of machinery for mining, quarrying and construction
2910	Manufacture of motor vehicles
2920	Manufacture of bodies for motor vehicles; manufacture of trailers and semi-trailers
2930	Manufacture of parts and accessories for motor vehicles
3510	Electric power generation, transmission and distribution
4321	Electrical installation
4322	Plumbing, heat and air-conditioning installation
4661	Wholesale of solid, liquid and gaseous fuels and related products
4930	Transport via pipeline

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[1] While some of the codes listed correspond in scope directly to their respective energy subsectors, others are referenced with the understanding that only a subset of the workers enumerated under these ISIC codes work on energy infrastructure and value chains.

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Skill levels

Employment in this report is also presented by skill level, in harmony with the ISCO-08 occupations in ILOSTAT. Skill level is defined by ILOSTAT as "a function of the complexity and range of tasks and duties to be performed in an occupation," considering:

- The nature of work performed.
- The level of formal education required for competent performance, as defined by ISCED-97.
- The amount of work experience and/or on-the-job training required for competent performance.

The following table illustrates the occupations, education level, and characteristic tasks typically observed at each skill level. In many cases, formal education is not an ideal method for approximating skill level, and as such the ISCED-97 level assigned is indicative of how workers of that skill level generally obtain the knowledge and skills required for competent performance. It is always possible that the appropriate degree of work experience and/or on-the-job training may substitute for the level of formal education indicated.

Skill level	ILOSTAT skill levels	Associated ISCED-97 levels	Associated ISCO-08 occupations	Characteristics
Low-skill	1	ISCED Level 1: Completion of primary education or the first stage of basic education may be required, along with possible on-the-job training.	9. Elemental occupations	• Performance of simple/routine physical/manual tasks • Literacy and numeracy, if required, are not a significant portion of work
Medium-skill	2	ISCED Level 2: Completion of the first stage of secondary education. ISCED Level 3: Completion of the second stage of secondary education, which may include a significant component of vocational education and/or on-the-job training. ISCED Level 4: Completion of vocation-specific education undertaken after completion of secondary education.	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	• 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
High-skill	3-4	ISCED Level 5b: 1-3 years of study at a higher educational institute following completion of secondary education. ISCED Level 5a or higher: 3-6 years of study at a higher educational institute leading to the award of a first degree or higher qualification; formal qualifications may be required for entry to the occupation.	1. Managers 2. Professionals 3. Technicians and associate professionals	• 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

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Glossary

Clean energy: In power, clean energy includes generation from renewable sources, nuclear and fossil fuels fitted with CCUS; battery storage; and electricity grids. In efficiency, clean energy includes energy efficiency in buildings, industry and transport, excluding aviation bunkers and domestic navigation. In end-use applications, clean energy includes direct use of renewables; electric vehicles; electrification in buildings, industry and international marine transport; use of hydrogen and hydrogen-based fuels; CCUS in industry and direct air capture. In fuel supply, clean energy includes low-emissions fuels, liquid biofuels and biogases, low-emissions hydrogen and hydrogen-based fuels.

Fossil fuels: Include coal, natural gas, oil and peat.

Informal employment: Includes all remunerative work (workers, self-employed workers) 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 in accordance with guidelines concerning a statistical definition of informal employment by the 17th International Conference of Labour Statisticians.

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.

Economic sectors

Construction: Refers to economic activities related to both general construction and specialised construction activities for buildings and civil engineering works; in alignment with ISIC Rev.4 section F. This includes electrical contractors.

Economic sectors: Refers to industry groupings such as mining and quarrying, manufacturing and construction, which are categorised in accordance with Revision 4 of the International Standard Industrial Classification of All Economic Activities (ISIC Rev.4) – the international reference classification of productive activities.

Manufacturing: Economic activities related to the physical or chemical transformation of materials, substances, or components into new products; in alignment with ISIC Rev.4 section C.

Mining: Economic activities related to the extraction of minerals occurring naturally as solids (coal and ores), liquids (petroleum) or gases (natural gas), as well as the supplementary activities aimed at preparing the crude materials for marketing; in alignment with ISIC Rev.4 section B named “Mining and quarrying.”

Professionals: Economic activities related to specialised services including legal and accounting, activities in head offices and management consulting, architecture and engineering, scientific

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research and development, advertising and market research, etc.; in alignment with ISIC Rev.4 section M titled “Professional, scientific and technical activities.”

Utilities: Economic activities related to the operation of electric and gas utilities, which generate, control and distribute electric power or gas; in alignment with ISIC Rev.4 section D that is named “Electricity, gas, steam and air conditioning supply.”

Wholesale: Economic activities related to wholesale and retail sale (i.e. sale without transformation) of any type of goods and the rendering of services incidental to the sale of these goods; in alignment with ISIC Rev.4 section G, named “Wholesale and retail trade; repair of motor vehicles and motorcycles.”

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 (C and S 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: All countries not included in the advanced economies regional grouping.

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

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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 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.

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