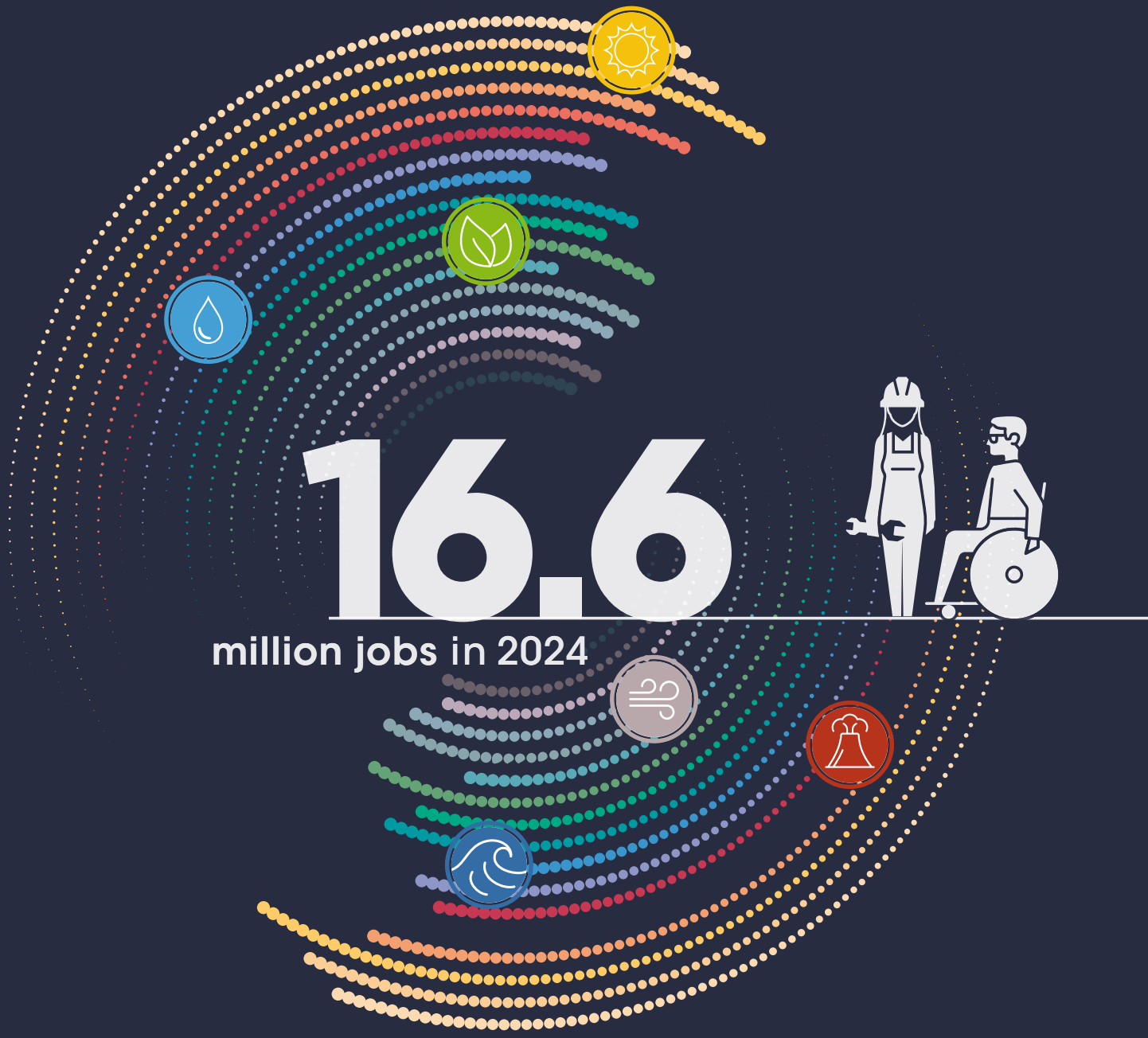
IRENA
International Renewable Energy Agency

Renewable Energy and Jobs
Annual Review 2025



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ABOUT IRENA

The International Renewable Energy Agency (IRENA), a global intergovernmental organisation established in 2011, is the world's principal platform for co-operation to advance the transformation of the global energy system in pursuit of sustainable development, energy access, energy security, and low-carbon economic growth and prosperity. Serving as a centre of excellence and repository of knowledge, IRENA promotes the adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy.

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ABOUT ILO

The only tripartite UN agency, the International Labour Organization (ILO) has, since 1919, brought together governments, employers and workers in 187 Member States to set labour standards, develop policies and devise programmes promoting decent work for all women and men.

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FOREWORD

We are pleased to present the 2025 edition of Renewable energy and jobs, which offers the latest available estimates for renewable energy employment worldwide. Those estimates are complemented by an analysis of the evolving industry and public policy landscape for renewable energy employment, with a specific focus on the inclusive policies necessary to support a successful energy transition.

Francesco La Camera

Director-General

International Renewable Energy Agency

Gilbert F. Houngbo

Director-General

International Labour Organization

At least 16.6 million people were directly or indirectly employed in the renewable energy industry in 2024 – the highest level of employment recorded globally to date. Despite strong growth in new renewable energy capacity, however, employment growth slowed significantly – mainly because China reported a lower number of jobs than in 2023, as rising labour productivity and economies of scale have contributed to reducing job intensity, offsetting increases seen in other countries. This was despite growth in China's renewable power capacity, and its manufacturing of solar panels, wind turbines and other energy transition equipment.

This suggests the emergence of a new phase in the energy transition. Growing automation and economies of scale mean that comparatively less human labour is required for each new unit of capacity – although impacts vary across countries, technologies and segments of the renewable energy value chain. The scale of deployment is another factor, with decentralised rooftop solar being more labour-intensive than utility-scale projects, for example. The rapid emergence of artificial intelligence will likely also have far-reaching impacts in the coming years, even though it remains to be seen to what extent this translates into job losses or gains, or a redefinition of occupational profiles and skilling requirements.

Workforce development, however, is increasingly critical to the success of the energy transition. Education and training (including reskilling and upskilling efforts) remain essential – including university degrees, vocational training and on-the-job learning – but many curricula remain rooted in the past and must adapt to cultivate the skills and competencies required by the future energy workforce.

This edition of the report highlights the need to expand training, job opportunities and career perspectives for population groups that are in danger of being left behind. It specifically discusses IRENA's latest findings on gender equity and shines a light on efforts to make hiring and workplaces more accessible to persons with disabilities. It is crucial to understand that beyond issues of equity and fairness, industry must not overlook their talents, insights and perspectives. It is the human element – the workers in a broad spectrum of occupations and with a wide range of skillsets – that ultimately will secure the success of the energy transition.

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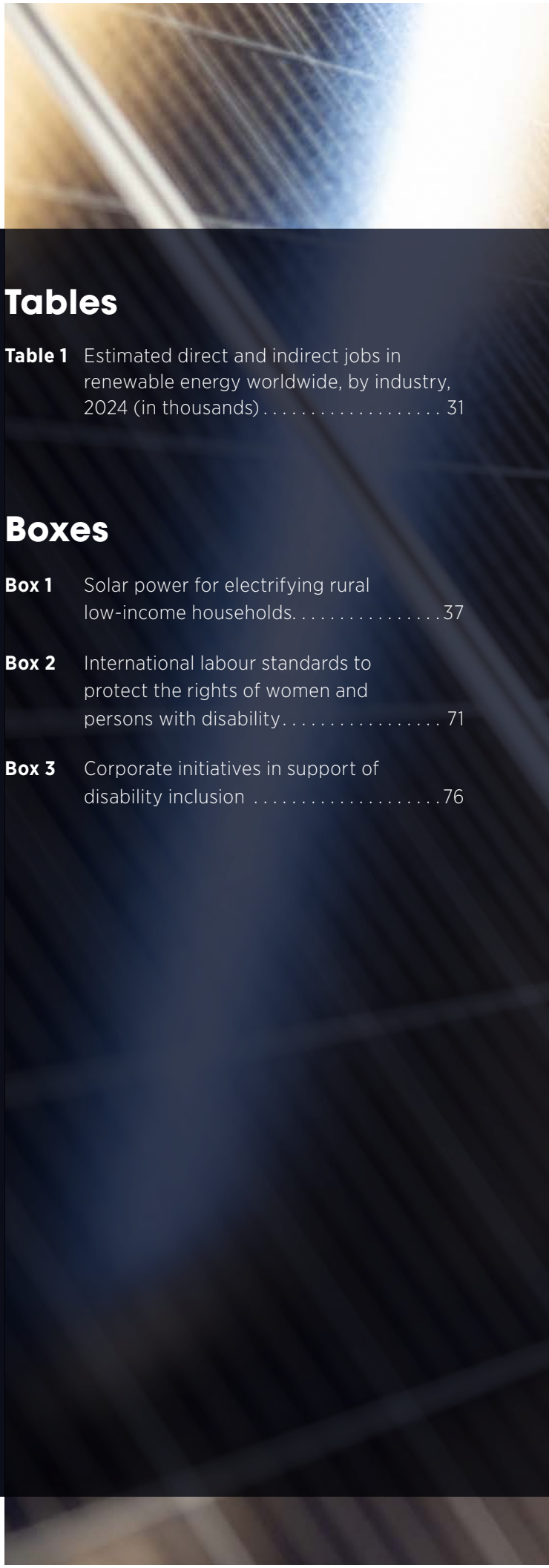

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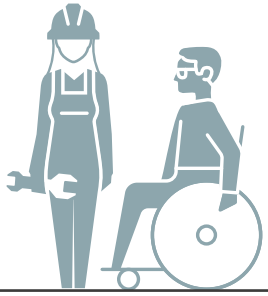
Abbreviations

EU	European Union
EU 27	27 Member States of the European Union
FTE	full-time equivalent
GBDN	Global Business and Disability Network
GW	gigawatt
ILO	International Labour Organization
IRA	Inflation Reduction Act (United States)
IRENA	International Renewable Energy Agency
MW	megawatt
O&M	operations and maintenance
PV	photovoltaic
STEM	science, technology, engineering and mathematics
TWh	terawatt hour

KEY DATA 2024

16.6 million jobs in 2024



+2.3 % vs. 2023

Renewable energy employment by technology (million jobs)

Solar photovoltaic 7.2

of which China accounts for 4.2 million

Biofuels 2.6

Hydro-power 2.3

Wind energy 1.9

Solid biomass 0.7

Heat pumps 0.4

Geothermal 0.2

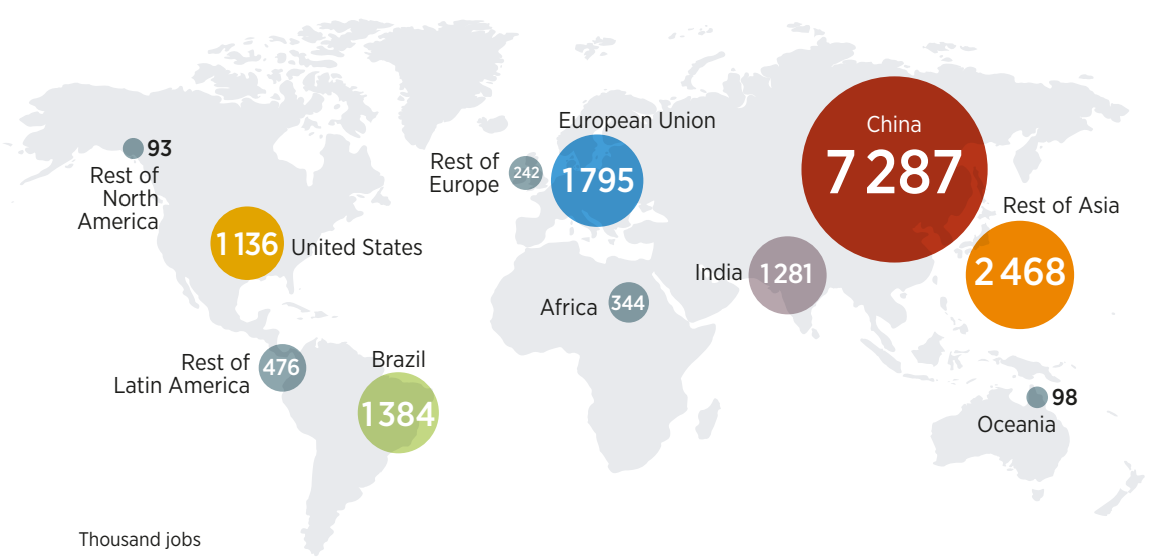
Concentrated solar power 0.1

Solar heating/ cooling 0.6

Biogas 0.3

Others 0.2

Renewable energy employment in selected countries and regions, 2024



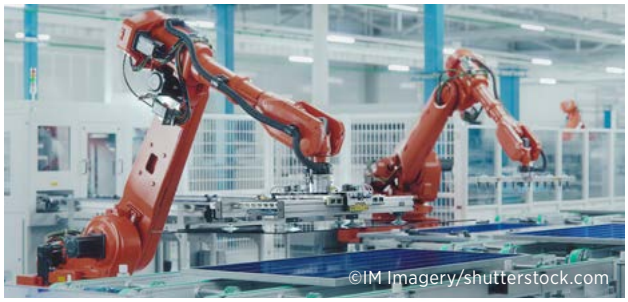
KEY MESSAGES 2024

› UNEVEN DISTRIBUTION.

China remains the pre-eminent location for renewable energy jobs. Imbalances elsewhere across the world reflect not only diverging levels of commitment and investment, but also uneven capacity to act, given varying industrial and supply chain structures, technological dependencies and availability of skilled labour.

› LIMITS TO GROWTH.

Despite record capacity additions, employment growth was moderated by economies of scale; automation and other forms of technological innovation; excess equipment manufacturing capacity; and grid bottlenecks leading to curtailment of electricity generation.



› PEOPLE ARE KEY.

The people who work in renewable energy represent the key to a successful energy transition. Education and training are essential, and must rapidly adapt to provide the skills and competencies required by the future energy workforce. Equal access to training and career progression should be afforded to all.

› LACK OF DIVERSITY.

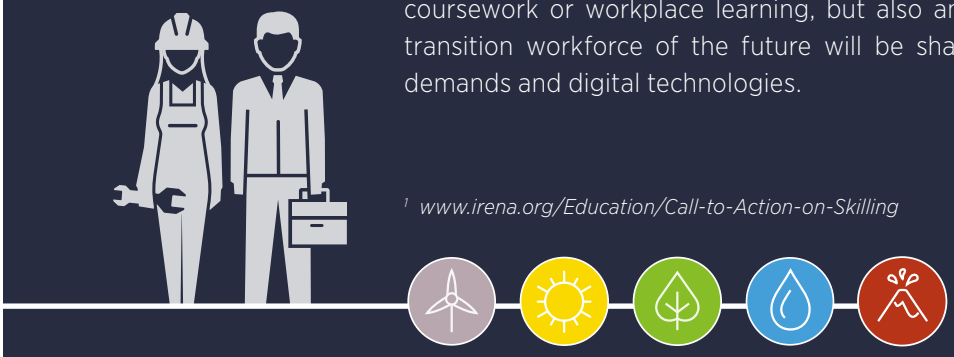
Job quality matters; as does equitable access. Women still face barriers to hiring and career advancement. People with disabilities are only just beginning to receive more opportunities. Making equity a lived reality for all will allow the renewable energy sector to access a wider pool of talent and ensure fairer outcomes.

Introduction

THE HUMAN SIDE OF THE RENEWABLE ENERGY INDUSTRY

Much of the attention in the renewable energy sector is paid to issues surrounding technology, cost and market trends. However, the human side – the workers who make it all happen – is too often overlooked. People are required in a broad spectrum of occupations and skillsets – including materials scientists and technology specialists, plumbers and electricians, machinists and engineers, construction workers, sales personnel, planners and administrators, and many others. Continued growth of renewable energy deployment will keep adding to employment in the sector. This is the case even as technology development (robots, drones, artificial intelligence [AI] applications) may reduce the number of individuals required for a particular task or change the profile of the expertise most needed in certain occupations. All of this will unfold in the context of how investment decisions and public policy making shape supply chain structures.

Comprehensive education and training strategies, including upskilling and reskilling efforts, are essential to both develop and maintain a capable energy transition workforce. This workforce requires both expertise and experience. As recognised in IRENA's Call to Action on Skilling for the Energy Transition,[1] building this workforce requires multi-pronged solutions encompassing measures to integrate skilling within broader energy policies, innovative financing mechanisms, improved data availability on skill supply and demand and harmonisation of qualifications to promote quality and consistency and facilitate workforce mobility. It is not only a matter of acquiring knowledge specific to a particular industry segment of today, whether through vocational training, academic coursework or workplace learning, but also an ongoing quest to determine how the transition workforce of the future will be shaped by factors such as emerging skill demands and digital technologies.



[1] *www.irena.org/Education/Call-to-Action-on-Skilling*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Living up to the commitment made at the 28th United Nations Climate Change Conference (COP28) to triple renewable power capacities by 2030 will require an all-hands-on-deck approach. The renewable energy industry will have to fully tap the world's pool of talent, ideas and ingenuity. Drawing on the International Renewable Energy Agency's pathbreaking gender analysis (IRENA, 2025a), the Jobs Annual Review series has often reported on the share of women in the sector's workforce and the barriers that women face in entering and advancing in the industry. But other population groups – youth, minorities and Indigenous Peoples – have perspectives, needs and wisdom that can also help bring about a comprehensive and just energy transition. This report casts a spotlight on the role of persons with disabilities.

Employment in the renewable energy sector is driven by several factors. Key among them are trends in installations of generating capacity and in equipment manufacturing industries and the degree to which such capacities are in use. Installations and supply chains are shaped, on the one hand, by corporate investments and decision making, and on the other, by a multitude of policies at the national, subnational and international levels. By their investment decisions, private sector actors exert strong influence on policy making; conversely, public policies shape the investment climate and market stability.

Job creation is influenced by several drivers, key among them investment decisions and public policies

While the particular mix of public and private drivers varies around the world, together they shape research and development, investments, market design and cost structures. Costs are driven not only by technological advances and economies of scale, but also by industrial policy (such as measures to develop supply chains); subsidies (including the balance between support for renewables vis-à-vis fossil fuels), tax credits and other fiscal tools; supply-and-demand dynamics, including overcapacity; as well as patterns of industry competition versus consolidation.

Given that renewable energy deployment trends are a key factor influencing job creation, this introduction briefly reviews the most recent developments – principally for 2024, the most recent year for which comprehensive data are available – in renewable energy installations and in related equipment manufacturing capacities.

Global renewable power capacity, 2024

4 443 gigawatts

2/3

of the increase occured in China

Solar PV

capacity more than doubled since 2020

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Global renewable power capacity reached 4 443 gigawatts (GW) at the end of 2024. The 582 GW in additions set a new annual record. As in previous years, however, there were significant geographic disparities. The bulk of the increase occurred in Asia, and particularly in China, which alone accounted for close to two-thirds of new global installations. Worldwide, solar and wind energy together represented 97.5% of all net renewable additions in 2024. Some 453 GW of solar photovoltaic (PV) were added, up substantially from the previous record of 357 GW in 2023, for a cumulative capacity of 1 859 GW. Wind power reached a cumulative total of 1133 GW. New installations of 114 GW were slightly below those of the previous year. While onshore installations set a new record, the offshore pace was far slower than in the previous four years. Cumulative renewable hydropower capacity, at 1 277 GW, is just marginally greater than that of wind. But hydropower is growing much more slowly; new additions amounted to less than 10 GW (IRENA, 2025b).

For heating and cooling, cumulative global solar thermal capacity had risen to 544 gigawatts thermal by the end of 2024, equivalent to 777 million square metres of collector area. Annual additions peaked in 2013 and have since fallen to about a third of that record rate (Weiss and Spörk-Dür, 2025). Liquid biofuel production was estimated at 175 billion litres (L) in 2023, a new peak value (REN21, 2025).

In 2024, 70.5% and 61.5%, respectively, of the world's new wind and solar PV capacities were installed in China. The country now accounts for 46% and 48%, respectively, of the world's cumulative capacity in these two industries. Outside of China, the world's pace of solar PV additions is still strong, more than doubling since 2020. But in the wind sector, installations outside of China in 2024 fell back to the level of 2016 (IRENA, 2025b).

There has been much discussion about diversifying global supply chains in recent years. Given the continued dominance of China in equipment manufacturing, many countries have adopted subsidies and support schemes to build their domestic manufacturing base. However, the global geography of renewable energy manufacturing is slow to change. One reason is the depth of China's manufacturing ecosystem and its considerable cost advantages. Global overcapacities in wind, solar and battery manufacturing have translated into intense competition and price wars among companies. While price is not the only factor, these conditions make it difficult for new entrants to scale up and succeed.

In recent years, by far the most money in support of domestic supply chain development was made available in the United States (US), through the 2022 Inflation Reduction Act's tax credits, loans and grants. That legislation triggered large-scale investment announcements, and some additional capacity was built. But future prospects are now uncertain. India, through a mix of subsidies and industrial policy prescriptions, succeeded in significantly expanding its domestic solar PV manufacturing industry, even though it continues to be reliant on imported cells, principally from China. The European Union has established ambitious (but non-binding) goals for greater manufacturing on the continent. Yet the available funding is quite modest. By contrast, policies pursued by Japan and the Republic of Korea are focused on expanding their companies' manufacturing footprint, irrespective of whether facilities are located at home or abroad (Bloomberg NEF, 2025).

Especially in the solar and wind industries, several countries are using tariffs and other trade restrictions, sometimes in connection with industrial policy measures, to raise domestic content and garner related socio-economic benefits, including local job creation. For example, the United States has imposed tariffs on imported solar and wind equipment for many years. Brazil, India and other countries like Türkiye have all instituted tariffs or local-content rules, mostly on solar equipment but in some cases also in the wind industry. A key question is whether such measures are part of an effort to build up domestic industries and skills over time, beyond a simple-minded protectionism that could slow down renewable energy deployment and have negative effects on jobs. According to Bloomberg NEF (2025), "most of the world's clean-tech imports today face relatively minimal tariffs. In 2024, around 59% of clean-tech imports were subject to tariffs of just 0–10%. Wind and solar products benefited from broad exemptions."


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Tariffs, sometimes in connection with industrial policy measures, are used to raise domestic content and create jobs

In early 2025, the incoming US administration adopted trade restrictions as a major policy instrument, and targeted tariffs have given way to wholesale measures affecting industries like aluminium and steel (on which renewable energy industries critically depend), and indeed entire economies. Announced rate increases have been steep, but there have also been frequent revisions, creating much uncertainty. Reflecting geopolitical competition, US tariffs on Chinese imports are much higher than those applicable to other countries. This new trade policy has prompted retaliation by China and other countries, but it has also triggered urgent rounds of trade negotiations on multiple fronts.

The ultimate outcome remains to be seen. But without a doubt, the renewable energy industry and the energy transition are increasingly buffeted by growing geopolitical and geo-economic rivalries that threaten to slow the expansion of renewables and undermine international collaboration in pursuit of critical energy and climate objectives.

Against this background, this annual review discusses the latest available data and highlights specific aspects. It consists of two parts. The first (Chapters 1 to 3) focuses on renewable energy employment estimates in the context of industry developments and policy changes. The second (Chapters 4 and 5) provides a more qualitative dimension that argues for changes beyond the realm of renewable energy deployment and enabling policies as such, embracing multi-faceted efforts to provide access to jobs, training opportunities and career networks for groups of people who all too often are left behind. While such efforts may be driven by equity objectives, they allow industry to tap broader pools of talent as the renewable energy workforce expands.

Chapter 1 discusses renewable energy employment trends globally, by major technology – in particular the solar PV and wind sectors, followed by hydropower, liquid biofuels and heat pumps. Chapter 2 offers insights on leading countries. As in previous years, these include China, Brazil, India, the United States and the Member States of the European Union. Chapter 3 provides snapshots of information on selected other countries in different regions of the world. Chapter 4 offers highlights of IRENA's latest findings on gender equity and widens the focus on a particular dimension of workforce diversity, namely efforts to make hiring and workplaces more accessible to people with disabilities. Chapter 5 concludes with some observations about rising challenges and the way forward.

CHAPTER 1

1 RENEWABLE ENERGY EMPLOYMENT WORLDWIDE AND BY TECHNOLOGY

This edition of the International Renewable Energy Agency's (IRENA's) *Renewable energy and Jobs: Annual review* is the twelfth in the series. It is the fifth produced in collaboration with the International Labour Organization (ILO). The report surveys global renewable energy employment as of 2024.[2] Estimates are based on a broad array of reports and analyses published by government agencies, industry associations, non-governmental organisations and academic researchers, supplemented by IRENA's own calculations and estimates. In the context of industry dynamics affecting equipment manufacturing and deployment, as well as national policy making, the study explores employment in quantitative and qualitative terms.

The headline finding of this edition is that renewable energy employed 16.6 million people directly and indirectly in 2024.[3] This is a nominal increase from the previous year's 16.2 million, but it should be noted that the new figure includes a revised estimate for biofuels employment in India that was not included in the 2024 edition. Since 2012, employment has grown from 7.3 million (see Figure 1).[4]

[2] *In some cases, 2023 is the most recent year for which data are available, and some estimates – like the hydropower figures – refer to direct employment only.*

[3] *Direct employment refers to jobs generated by core activities, without accounting for intermediate inputs necessary to manufacture renewable energy equipment, or construct and operate facilities. Indirect employment includes employment in the upstream industries that supply and support the core activities of renewable energy deployment. Workers in such positions may be engaged in the production of steel, plastics or other materials, or provide financial and other services. These industries are not directly involved in renewable energy activities but produce intermediate inputs along the value chain of each renewable energy technology. Data are principally for 2023, with some 2022 data and some instances where only information from earlier years is available. The data for hydropower include direct employment only, whereas data for other technologies include both direct and indirect employment wherever possible.*

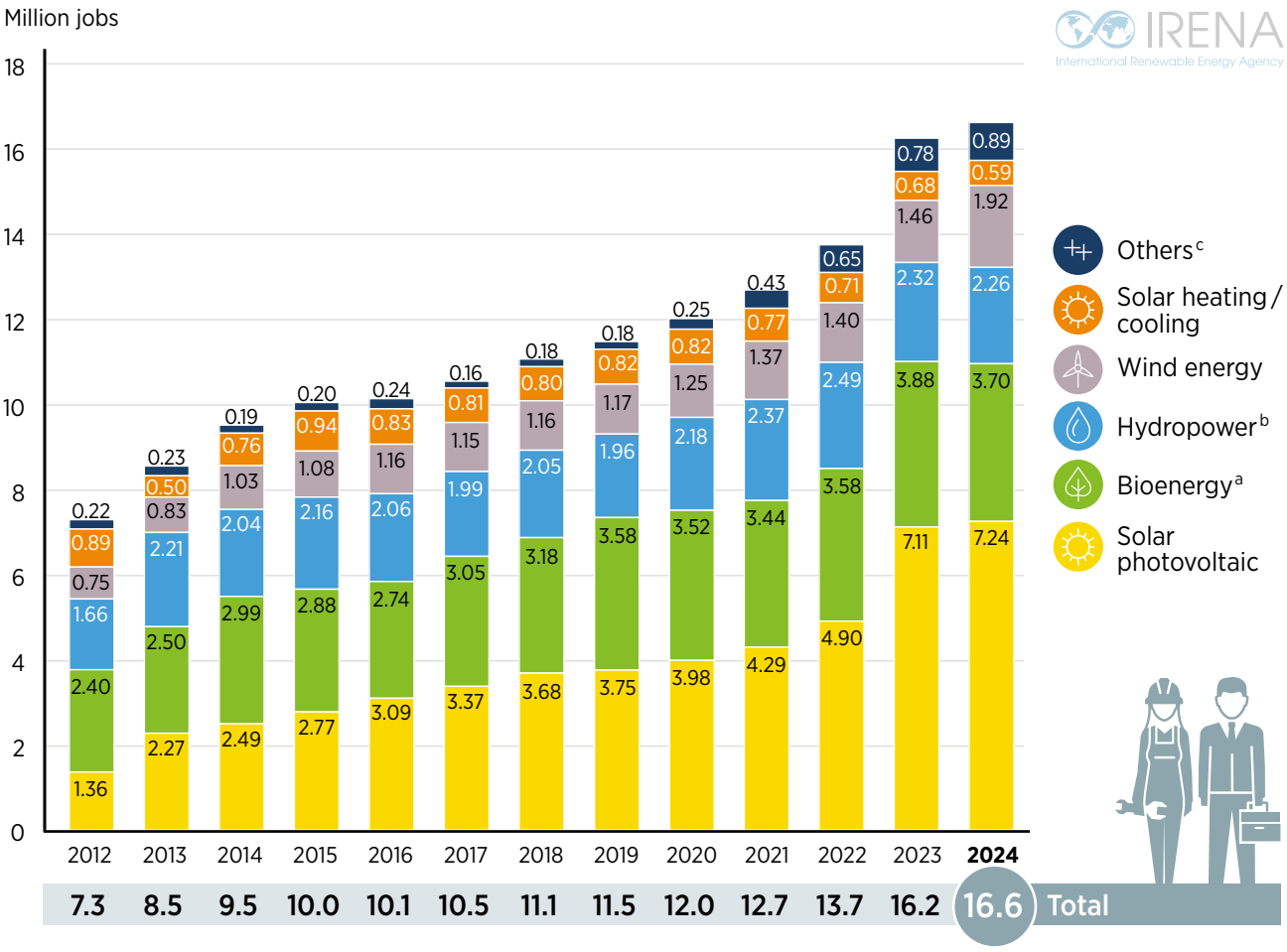
[4] *The job numbers shown in the figure for the period 2012-2024 reflect the figures reported in earlier editions of this series.*

These job estimates likely understate the full extent of employment generated by renewable energy for several reasons. National statistical classifications typically do not capture renewable energy employment as such, given that renewables and their value chains span a broad group of technologies and inputs, across agriculture and forestry, mining, manufacturing, construction and a wide array of services. Some studies do not include indirect employment, and the definition of what is considered a direct or indirect job may vary. Informal employment is notoriously hard to capture. This may affect estimates in decentralised applications, in particular. Moreover, there are questions whether or not informal jobs are full-time equivalents. In bioenergy feedstock operations, harvesting activities may be seasonal in nature.

16.6 million

people worked in the renewable energy sector in 2024

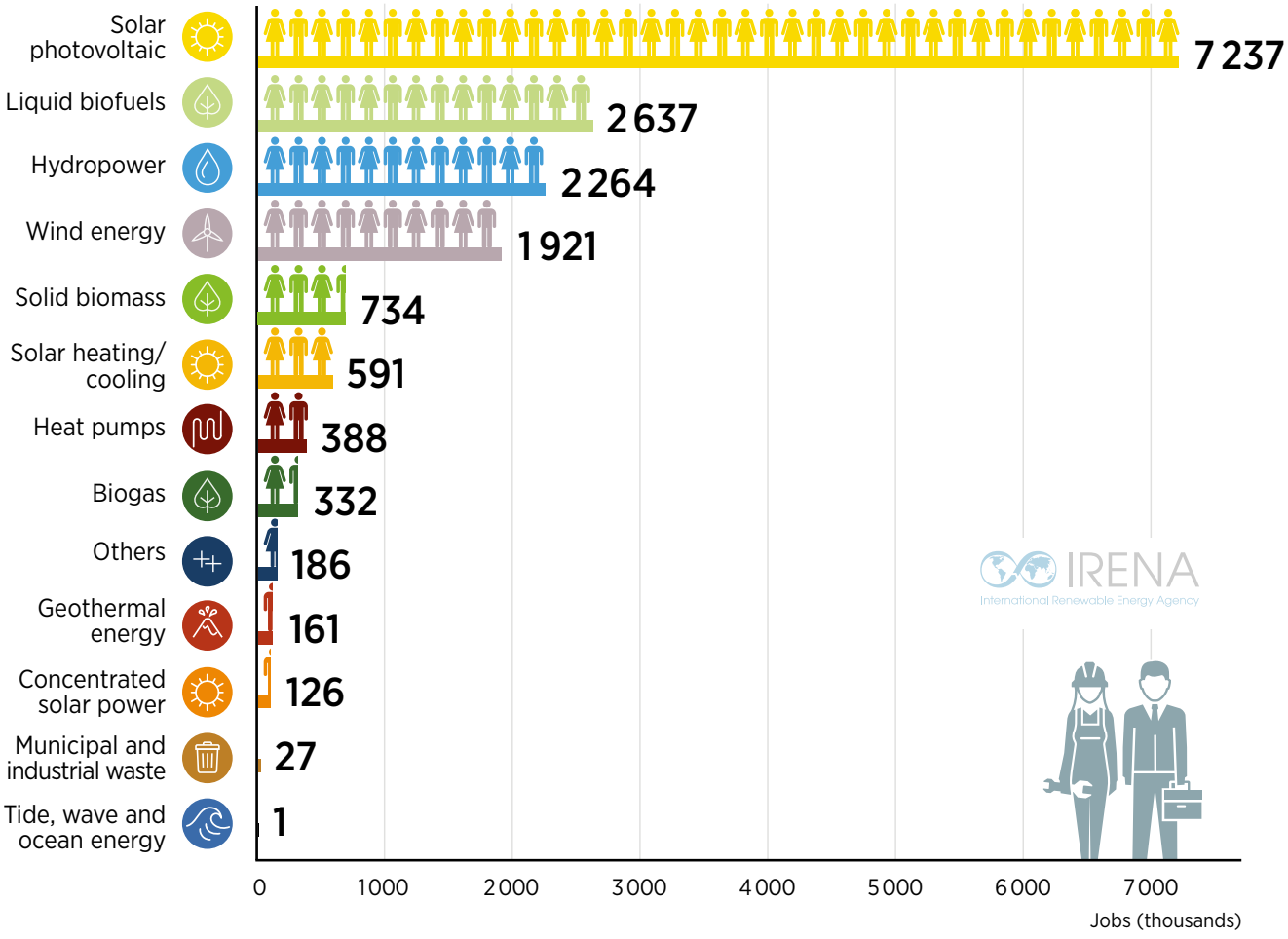
Figure 1 Evolution of global renewable energy employment by technology, 2012-2024



Notes:
a Includes liquid biofuels, solid biomass and biogas.
b Direct jobs only.
c "Others" includes geothermal energy, concentrated solar power, heat pumps (ground based), municipal and industrial waste, and ocean energy.

Employment details for 2024 by renewable energy technology are shown in Figure 2. Solar photovoltaic (PV) is clearly in the vanguard, followed by liquid biofuels, hydropower and wind. As noted in previous editions, the other renewables technologies are smaller in scale, dynamism and employment. This chapter highlights solar PV's prominent role compared to other renewables, providing a more detailed picture of the industry's dynamics.

Figure 2 Global renewable energy employment, by technology, 2024



1.1 Solar photovoltaic

7.2
million jobs

In 2024, China, the United States, India, Germany and Brazil set new annual solar PV deployment records, far ahead of other countries, although additions in Türkiye, Spain, Italy, Australia and France were also significant. By contrast, the pace of new additions in Japan, Spain, the Republic of Korea, Poland and Mexico fell behind levels achieved in earlier years (IRENA, 2025b).

The global solar PV landscape remains remarkably concentrated. The top ten countries together accounted for 89% of new additions and 82.5% of cumulative generating capacities at the end of 2024. China remains in a class of its own, single-handedly accounting for more than 60% of new global installations in 2024. At 278 gigawatts (GW) added, its pace was up almost six times from its 2020 additions. In terms of cumulative capacity, China now has almost double that of the next four leading countries (the United States, Japan, India and Germany) combined, and close to triple the capacity of the entire European Union (EU) (IRENA, 2025b).

The solar PV industry is marked by continued rapid expansion of manufacturing plants. In 2024 alone, global module manufacturing capacity expanded by 315 GW to reach 1554 GW, an increase of 25% (Wood Mackenzie, 2025a). Notwithstanding soaring interest in diversifying supply chains in many countries, China commands the lion's share of manufacturing capacity; the country produced 81.6% of the world's PV modules in 2024. Southeast Asia[5] held a 8.6% share, India 4.8%, the United States 2.7% and Europe 1.8% (Wood Mackenzie, 2025a).

Solar PV
manufacturing and deployment remain geographically concentrated.

Actual global module production in 2024 was a comparatively small 719.5 GW. Massive overcapacity persisted, with worldwide average capacity utilisation at 46%, down from 48% the previous year (Wood Mackenzie, 2025a). This has pushed market prices down, benefiting consumers while manufacturers struggle. Non-Chinese companies typically cannot match China's cost advantages, which are based on economies of scale, strong research and development spending, and a high degree of vertical integration (Wood Mackenzie, 2024). Even where other countries are expanding their module assembly operations, many still rely heavily on Chinese-made cells. Thus it is not surprising that China continues to account for the bulk of employment in solar PV equipment manufacturing.

[5] *In particular, Cambodia, Malaysia, Thailand and Viet Nam, with smaller roles played by Indonesia and the Lao People's Democratic Republic, as discussed in more detail in Chapter 3.*

In 2024,

China's module exports were more than seven times the volume recorded in 2017.

Over the last two decades (2004-2024), the share of global PV shipments manufactured in China rose from just 1% to 83%. Southeast Asia's share went from 0% to a peak of 23% in 2022 before dipping to 12% in 2024. By contrast, the US percentage declined from 13% to 0.9% (NREL, 2025a). The fact that a small number of countries hold a large share of the world's panel production capacity means that solar PV jobs elsewhere are mostly in construction and installation, and operations and maintenance (O&M), rather than in manufacturing.

China's exports of PV modules rose from 219.1 GW in 2023 to 241.9 GW in 2024; shipments were up more than seven times the volume recorded in 2017 (Ember, 2025). The geography of trade flows is shifting. Following years of rapidly rising sales to the EU (which absorbed more than half of China's exports in 2022), volume fell by 7% in 2024, bringing the EU's share of China's exports from 53% down to 39%. The trajectory of China's exports to Asian countries was the opposite, soaring after a dip in 2020-2022. Though still much smaller, both the volume and the share going to the Middle East and Africa rose strongly in 2023 and 2024 (Ember, 2025).

The top four importers absorbed almost 30% of China's exports[6] (see Figure 3). Brazil has expanded its purchases tenfold since 2018, to more than 22 GW in 2024. Likewise, imports by Pakistan and Saudi Arabia are rising rapidly and now surpass India's, whose purchases have heavily fluctuated over the years in line with changes in installation levels and impacts of industrial policy making. Australia's and South Africa's purchases had grown in recent years but fell in 2024; they remain at much lower levels than those of the leading importers. By contrast, Japan's imports have stagnated, and Germany's have been cut in half since 2022 even as the country installs record amounts of capacity, thus indicating a major shift in its supply chains (Ember, 2025).

Solar panel imports

are surging in Brazil, Pakistan and Saudi Arabia, surpassing those of India.

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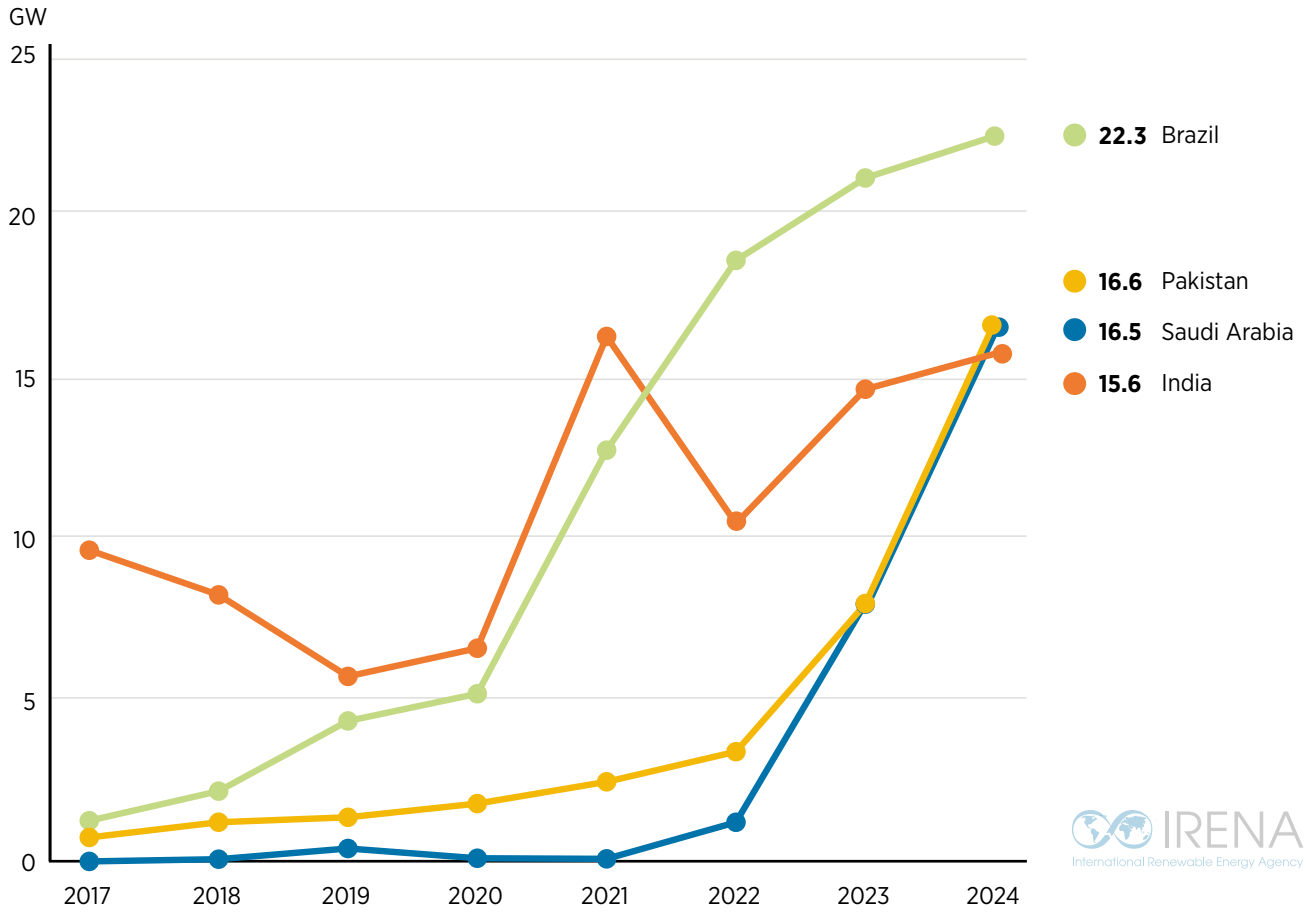
[6] *Nominally, the Netherlands receives by far the largest volume of any importer (some 40 GW), but the bulk of panels go on to other destinations. The port of Rotterdam serves as a principal entry point for the European market.*

Figure 3a China's PV module exports, selected countries, 2017-2024



Source: (Ember, 2025).

Imports by some countries far surpass their officially recorded deployments, implying that the number of solar jobs they generate is likely substantially larger than reported, especially if most of the imported panels are used for decentralised rooftop installations. Time lags between import and actual deployment account for some of the difference, including strategic stockpiling, warehousing in anticipation of large-scale projects, and unaccounted or unreported captive or off-grid installations. But there are important additional factors.

In **Pakistan**, for example (see additional discussion in the section on selected country experiences), rooftop installations – and thus associated job creation – are not fully captured in official statistics, due to uneven customs enforcement and the tax-free status of solar equipment (Renewables First & Herald Analytics, 2024). Official statistics indicate new installations of 500 megawatts (MW) and cumulative deployments of just 3.7 GW in 2024 (IRENA, 2025b), even as imports from China reached 16.6 GW that year (Ember, 2025). The explosive growth of off-grid solar is spurred by falling solar module costs and Pakistan's net metering policy, but it is also driven by the experience of frequent power outages and spiralling retail electricity costs. Power tariffs more than doubled in the course of three years, while subsidies were cut. Estimates suggest Pakistan may have installed 10–15 GW of solar PV in 2024 (Jones and Copsey, 2025; Jilani, 2024).

Imports

by some countries far surpass their officially recorded deployments, implying a much larger number of solar jobs being created.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Six of the ten countries

with the largest number of solar jobs are in Asia.

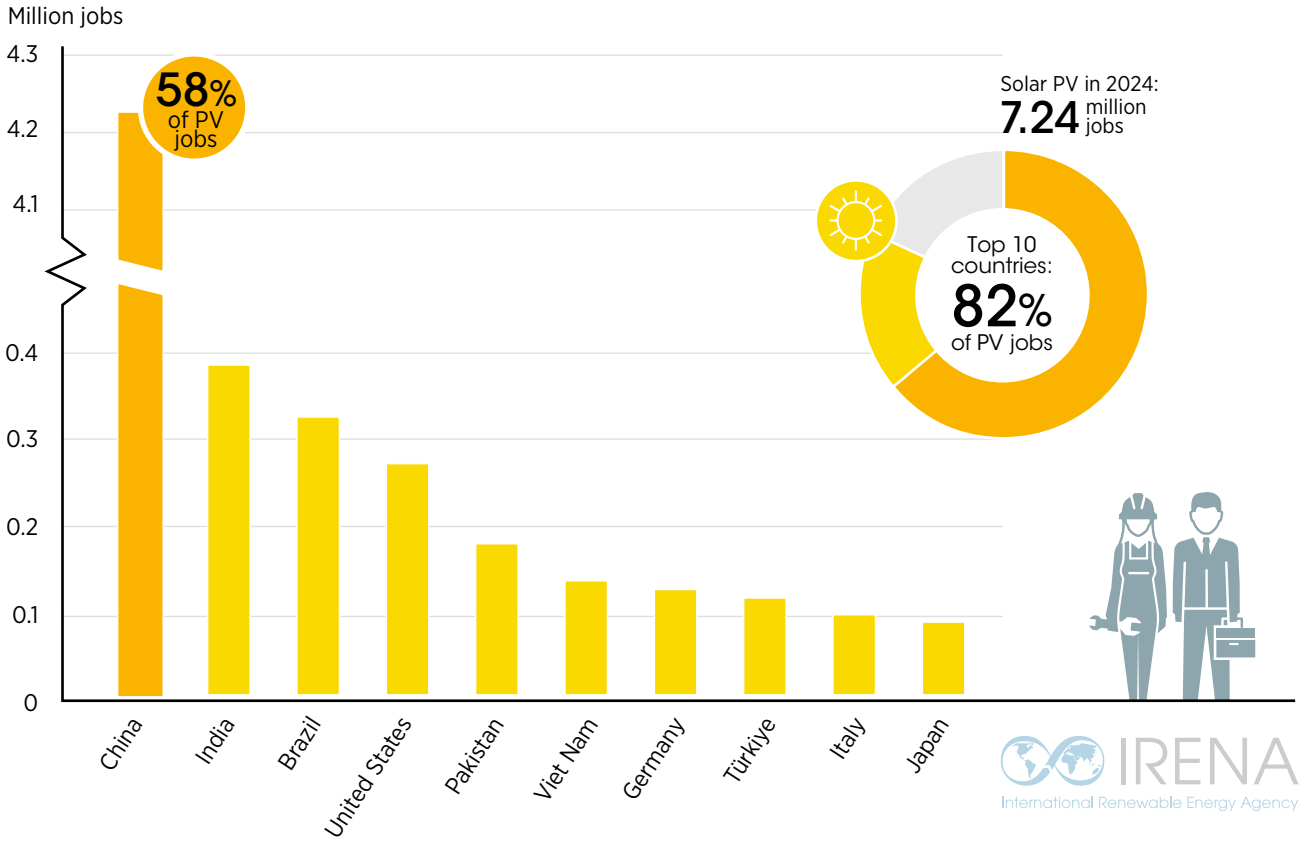
Saudi Arabia is also importing far more modules than it has been installing. Unlike in Pakistan, the Saudi goal is presumably to stockpile supplies for large-scale projects either under construction or to be mounted in future auction rounds (Jones *et al.*, 2025). Saudi Arabia's ACWA Power has announced 15 GW of renewable energy projects, of which 12 GW were solar (Shah, 2025). But the country is also aiming to localise its supply chain, decreasing reliance on equipment imports and enhancing domestic manufacturing (Hryshko *et al.*, 2024).

With tariffs high, Chinese module exports to the United States are minimal. Instead, the bulk of US imports comes from Southeast Asia, where Chinese-owned factories predominate. However, US tariffs imposed on these countries, too, are leading to shifts in the region's supply chain. Cambodia, Malaysia and Thailand together shipped 28.7 GW to the United States in 2023, but this fell to 25.9 GW in 2024, while Viet Nam's exports rose from 15.7 GW to 19.7 GW. The Lao People's Democratic Republic (Lao PDR) and Indonesia are still smaller players, but because they were not affected by US tariffs their sales to the United States have risen quickly – from 0.5 GW to 3 GW. In 2023 and 2024, the United States also imported growing volumes of modules from India (Wood Mackenzie, 2024; 2025).

IRENA estimates worldwide solar PV employment in 2024 at 7.2 million, up from 7.1 million in 2023. Among the top ten countries (see Figure 4), six are in Asia, two in Europe and two in the Americas. Employment in the top ten was a cumulative 6 million jobs, or 82% of the global total. Asian countries hosted 75% of the world's PV jobs. Europe had an 11.3% share (with the European Union accounting for 10.6%). The Americas held 9.6%, with all others making up the remaining 3.7%.

By country, China accounted for 58% of global PV employment in 2024, or some 4.2 million jobs. Of Europe's estimated 821 200 PV jobs in 2024, 764 400 were in EU Member States. India had an estimated 384 900 solar jobs – 304 300 jobs in grid connected solar and 80 600 in off-grid settings. The United States had close to 280 100 PV jobs in 2024.

Figure 4 Solar photovoltaic employment in 2024: Top ten countries



Note: PV = photovoltaic.

A surge in solar PV installations in Brazil raised its job count to 323 800. Pakistan, Germany, Türkiye and Italy all ranked among the top ten, driven by strong growth in both distributed and utility-scale solar markets. Japan's new capacity additions fell for yet another year in 2024, and IRENA estimates its workforce at 95 000. Southeast Asia's solar manufacturing hubs remained major exporters in 2024, with Viet Nam, the region's largest producer, rising to sixth place globally.

1.2 Wind

1.9
million jobs

In 2024, the wind energy sector installed 114 GW of capacity worldwide, very close to the peak volume in 2023. China added a record 79.4 GW, about 70% of the global total. But the rest of the top ten countries deployed just 23.6 GW combined, or 20.6% of the total. In fact, annual new installations in the world excluding China have fallen from a peak of 44 GW in 2021 to 34.9 GW (IRENA, 2025b).

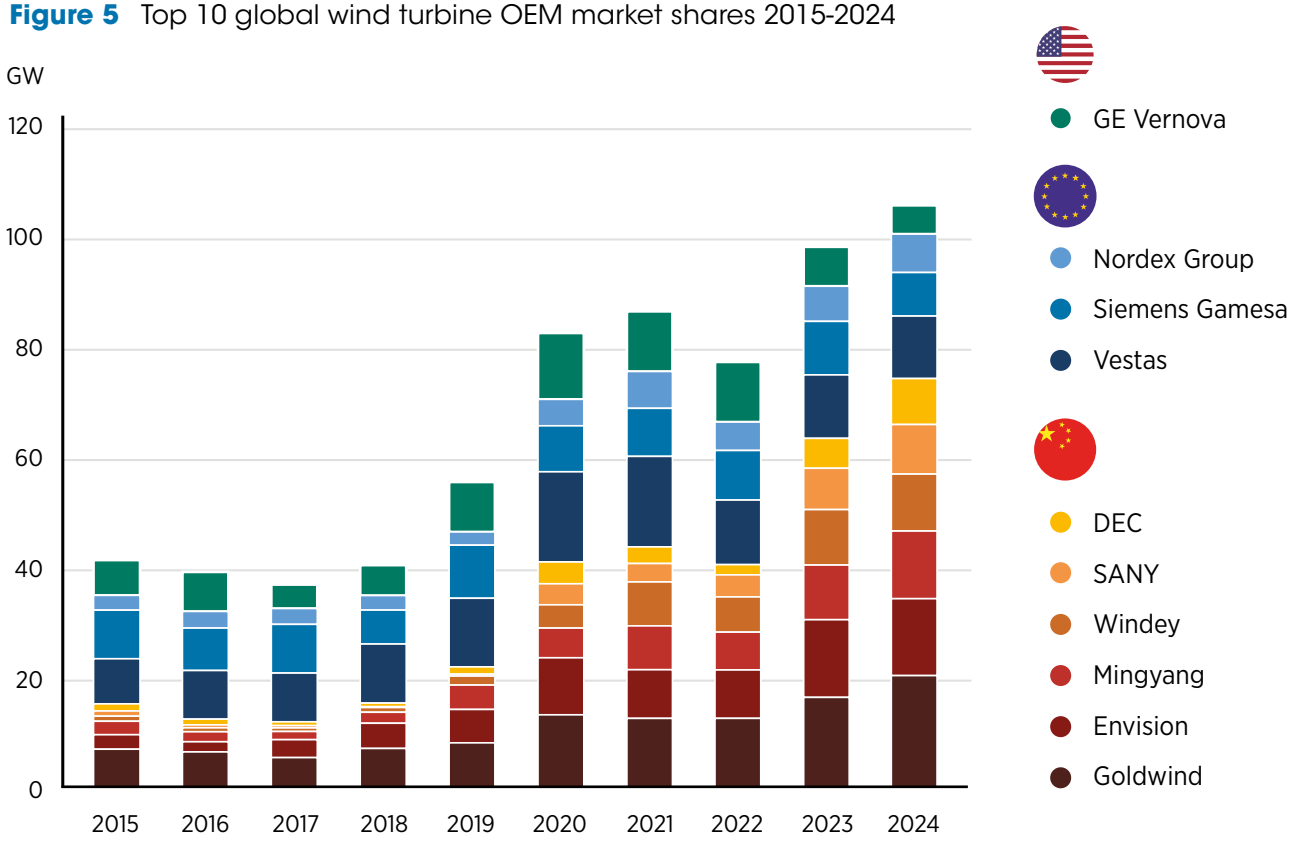
Most leading countries installed less, and sometimes far less, than they had in earlier years. The United States, for example, added just 5.1 GW, compared to 14.8 GW in 2020. Germany's 3.3 GW was just over half its record 6.1 GW in 2017, and the United Kingdom's pace is only one-fifth of what was deployed in 2017. India's 3.4 GW represents the fifth straight year of increases yet still falls short of the pace in 2017, when 4.1 GW were added (IRENA, 2025b).

China is also the largest manufacturer of wind power components. In 2024, Chinese firms had 70% of all turbine orders worldwide, ahead of companies headquartered in Europe (19.4%), the United States (6.5%) and India (0.8%) (Wood Mackenzie, 2025b). However, unlike in the solar industry, Chinese companies' output is still almost exclusively devoted to serving their massive domestic market, with a marginal presence elsewhere in the world. Domestic sales account for 97% of their total.

In terms of market share for cumulative installations through the end of 2024, the top three Chinese equipment manufacturers (Goldwind, Envision and Minyang) together held a 38.6% share. European companies Vestas, Siemens Gamesa, Enercon and Nordex have supplied 37% of all the wind turbines deployed worldwide by the end of 2024. The cumulative market share of US-headquartered GE Vernova is 10%, but in 2024 it accounted only for about 4% of new installations (see Figure 5). Vestas and Siemens Gamesa have the most diverse geographic portfolio. Their turbines have been deployed in more than 80 countries, compared with 51 for GE Vernova (Wood Mackenzie, 2025c).

Wind employed about 1.9 million people in 2024. Employment was highest in Asia (68% share), followed by Europe (18%) and the Americas (13%), while Oceania and Africa had a combined 1.4%. The top ten countries (see Figure 6) together employed 1.7 million people, or 89% of the global total. Four of these countries are in Europe, three in the Americas and three in Asia. But China had the clear lead with 1.16 million jobs, or 61% of the global total.

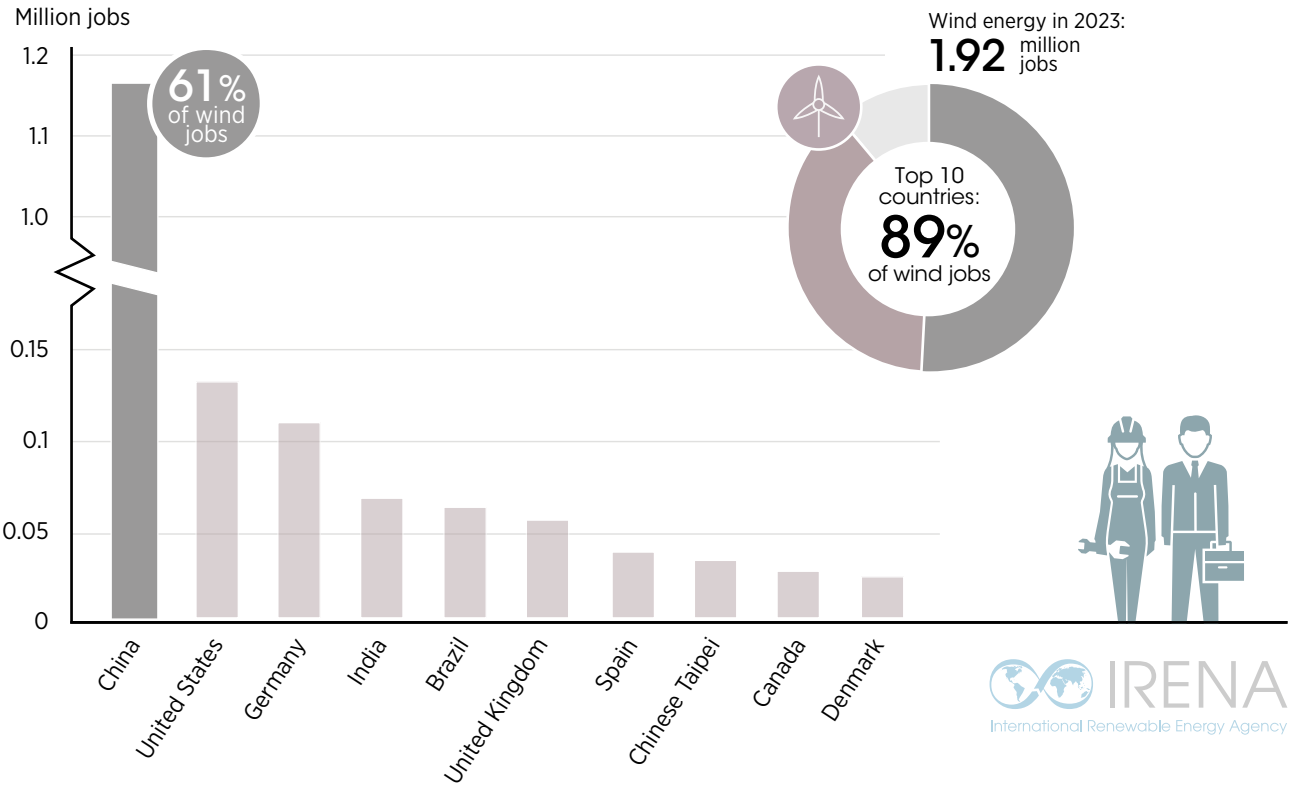
Figure 5 Top 10 global wind turbine OEM market shares 2015-2024



Source: (Wood Mackenzie, 2025c).

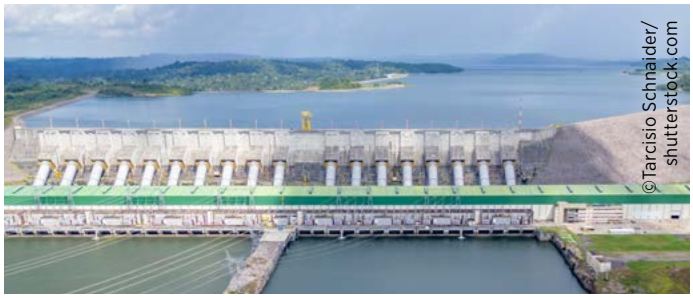
Note: OEM = original equipment manufacturer.

Figure 6 Wind employment in 2024: Top ten countries



1.3 Hydropower

2.3
million jobs



Hydropower continues to play a central role in the global energy system, accounting for 48% of total renewable electricity generation in 2024 (IRENA, 2025b). In terms of installed capacity, it remains the largest single source of renewable power, though its growth trajectory is relatively flat as the technology matures and the world diversifies towards other renewable options. The share of renewable hydropower (excluding pumped hydropower deployed for energy storage) in total installed renewable capacity declined from 31.3% in 2023 to 27.4% in 2024, reflecting this relative change.

China remains the dominant player in hydropower development, adding 6.7 GW of renewable hydro in 2024 (again, excluding pumped storage and mixed projects). In comparison, Africa as a region installed 1.3 GW, signalling progress but still underscoring the gap in scale. These figures illustrate the contrasting dynamics between mature hydropower markets with ongoing large-scale deployment and emerging regions where growth is steady but smaller in absolute terms (IRENA, 2025b).

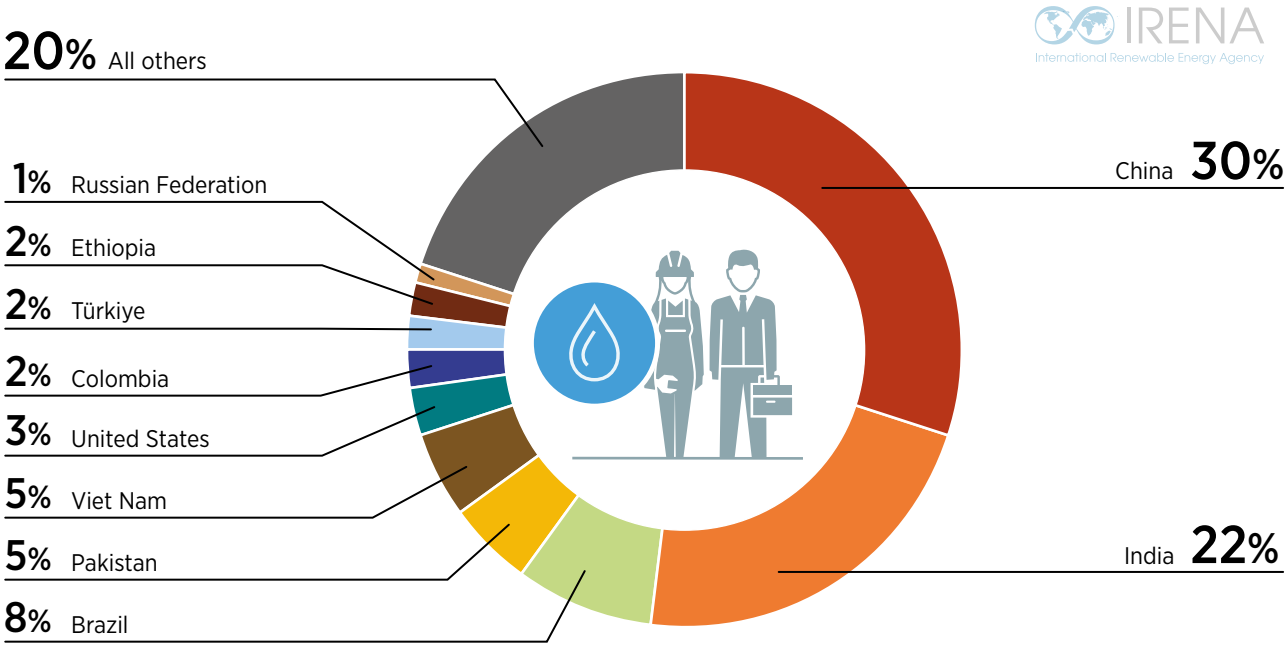
Employment trends closely mirror these capacity shifts. In 2024, renewable hydropower directly provided jobs for 2.26 million people worldwide. China accounts for the largest share, employing about 30% of the global workforce, while India follows with 22%, or close to half a million jobs. Brazil contributes around 8%, while Pakistan and Viet Nam each account for about 5% (see Figure 7). This distribution underscores both the concentration of employment in a few major markets and the more modest, though still significant, role hydropower plays in dozens of others.

Hydro-power
has entered a phase of maturity, yet it remains a cornerstone of renewable energy.

Slower growth in new project development, often linked to financing challenges and environmental or social permitting, has tempered job creation. Nonetheless, employment in O&M remains steady thanks to the long operational lifespans of hydropower plants.

While hydropower has entered a phase of maturity, it remains a cornerstone of renewable energy. It offers not only direct employment, especially in O&M in the large-scale projects, but also enables indirect and induced opportunities, particularly in smaller-scale applications for remote regions. In many cases, micro- and small-scale facilities serve as vital anchors for rural livelihoods, unlocking access to energy and fostering community development (IRENA, 2023). With careful planning to address environmental concerns and adequate training to ensure local ownership of operations, hydropower can continue to deliver sustainable employment while supporting the broader energy transition.

Figure 7 Hydropower employment (direct jobs), shares of major countries in 2024

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China and India

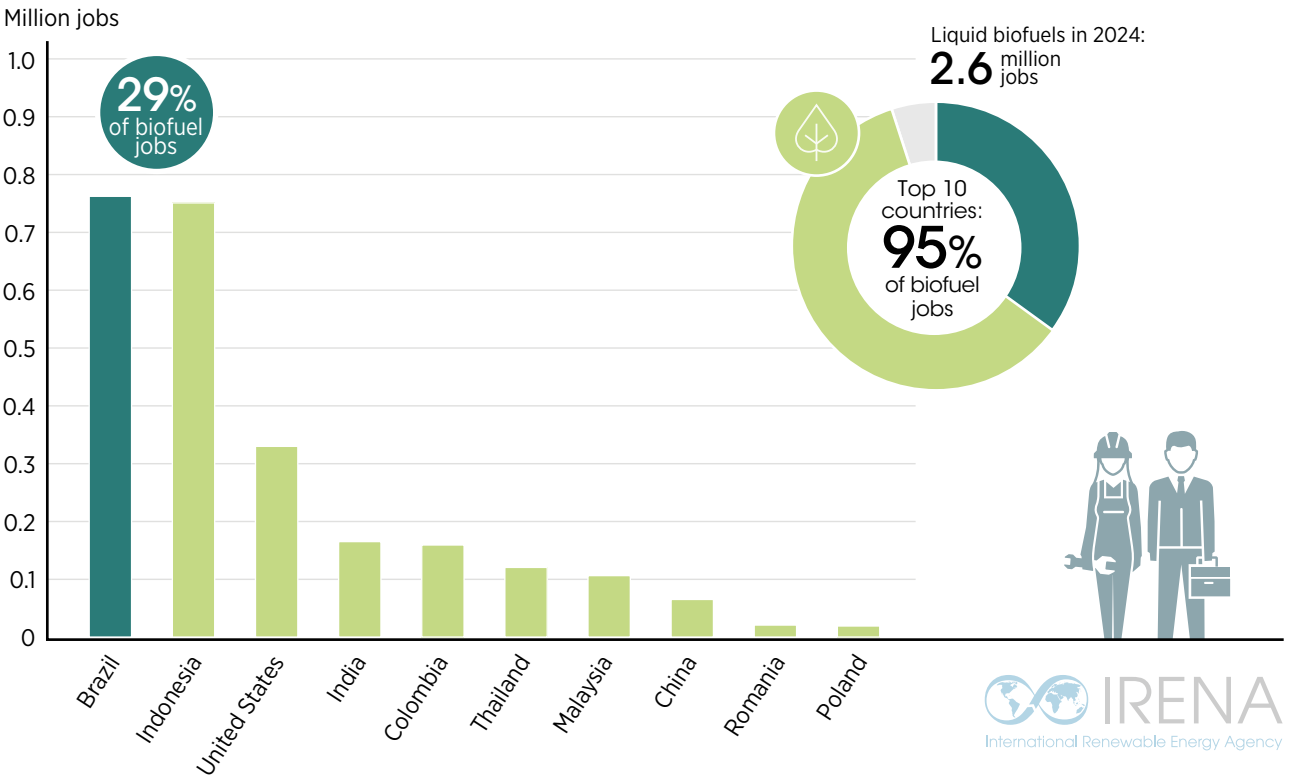
accounted for half of all hydropower employment worldwide in 2024.

1.4 Liquid biofuels

2.6
million jobs

Estimates of liquid biofuel production in 2023 (the most recent year for which data are available) ran to 175 billion L, up 7% from 2022 and up 25% over the last decade (REN21, 2025). IRENA estimates worldwide biofuel employment at 2.64 million in 2024. Asia accounts for 46.5% of all biofuel jobs worldwide, while Latin America holds another 35%. North America and Europe have smaller shares (12.6% and 5.6%, respectively). Among the top ten countries, five are in Asia, three in the Americas and two in Europe. Together, the top ten account for 95% of the global total (Figure 8).

Figure 8 Liquid biofuels employment in 2024: Top ten countries



Biorefineries offer limited employment, but many of the jobs are skilled and well paid, involving experienced tradespeople, technicians, engineers and other positions in science, technology, engineering and mathematics. Most jobs in the biofuels sector are in the agricultural supply chain, producing sugarcane, palm oil, corn and other types of feedstock. In the United States and the European Union, these operations are heavily industrialised. In many other parts of the world, planting, harvesting and transporting feedstock materials still involves a great deal of manual work.

That said, the expanding use of machinery is reducing the need for human labour in sugarcane cutting and palm fruit collection, while the number of jobs in equipment manufacturing rises. The extent and pace of mechanisation vary widely among countries (given different levels of industrialisation) and farms (given diverging abilities of farmers to invest in machinery), and among types of feedstock (owing to the characteristics of how readily different crops can be handled by machinery).

Another factor affecting employment is the seasonality of much of farm work, though the length of growing seasons varies widely geographically and among different crops, as does the number of harvesting cycles. This means that calculations of jobs in the supply chain may not represent full-time equivalent jobs.

On job quality, it should be noted that many of the affected positions are physically extremely demanding. The work is strenuous, involves long hours and often exposes workers to multiple risks such as extreme heat (worsened by climate change) and harmful pesticides or other hazards. Pay is typically based on the volume of material handled, rather than a guaranteed salary. In many cases, labour protections are limited or non-existent, given that formal work contracts are rare. Agricultural labourers, especially migrant workers, may have few viable livelihood alternatives.

Though it is second to the United States in terms of biofuels production, Brazil has the largest workforce – an estimated 762 000 people in 2024. Like Brazil, several other countries have large-scale (and in some cases, fast-growing) biofuels outputs and sizable workforces, particularly in feedstock harvesting. They include Indonesia (where employment is estimated at 750 600), Colombia (159 150), Thailand (120 400) and Malaysia (106 200). India may have 165 000 jobs, on the basis of a rough estimate. These numbers do not, however, necessarily represent full-time equivalents given the seasonality of work. With more industrial feedstock operations, the United States employs about 330 000 people in biofuels, 69% of whom are in ethanol, 20% in biodiesel and the remaining 11% in renewable diesel, waste fuels and other biofuels. In the European Union, biofuels supported an estimated 135 800 jobs in 2023.

Biofuels jobs

are concentrated in the agricultural supply chain, but many of these are seasonal, physically demanding, and offer few labour protections.

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1.5 Heat pumps

0.4
million jobs

Heat pumps are not an energy source *per se*, but they are an important tool for making ground-source geothermal heat available. Global heat pump sales rose from 13.5 million units in 2023 to 14.4 million in 2024 (BNEF, 2025), with China, the United States, Europe and Japan being the largest markets. No global employment estimates are available, but there are at least 388 000 jobs in the three leading markets. No complete estimates are available for Japan.

Preliminary statistics by the China Heat Pump Alliance suggest that the industry provided employment opportunities for approximately 140 000 people in China in 2024. Among them, 35 000 people were employed in the production of heat pump main units, and 25 000 in the production of components, accounting for 42% of the total employment in the Chinese heat pump industry. Sales and service providers, including those engaged in sales, logistics, installation and after-sales services, offered 80 000 jobs, accounting for the remaining 58% (CHPA, 2025).

As reported by the *Energy and Employment Report*, the United States had 7 078 jobs related to ground-source or geothermal heat pumps in 2024 and 70 554 related to air-source heat pumps, adding to 77 631 direct jobs (indirect employment adds an unknown number). This was up from 72 974 in 2023 (USDOE, 2025).

Global heat pump sales rose from 13.5 million units in 2023 to **14.4 million** in 2024, but sales fell in Europe.

Europe suffered a significant downturn in 2024, as sales of heat pumps in 14 countries fell by 21%, according to the European Heat Pump Association (EHPA). Only 2.2 million heat pumps were sold in 2024 compared to 2.8 million in 2023 and a peak volume of 3 million in 2022. The plunge is ascribable to many factors, including changes in governmental support schemes that weakened consumer confidence, an overall economic slowdown and the low price of gas. Sales plunged 48% in Germany, 40% in Belgium, and 25-35% in Denmark, the Netherlands and Poland. The EHPA reports that at least 4 000 jobs have been cut, and more than 6 000 workers were put on shorter working hours with reduced pay. Overall, the sector provides around 170 000 direct jobs in Europe (EHPA, 2025).

CHAPTER 2

2 RENEWABLE ENERGY JOBS IN MAJOR COUNTRIES

Ongoing technology development, especially the rapid emergence of artificial intelligence and its applications in the sector, will fundamentally affect labour needs and occupational profiles. Renewable energy employment is also being shaped by a raft of national policies that influence market development and may serve to accelerate or slow the pace of investment. Another factor is whether the development of grid capacity, transmission lines and other types of infrastructure can match the often rapid pace of renewables development or force unforeseen curtailments. Furthermore, supply chains are being reshaped geopolitically by trade restrictions, industrial policy efforts and other measures. Workforce development itself (*i.e.* skilling, reskilling and upskilling) is a critical factor, not only in avoiding skill gaps but also in influencing where manufacturing hubs and generating assets are located.

As in previous years, China, Brazil, India, the United States and members of the European Union are the defining actors in equipment manufacturing, installations and related services such as engineering. Accordingly, they are major employers, as highlighted in Figure 9, with more detailed data in Table 1. Reflecting its commitment to renewable energy and its achievement in building a massive domestic manufacturing sector to underpin this commitment, China predominates. In addition to the leading countries identified here, others are discussed in Chapter 3.

Figure 9 Renewable energy employment in selected countries

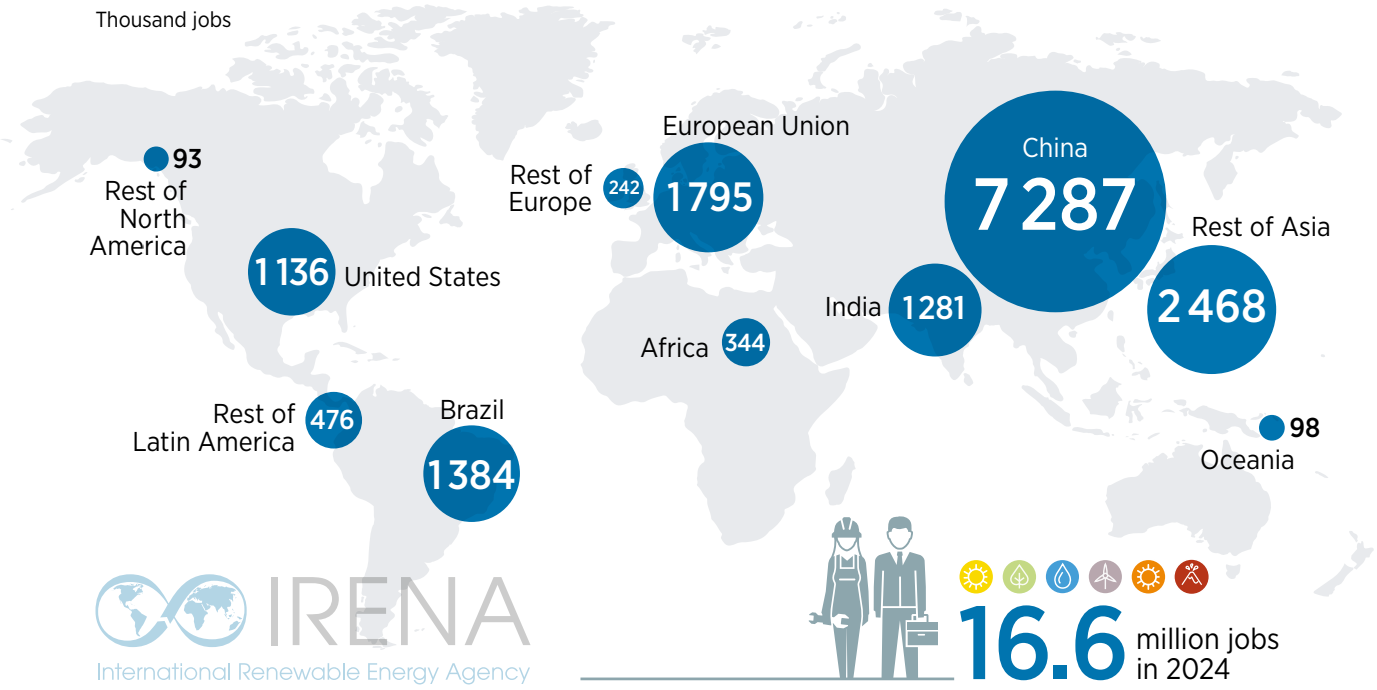

Table 1 Estimated direct and indirect jobs in renewable energy worldwide, by industry, 2024 (in thousands)

	World	China	Brazil	India	United States	European Union (EU-27)
Solar photovoltaic	7 237	4 220	324	385[l]	280	764
Liquid biofuels	2 758	65	762[e]	165	330[g]	136
Hydropower[a]	2 264	674	180.4	503	70[h]	83
Wind power	1 925	1 164	62	67	133	279
Solid biomass[b, c]	729	215		58	47[i]	280
Solar heating and cooling	591	421	56[f]	17	32	19
Biogas	332	187		85		43
Geothermal energy[b]	161	95			9[j]	7
Concentrated solar power	126	107				5
Total	**16 605[d]**	**7 287**	**1 384**	**1 281**	**1 136[k]**	**1 795**

Notes: The figures in the table are the result of a comprehensive review of primary national entities such as ministries and statistical agencies and secondary data sources such as regional and global studies. Empty cells indicate that no estimate is available. The values in the columns may not add up precisely due to rounding.

a. Direct jobs only.

b. Power and heating applications.

c. Traditional biomass not included.

d. Includes 26 000 jobs in waste to energy and close to 388 000 jobs in heat pumps (140 000 jobs in China, 170 000 in European countries and about 78 000 in the United States).

e. Includes 378 100 jobs in bioethanol and 383 800 jobs in biodiesel.

f. Direct jobs only.

g. Includes 228 331 jobs in ethanol and 65 208 jobs in biodiesel, plus 36 199 jobs in renewable diesel, waste fuels and other biofuels.

h. Includes 58 089 jobs in traditional hydropower and 12 111 jobs in low-impact hydropower. Does not include 9 799 jobs in pumped hydropower (energy storage).

i. Includes woody biomass fuels (33 773 jobs) and biomass-based power (13 294 jobs).

j. The figure represents direct employment in geothermal power.

k. Includes 157 636 jobs in technologies not individually identified in the table (geothermal heat, heat pumps and others).

l. Includes 304 300 grid-connected and 80 600 off-grid solar PV jobs.

EU-27 = 27 Member States of the European Union.

7.29
million jobs

2.1 China

Clean energy drove a quarter of the country's economic growth in 2024, according to an analysis of government statistics by the Helsinki-based Centre for Research on Energy and Clean Air (Millard, 2025).

In 2024, China installed 276.8 GW of solar photovoltaic (PV) capacity, up from 216.9 GW in 2023. This equalled about 60% of the world's new additions. Still, Chinese residential PV installation rates dropped 32% in 2024 (NREL, 2025a), meaning that less labour-intensive utility-scale installations were preponderant. In wind power, China added 79.4 GW of new capacity, more than the previous peak of 75.9 GW in 2023. This was equivalent to about 70% of new installations worldwide (IRENA, 2025b). On the manufacturing side, 69% of worldwide component production capacities for wind generators in early 2024 were in China.[7] For major solar PV components it was 88% to 95%, and for energy storage it was 89% (Li, 2024). China's integrated, large-scale supply chains are able to deliver equipment at unmatched prices. According to Wood Mackenzie data, not only are wind turbines and solar panels made in China far cheaper than those produced elsewhere, but products made outside of China with Chinese components are also cheaper than products made outside of China with inputs that were produced elsewhere (Li, 2025).

Based on surveys, supply chain analyses and employment factor calculations, the China Renewable Energy Society estimates China's total renewable energy employment at 7.29 million in 2024.[8] This figure is slightly less than the previous year's estimate. At first glance, this is surprising, given that China continues to install record amounts of wind and solar capacity and to expand its capacities for equipment manufacturing.

Renewable energy employment in China is modulated by several factors, including growing labour productivity, resulting from rising economies of scale, learning effects and the application of new technologies (such as drones used for easier and faster monitoring, planning, safety and other functions, and, increasingly, artificial intelligence). In both the installation and O&M segments of the value chain, the adoption of more intelligent technologies has improved operational efficiency while reducing workforce requirements. The combined effect of growing project scales, continuous process optimisation and resource integration through third-party O&M platforms has translated into lower employment levels than would otherwise be the case.

Integration problems have caused curtailments. As a result, installed wind and solar generating capacities are not fully used. In fact, gaps between nominal capacities and actual power output are increasing (Li, 2024). The bottom line is that less labour is required to operate and maintain wind and solar farms than nameplate capacity figures would suggest.

On the manufacturing side, massive overcapacities are posing growing problems. For wind turbines, the utilisation rate declined from 49% in 2023 to 37% in 2024 (Li, 2024). For PV modules, the respective rates were 49% and 46% (Wood Mackenzie, 2025d). Price wars are forcing solar PV companies to find ways to keep slashing costs, including for labour.

[7] *For nacelles, the worldwide share was 76%; for gearboxes, 75%; for blades, 71%; for towers, 54%.*

[8] *Communication with experts, China Renewable Energy Society, Beijing, July. All employment estimates for China are derived from this source (except for heat pumps, which are included in the total jobs figure of 7.29 million, but derived from the China Heat Pump Alliance).*

Renewable energy employment in

China

is influenced by growing labour productivity and excess manufacturing capacities, among other factors.

Indeed, the Chinese government is trying to curb what it calls "disorderly" competition and reduce excess capacity across the solar PV supply chain, with guidelines aimed at ending destructive price wars and volatility, eliminating outdated capacity and also improving product quality (Shaw, 2025). In November 2024, revised guidelines for the PV industry were issued by China's Ministry of Industry and Information Technology, requiring stricter efficiency standards, minimum capital ratios for new PV projects, higher energy and resource consumption standards, and stricter compliance and quality assurance (Hryshko, 2024).

Prompted by mounting losses, in December 2024 some three dozen Chinese manufacturers signed a voluntary agreement intended to curb excess production and below-cost sales of modules (Hryshko *et al.*, 2025). Five of China's leading solar manufacturing companies – JA Solar, Jinko Solar, Longi Green Energy, Tongwei and Trina Solar – cut their workforces by a combined 87 000 staff, or 31% in 2024, as they tried to come to terms with falling prices and steep financial losses. This retrenchment took place in the form of layoffs but also reduced pay and work hours (Howe, 2025).

For the **solar PV** sector as a whole, the China Renewable Energy Society estimates employment at 4.2 million people in 2024, down from 4.59 million the previous year. Jobs in PV manufacturing were estimated at 2 million, while those in construction and installation, plus O&M, are believed to amount to 2.22 million. The estimate draws on a survey of 32 leading PV companies (covering silicon ingots, wafers, cells, modules, inverters, equipment and other categories). Performance varied across segments of the value chain. Notably, PV modules and related auxiliary materials saw significant reductions in employment, while other equipment manufacturers expanded their workforce.

China remains by far the world's dominant solar PV manufacturer. Exports are steadily expanding. Data from the General Administration of Customs of the People's Republic of China show that module shipments grew more than sevenfold, from 33 GW in 2017 to 242 GW in 2024. The European Union bought more than a third (38%) of shipments, followed by Asian countries (28.5%), Latin America and the Caribbean (14%), the Middle East (7%) and Africa (4%). Just 1% went to North America, reflecting import restrictions there. Falling prices caused export revenues to drop slightly from USD 42.3 billion in 2022 to USD 39.5 billion in 2023, before plunging to USD 28 billion in 2024 (Ember, 2025). Looking at exports of renewables more broadly (including solar, wind and batteries for energy storage), Chinese sales climbed 20% by volume in 2024, but revenues dropped 13% due to intense market competition (Li, 2025).

In the **wind** industry, Chinese equipment manufacturers account for the bulk of global wind turbine orders. Their share surged from 39% in 2020 to 80% in 2023 and 70% in 2024. But this expansion principally reflects the rapid expansion of the Chinese domestic market, while their presence in export markets is still quite limited (Wood Mackenzie, 2025b). During 2024, foreign orders came principally from project developers in India, Egypt, Saudi Arabia and the Philippines (Wood Mackenzie, 2025e).

Still, exports – and jobs tied to them – will grow in significance. European turbine manufacturers are becoming more receptive to using Chinese-made components, given their lower cost. Chinese original equipment manufacturers are also stepping up their investments in manufacturing plants abroad and are getting involved in project development, including Central Asia, the Middle East, India, Brazil and South Africa (Ren and Li, 2025).

The China Renewable Energy Society estimates Chinese wind industry employment at 1.16 million in 2024, up from 745 000 in 2023. This includes 785 437 people in wind power generation; 84 943 in manufacturing of power transmission, distribution, wires and instruments; 74 471 in financial and insurance services; 60 507 in electricity, heat, gas, and water production and supply; and about 219 000 in other industries supplying a variety of inputs.

Following solar PV and wind, the next largest employers are hydropower, solar heating and cooling, and bioenergy. Based on a survey of nearly 200 member organisations of the China Society for Hydropower Engineering, a conservative estimate of **hydropower** industry employment runs to 673 600 people in 2024. This includes jobs in investment, design, construction, equipment, O&M, research institutes and universities.[9]

Bioenergy employment (direct and indirect) ran to 467 000 jobs, up from 425 000 in 2023. By individual technology, 215 000 people worked in solid biomass, 187 000 in biogas and 65 000 in liquid biofuels. China's **solar heating and cooling** industry employed about 421 000 people (direct jobs only) in 2024; down from 514 000 the year before, this continues a multi-year decline that reflects the ongoing downturn in the real estate market. Installation, together with O&M, accounted for 325 600 jobs, while manufacturing contributed 95 300 jobs. Other renewable energy sectors employed fewer people. **Concentrated solar power** was estimated at 106 510 jobs (including indirect jobs) in 2024, up from 98 300 the previous year. Manufacturing offered employment for 65 880 persons; construction and installation, 37 880; and O&M, 2 750. **Geothermal heat** and power offered 91 500 direct jobs, down slightly from 93 900 in 2023. Most of these, some 79 000, were in O&M for heating technologies.

According to the China Heat Pump Alliance, the **heat pump** industry in China – covering components, main units, distributors, installation and after-sales services – provided employment opportunities for approximately 140 000 people in 2024. Among them, 35 000 people were employed in the production of heat pump main units, and 25 000 in the production of heat pump components, accounting for 42% of the total employment in the heat pump industry. Sales and service providers, including those engaged in sales, logistics, installation and after-sales services, offered 80 000 jobs, accounting for 58% (CHPA, 2025).

Following solar PV and wind, the next largest renewable energy employers in

China

are hydropower, solar heating and cooling, and bioenergy.

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[9] *This is an incomplete estimate, given that not all members responded to the survey. The China Society for Hydropower Engineering sought to fill the gaps by relying on information available on websites, but those figures represent total company headcounts, including non-hydropower personnel. The society's members represent about half of China's installed hydropower capacity. An extrapolation would suggest a doubling of the employment estimate, but such an extrapolation is of only limited reliability. The society's estimates were conveyed by the China Renewable Energy Society in the aforementioned communication.*

1.39
million jobs

2.2 Brazil

In 2024, Brazil had an estimated 1.39 million renewable energy jobs, most in biofuels, hydropower and solar PV. Solar and wind are the country's most dynamic renewable energy industries, but the biofuels sector remains Brazil's largest employer.

Continuing its growth, **biodiesel** production ran to 9.7 billion L in 2024, up from 7.6 billion L in 2023 (ABIOVE, 2025). A quarter of the output was from Rio Grande do Sul, and, altogether, the southern and midwestern parts of the country produce roughly 40% each (USDA-FAS, 2024a). In other words, most of the biodiesel jobs are in those parts of the country.

The Center for Advanced Studies in Applied Economics (CEPEA, 2024), in collaboration with the Brazilian Association of Vegetable Oil Industries (ABIOVE), publishes employment figures for the soybean sector, which are the largest biodiesel feedstock. The soybean supply chain employed 2.28 million people in agricultural and other inputs, industrial equipment and services in 2023. But given that biodiesel production absorbs only 3-4% of soybean output, biodiesel-related jobs may have amounted to about 150 000. Strong output growth may have raised this to 190 000 jobs in 2024. Soybean represents three-quarters of biodiesel feedstock. A rough extrapolation would suggest 258 000 jobs in 2024 if other feedstocks are included. This may be a conservative estimate. A different methodology that this report series has long used (based on employment factors for different types of feedstock) suggests that there may have been 383 800 biodiesel-related jobs in 2024.[10]

Brazil is the second-largest **bioethanol** producer in the world. According to the Sugarcane and Bioenergy Observatory (UNICAdata, 2025), total employment in the sugarcane-energy sector in 2024 was 751 377 jobs (down from a peak of close to 1.3 million in 2008). As confirmed by government data (see below), about half of these can be regarded as biofuels jobs, reflecting the share of Brazil's sugarcane crop used for ethanol. UNICAdata offers some interesting breakdowns: some 474 211 sugarcane jobs, or 63%, were in agriculture, 176 421 (23%) in industry and the rest in other sectors. But while half of the jobs in the agriculture sector are classified as "rural/manual activities", 43% are related to mechanisation efforts, which suggests that the need for manual labour will likely continue to decline.

According to government statistics, there were 378 100 bioethanol jobs in 2024, up from 367 500 in 2023. Since reaching a low point in 2020 with 336 200 jobs (the result of growing mechanisation in the agricultural supply chain), employment has steadily expanded again (MTE/RAIS, 2025) due to output growth.[11] The bulk of jobs are in agriculture, principally sugarcane growing, but also increasingly corn, with production and distilling growing rapidly. Sugarcane-based jobs are mostly in the country's centre-south, especially in São Paulo, while corn-based operations are concentrated in Mato Grosso in the centre-west region (USDA-FAS, 2024a).

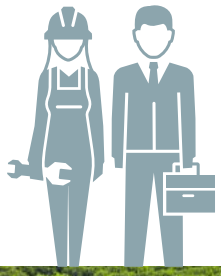
[10] The calculation is based on employment factors for different feedstocks, with an assumed annual rate of improvement in labour productivity, given mechanisation trends. The 2024 shares of feedstock raw materials, principally soybean oil and various vegetable oils, are derived from ABIOVE (2025).

[11] In 2024, about 176 100 workers cultivated sugarcane in Brazil, and 201 900 processed alcohol and ethanol.

IRENA data indicates that Brazil installed a record 15.2 GW of new **solar PV** capacity in 2024, continuing the country's rapid expansion in recent years (IRENA, 2025b). Close to two-thirds of the PV capacity added in 2024 was in decentralised generation facilities. Half of all decentralised capacity was in the most labour-intensive residential segment (ABSOLAR, 2025). According to Greener (2025), Brazil imported 22.3 GW of PV modules in 2024, surpassing the previous record of 17.8 GW, set in 2023, by 25%. Falling panel costs compensated for high interest rates on consumer bank loans.

In an effort to shield its small PV assembly industry from low-cost Chinese products, Brazil in 2024 placed a 25% tariff on imported solar modules (NREL, 2025a). The country had 153 domestic manufacturers of solar PV system kits, but only 7 manufactured modules, another 7 produced inverters, while 18 produced trackers (ABSOLAR, 2025). But Brazilian companies manufacture other components like aluminium frames, solar glass and junction boxes, an important source of employment (PVknowhow, 2025).

Given the rapid growth in installations, IRENA estimates Brazil's direct and indirect solar PV jobs at about 323 800 in 2024, up from a revised figure of 265 700 in 2023. Direct jobs alone amounted to about 120 330 in 2024.[12] Making solar panels affordable to rural and low-income households, as the rural electrification programme seeks to do (see Box 1), holds considerable additional employment potential, especially if locals can be trained in installation and maintenance.



Box 1
Solar power for electrifying rural low-income households

A June 2024 law brought together the Amazon region's rural electrification programme *Luz para todos* (Light for All, which was started in 2003) with the *Minha Casa, Minha Vida* (Our House, Our Life) clean energy programme. The intent is to invest BRL 3 billion (USD 560 million[13]) to fund purchase and installation of solar panels in the homes of 500 000 low-income households by 2027. In addition to making energy more affordable for families, the initiative is expected to create jobs and build skills in installing and maintaining solar panels (Polar ESS, 2024).

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[12] *Information received from the Ministry of Mines and Energy of Brazil.*

[13] *Exchange rate of Brazilian Real: BRL 1 = USD 0.19 as of 19 November 2025.*

The solar PV equipment distribution companies surveyed by Greener (2025) employed 2 625 people in 2024, 41% of them women. System integrators employed 46 861 people, 20% of them women. Women were concentrated in administrative, human resource and finance roles (56% of the workforce), followed by 23% in commercial activities, 7% in marketing, 6% each in management and project engineering, and just 1% in assembly and installation (Greener, 2025).

In 2024, Brazil added 2 million square metres of **solar water heating** capacity, the most so far in a single year, representing a growth of 10.8% year-on-year (ABRASOL, 2025). The country's southeast region accounts for 70% of the market, and thus for the bulk of installation and maintenance jobs. Three-quarters of sales nationwide are in the residential sector. IRENA estimates about 55 900 jobs in the solar water heating industry (including manufacturing and installation) in 2024.

Brazil added 3.8 GW of **wind** generating capacity in 2024, a slower pace than the 4.9 GW installed in 2023 (IRENA, 2025b). Bahia and Rio Grande do Norte, two states in the northeast, continue to lead in deployment, with close to two-thirds of the country's total capacity (ABEEólica, 2025). Based on its employment factor analysis, IRENA estimates Brazil's wind industry jobs at about 62 300, down from 80 300 the year before. While O&M jobs continue to grow, those in manufacturing and construction are fewer, reflecting the lower installation rate. Direct jobs alone amounted to about 12 450 in 2024.[14]

1.28
million jobs

2.3 India

In 2024, India had an estimated 1.3 million renewable energy jobs. Hydropower remained the largest source of employment (around 503 000 jobs), with solar PV also employing a substantial workforce (about 385 000) in grid connected and off-grid systems. Biofuels accounted for a notable share as well (roughly 165 000), while wind, biogas and other renewables contributed comparatively smaller numbers.

India established a new record for its **solar PV** installations in 2024, adding 24.5 GW, or almost double the previous high of 13.5 GW reached in 2022. The country was ranked third in the world for new installations and fourth for cumulative capacity (97.2 GW) at the end of 2024 (IRENA, 2025b). According to NREL (2025b), about 80% of India's cumulative PV capacity is utility scale, which is less labour intensive than rooftop installations. The rooftop share of new installations in 2024 was also about 20% (Gupta, 2025a).

Module manufacturing capacity rose from 49.3 GW in 2023 to 68.2 GW in 2024. Given capacity utilisation of about 50%, actual output was 34.2 GW. This represents close to a doubling from 18.3 GW in 2023. It was the third-largest volume after China's 587 GW and a combined 62 GW for the nations of Southeast Asia. But India's cell capacity stood at 22.4 GW, lagging behind its module capacity. (Wood Mackenzie, 2025d).

[14] *Information received from the Ministry of Mines and Energy of Brazil.*


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India's

solar PV industry remains one of the world's biggest module importers (buying from China), but is also a rising exporter (selling to the United States).

Changing trade patterns play a major role for India's solar PV industry. On the one hand, despite imposing tariffs, India remains one of the biggest module importers, buying 15.6 GW's worth from China alone in 2024 (Ember, 2025). Indian module manufacturers mostly rely on imported cells from China and from Chinese-owned factories in Viet Nam, Thailand and Malaysia. Cell imports quadrupled to 30.9 GW in 2022–2024 (Wood Mackenzie, 2025d). Domestically produced PV modules remain more expensive and of lower quality than imported ones, notwithstanding India's tariffs (IEEFA, 2024). Cost differentials and allegations of dumping practices by Chinese and Vietnamese producers also led India to impose anti-dumping duties on imported solar glass (Mathew, 2025).

At the same time, India's PV module exports (nearly all to the United States) have tripled since 2022, reaching 5.8 GW in fiscal year 2024 (IEEFA, 2024). Exports accounted for 30% of module production, up from about 20% the previous year (NREL, 2025b). A number of factors brought about the surge in exports. One such factor was the reduced domestic demand for PV modules. This was partly due to the postponement of the "Approved List of Models and Manufacturers (ALMM)" requirement until April 2024, a policy that restricts eligible PV modules for certain projects to support domestic manufacturing. In addition, Indian PV manufacturers enjoy much higher profit margins selling to the United States than in the Indian market. They took advantage of US tariffs (a so-called anti-dumping and countervailing duty) imposed on China and Southeast Asian exporters (IEEFA, 2024). However, in 2025, the United States raised tariffs on all imports from India, including PV modules, to 50%, making them more expensive than their Southeast Asian competitors (Nagaraj, 2025).

Gujarat is by far the most prominent state for module manufacturing (with 42% of capacity), followed by Tamil Nadu (11%), which offers low-cost land and subsidies for manufacturers. Tamil Nadu also provides pensions and housing for workers. It has a long track record of support for women's education, and this made it possible for many women with college degrees to join the solar PV manufacturing workforce (Sengupta, 2025). A 4.3 GW Tata Power solar cell and module factory was opened in February 2025 near Tirunelveli. The facility is expected to employ some 4 000 persons (The Economic Times, 2025). Some 80% of the workforce are women who, following six weeks of training, operate the machinery and robotics. The facility offers extensive safety and health measures, including women's programmes, medical checkups and transport arrangements for safe travel to and from work during night shifts (Gupta, 2025b; Green is the Future, 2025).

IRENA's employment factor calculation, considering local manufacturing shares and the varying labour intensities of utility-scale and rooftop installations in supply chain segments, suggests that India may have had 304 340 solar PV jobs in 2024. This includes 127 230 jobs in rooftop solar and 177 110 in utility-scale solar. In addition, earlier estimates suggest that around 80 600 additional jobs are linked to the off-grid solar PV sector.

With cumulative installed **wind** power capacity of 48.2 GW, India ranks fourth globally. Additions of 3.4 GW in 2024 were the highest in seven years – but still below the 2017 peak of 4.1 GW (IRENA, 2025b).

India's Ministry of New and Renewable Energy reports that the domestic share of wind sector manufacturing has reached 70–80%. Fourteen manufacturing companies have a presence in the country, including subsidiaries of foreign companies, joint ventures and domestic enterprises like Suzlon, Inox and Adani Wind (MNRE, n.d.). India can assemble 18 GW worth of wind turbines annually, for domestic use and exports. But a March 2024 study indicated that the manufacturing capacity for some key components is significantly lower (about 5 GW for wind towers and 8 GW for gearboxes), with most imports coming from China. Under policies proposed in early 2025, the ministry aims to strengthen domestic manufacturing via non-tariff barriers and achieve a domestic share of at least 64% of the cost of all components (JMK Research & Analytics, 2025). In August 2025, the government required that manufacturers buy components from vendors on an approved list (Reuters, 2025).

Based on an employment factor analysis, IRENA estimates that the Indian wind sector had about 67 400 employees in 2024, up from 52 200 jobs in 2023. Employment was distributed roughly in thirds across manufacturing, construction and installation, and O&M.

India's **biofuels** production – mostly ethanol – has quadrupled since 2018 (and expanded twelvefold since 2015) to about 7 billion L. Initially sugarcane based, in recent years a rapidly growing share of output relies on maize (and other grains) as feedstock, with a rough 50:50 split in 2024 (USDA-FAS, 2025a). This shift has been driven by the government's Ethanol Blended Petrol programme (Karad, 2025).

Based on employment-factor estimates (Chandel *et al.*, 2017), in 2024 sugarcane-based ethanol production may have employed 32 500 sugar mill workers and 376 700 seasonal harvest workers. Employment in harvesting sugarcane is far from full-time equivalent (FTE), as seasonal work typically extends to 130-150 days per year, or as few as 90-100 days in a lean, drought-affected growing season (Patil, 2025). Assuming an average of 120 workdays, an FTE estimate for harvest work may be 124 300 jobs. Together with the sugar mill employment, an estimate for sugarcane-based ethanol production runs to 156 800 jobs. Maize harvesting is far less labour intensive than sugarcane, and could run as low as 8 300 jobs.[15] Overall ethanol-related employment may thus be on the order of about 165 000 jobs.

[15] *Maize harvesting and handling typically requires 15-25 person-days per hectare (120-200 person-hours) (De Lucia and Assennato, 1994). Sugarcane harvesting requires 375 person-days (or about 3 000 person-hours) per hectare (Singh and Singh, 2022). Mechanisation can dramatically reduce labour needs for both crops. Applying a labour needs ratio of 25/375 person-days per hectare, or 0.067, to estimate potential employment in the maize-based half of India's ethanol production yields a figure of about 8 300 jobs.*

2.4 United States

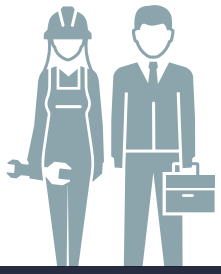
1.15
million jobs

The United States had an estimated 1.15 million renewable energy jobs in 2024, the largest shares being in solar PV industry and biofuels, followed by wind power.

The Inflation Reduction Act (IRA) of 2022, along with the Bipartisan Infrastructure Law of 2021, had led to ambitious investment announcements in solar and wind, as well as in battery storage. Tax credits and other incentives boosted both the deployment of renewable energy and the construction of factories producing needed equipment.

Since early 2025, the current US administration has rolled back certain provisions of the IRA. While its "One Big Beautiful Bill Act" leaves in place the IRA's "45X Advanced Manufacturing Credit", it reduces the rate to 75% in 2030 and 50% in 2031, and phases it out entirely in 2032 (Norman, 2025). Under the previous administration, companies building wind and solar farms could claim an IRA tax credit worth at least 30% of costs if they began construction before 2034. The new act requires construction to start by July 2026; later, the subsidy will be harder to secure. Projects that meet that deadline will also need to be fully operational by 31 December 2028 to retain the credit. As a result, the amount of wind and solar capacity expected to come online by 2035 could fall by half (Plumer, 2025a). A subsequent presidential executive order instructed the Treasury Department to further tighten eligibility for the tax breaks (Norman, 2025).

The present administration introduced an array of measures to delay or halt many renewable energy projects, even some close to completion, announcing that in place of routine approvals, it would require wind and solar projects to undergo several layers of political review by the office of the Secretary of the Interior. This policy affects dozens of projects and includes close to 70 types of actions, including federal permits, environmental and wildlife impact assessments, lease sales, site plans, and rights of way (Plumer, 2025b). In October 2025, the 6.2 GW Esmeralda 7 solar project (which would have been by far the largest in the country) was cancelled (Kennedy, 2025). Furthermore, the Department of Agriculture discontinued funding for solar projects, including support to farms and small businesses via the USD 4 billion "Rural Energy for America" grant programme. Some USD 7 billion in "Solar for All" grants for solar projects in low-income communities is being reclaimed by the Environmental Protection Agency (Kennedy, 2025).



US **wind** installations declined for the third year in a row, to 5.1 GW in 2024, down from more than 14 GW added in 2020 and again in 2021 (IRENA 2025b). Virtually all activity has been onshore. Offshore wind remains marginal and shackled by supply chain delays and rising project costs. This led to several project cancellations, as discussed in the 2024 edition of this report. There were an estimated 132 984 wind power jobs in 2024, up marginally from 2023. Onshore wind projects accounted for virtually all of these. Construction was the largest contributor to employment, with a bit more than 44 000 jobs. Professional services provided about 36 500 jobs, and manufacturing slightly more than 24 000 jobs (USDOE 2025).

The US offshore wind industry had already struggled with high interest rates and inflation. In January 2025, a presidential executive order paused all leasing of federal lands and waters for new wind farms and ordered reviews of approved projects (Chu, 2025). The Department of Transportation cancelled or withdrew USD 679 million in federal funding for a dozen marine facilities supporting offshore wind (USDOT, 2025). In August 2025, the Department of the Interior ordered that all construction work be stopped on the nearly completed revolution wind farm off the coast of Rhode Island, developed by Denmark's Ørsted, affecting some 1 000 construction workers (Friedman *et al.*, 2025).[16] Other moves were announced against offshore wind farms in Maryland, Massachusetts, New York and Virginia. *The New York Times* (Joselow *et al.*, 2025) reported that a half-dozen federal agencies have been tasked with investigating alleged impacts of the offshore wind industry, such as health effects of electromagnetic fields (Health and Human Services Department) and risks to national security (Department of Defense).

The current US administration has also taken action against onshore projects. In August 2025, it reversed the previous administration's approval of Lava Ridge, a 1 GW wind farm in Idaho. It will also review, and may rescind, permits for already-approved wind projects that are facing lawsuits by opponents. Limiting where new onshore wind farms can be built, the Transportation Department is now requiring that they be sited no closer than 1.2 miles (2 kilometres) to federal highways and railroads, and the Federal Aviation Administration has been instructed to re-evaluate whether wind farms pose a danger to aviation (Plumer and Friedman, 2025). In the wake of these measures, new wind installations may plummet from an expected more than 10 GW annually for a number of years to possibly zero in 2028–2030 (Dlouhy, 2025).

[16] *Subsequently, a federal judge granted a preliminary injunction in September 2025 that allowed work on the project to recommence.*

Targeted **tariffs** have been used for several years to protect fledgling US solar manufacturers. Tariffs were first imposed on imports from China but later extended to many Southeast Asian countries (where Chinese-owned factories predominate). The previous US administration further announced that tariffs on polysilicon and solar wafers made in China would increase from 25% to 50% in January 2025 (Jacobo, 2024). In April 2025, the US Department of Commerce announced final rates for anti-dumping and countervailing duties imposed on cells and modules from Southeast Asia (NREL, 2025a).

The current administration has not only maintained these tariff policies, while hiking rates substantially, but has taken them to a new level by imposing much more sweeping, sector and economy-wide levies. After 2018, the United States applied the so-called "Section 232" tariffs on imports of raw steel (25%) and aluminium (10%), materials used in solar tracker systems, racking and module frames, as well as in wind towers. Bilateral agreements had suspended these tariffs for many countries. But in March 2025, the United States imposed a 25% rate on all steel and aluminium imports with no exemptions (NREL, 2025a). The so-called "Liberation Day" tariffs announced on 2 April 2025[17] (and subsequent actions and revisions) are levied across a much broader range of products and industries, and even on all imports from certain countries (NREL, 2025a).

Tariffs render equipment more expensive and could make certain projects economically unviable, thus depressing the scale of overall renewable energy deployment. At the same time, the decline in PV costs has offset past tariff impacts. Together with uncertainty resulting from on-again, off-again tariff announcements, broadly applied tariffs (and counter-tariffs) dampen overall economic activity and energy demand. This may affect investments and the pace of new renewable energy installations and employment creation.

[17] *Polysilicon, wafers and solar manufacturing equipment were exempted from "Liberation Day" tariffs, but not solar cells and modules, which account for the bulk of US solar imports.*

Tariff policies have a particularly pronounced impact on the **solar PV** industry, and US module imports have plummeted. Accounting for various types of tariffs (including base rates imposed on countries' overall exports to the United States), the rates for solar imports in mid-2025 ranged from 80% for Malaysia to 425% for Thailand, 456% for Viet Nam and 696% for Cambodia – the main exporters to the United States. Indonesia (32%), India (40%) and Lao PDR (54%) faced much lower rates, while tariffs on China ran to 352% (Wood Mackenzie, 2025f).

Evolving US tariffs and Chinese manufacturers' investment strategies in response to the tariffs are reshaping solar PV supply chains in Southeast Asia, with implications for where jobs are being created. Increasingly, wafers from factories in China and Chinese-owned plants in Viet Nam and Thailand are sent to cell manufacturers in Indonesia and Lao PDR for cell production. Cells made there are then shipped to Cambodia, Thailand and Viet Nam to make modules (Wood Mackenzie, 2025f). And instead of direct exports to the United States, Southeast Asian manufacturers are also increasingly shipping PV cells to India, where modules are assembled for export to the United States (IEEFA, 2024).

In 2024, the United States imported 55.7 GW of PV modules, slightly less than in 2023 due to the availability of excess inventory. The bulk of imports – more than 80% – came from Viet Nam, Thailand, Malaysia and Cambodia, but in the course of 2024, shipments from these countries declined sharply, even as imports from Indonesia and Lao PDR began to rise (Wood Mackenzie, 2025d). From a high of more than 14 GW in the second quarter of 2024, imports from Southeast Asia plunged below 6 GW in the fourth quarter and just above 3 GW in the first quarter of 2025. The IRA led to a quintupling of module capacity, surpassing 50 GW by early 2025. But the country still has only very limited upstream capacities. For solar cells, the capacity is only 2 GW, and there is no operational capacity for solar ingot and wafer production (Jacobo, 2025). Cell imports rose strongly during 2024 (NREL, 2025a).

The United States installed an estimated 37.7 GW of new solar PV capacity in 2024, a new record, and far above the previous year's peak value of 27.1 GW (IRENA, 2025b). Three-quarters of cumulative deployments were in the less labour-intensive utility-scale segment, and this was reinforced by the distribution of new installations in 2024 (NREL, 2025b). Residential PV installations were down 37% year on year in Q2 2024, following policy changes in California (Willis, 2024).

The US National Solar Jobs Census reported that some 280 119 people held jobs during 2024 in which they spent most of their working hours on solar-related tasks. This represents a tripling of employment since 2010, but the rate of job growth has been weaker since 2016 (and even turned into job loss in 2016-2020, during the first Trump administration). Solar employment in 2024 was up only marginally from the 279 447 jobs in 2023. The

reason why surging new installations did not translate into greater employment is rising labour productivity, reinforced by a 32% full-year decline in 2024 in more labour-intensive residential installations while utility-scale installations grew. Some 64% of solar PV jobs were in installation and project development, 12% each in manufacturing and in wholesale trade and distribution, 8% in O&M and another 4% in other functions (IREC, 2025).

Including workers who spent much, but not a majority, of their time on solar-related tasks, the number rises to 370 556. The latter figure is also what the US government's Energy & Employment Report (USDOE, 2025) reports, and that number is also just slightly above the 364 544 reported in 2023.

The 2025 Big Beautiful Bill extended an existing tax credit for "clean fuels" like ethanol until the end of 2029 but eased emission rules for biofuels made from crops like corn (Plumer, 2025a). US **ethanol** output expanded in 2024 to reach a new record slightly above the 2018 peak (USEIA, 2025). Input-output modelling results show that the corn ethanol sector may have employed some 228 300 people in 2024, including 55 800 directly and 172 500 indirectly. Two-thirds of the jobs, some 147 400, were in agriculture (with corn being the feedstock). Another 43 600 jobs were in ethanol production and 4 000 in research and development; growing exports supported some 33 400 jobs (RFA, 2025).

Biodiesel output in 2024 remained roughly at the same level (USEIA, 2025). Based on employment factors, IRENA estimates about 65 200 biodiesel-related jobs, slightly below the 66 200 in 2023. Altogether, including various other forms of biofuels, total employment comes to 329 700 jobs.[18]

According to US Department of Energy data (USDOE, 2025), **hydropower** employs 70 200 people (up slightly from 2023);[19] **solar heating and cooling**, 31 499, **geothermal power**, 8 979; and **biomass power**, 13 294. Various other **renewable heating and cooling** technologies account for 80 005 jobs.[20] The department also offers estimates for other energy transition technologies not included in the 1.15 million total.[21]

Relatively few workers in the US energy industry are represented by a labour union, but the 12% recorded in 2024 was marginally higher than in the previous year, and it compared favourably with the 7% average across the US economy as a whole. Wind, solar and hydropower score in the range of 12-14%, better than oil power plants (11%) but lower than fossil gas plants (15%) and nuclear (19%) (USDOE, 2025). Women held only 26% of US energy sector jobs in 2024, far below their 47% share in the overall national workforce. It was 29% in the wind and solar power sectors, less than the 33-34% in nuclear, coal- or gas-fired power plants (USDOE, 2025). These percentages indicate a lack of meaningful progress over the years. People with a self-identified disability had a 2% share of US energy sector jobs, compared with the 5% national workforce average. Among renewables, it was also 2%, with the exception of the hydropower sector (3%) (USDOE, 2025).

[18] *Additional biofuels jobs from the Energy and Employment Report (USDOE, 2025)*

[19] *This figure includes 12 111 jobs in low-impact hydropower and 58 089 jobs in traditional hydropower. An estimated 9 799 jobs in pumped hydropower storage are not included here.*

[20] *This figure includes jobs in geothermal heat, biomass heat and other technologies.*

[21] *Including jobs in battery storage (78 809), smart grids (27 220), micro-grids (21 470) and other grid modernisation work (22 963), as well as electric vehicle charging (2 892).*

1.8
million jobs

2.5 European Union

Europe as a whole had 2.04 million renewable energy jobs in 2024, of which just under 1.8 million were in the 27 Member States of the European Union (EU 27).

The continent's wind power capacity reached 270 GW in 2024, but fresh installations of 12.9 GW were significantly lower than those achieved in each of the previous two years. Offshore, less than 2 GW was installed (IRENA, 2025b). IRENA estimates that the EU's **wind power** sector employed 279 100 people in 2024. Germany was the leading employer, with about 110 000 jobs, followed by Spain and Denmark.

Europe retains its position as the world's second-largest installer and second-largest manufacturer of wind equipment. Suppliers based in the region dominated in 2024 with a 92% market share, four percentage points higher than in 2023. But European firms also continue to have a strong presence in export markets worldwide. Vestas turbines, for example, were installed in 34 different countries in 2024, while equipment produced by Nordex Acciona, Enercon and Siemens Gamesa was deployed in more than 20 countries (GWEC, 2025).

In Europe, as elsewhere, the offshore wind industry confronts a range of pressures including rising costs, project cancellations, grid integration challenges and supply chain difficulties (shortages of construction and installation vessels, transmission cables and converter stations, and inputs like rare earth elements). In December 2024, Denmark's offshore wind farm auction did not attract any bids. Companies like Ørsted declined to bid, given supply chain bottlenecks, higher inflation and rising interest rates. In August 2024, Equinor cancelled projects in Spain and Portugal (Barlow, 2025).

European countries installed about 59 GW of new **solar PV** capacity in 2024, surpassing their record established in the previous year. The EU-27 accounted for 57.5 GW of this total (IRENA, 2025b). Utility-scale projects made up 42% of new PV additions in the European Union, ahead of commercial and industrial installations (39%). Both performed better than in 2023, whereas residential PV (20% of new additions) actually declined by 8% (NREL, 2025a).

According to SolarPower Europe (2025), solar jobs in the European Union rose to about 865 000 FTEs in 2024 (up 5% from 2023). Deployment accounted for 86% of jobs; 7.7% were in O&M, 4.7% in manufacturing, and 1.6% in decommissioning and recycling. Looking at individual countries, SolarPower Europe estimates that Germany (127 085) remained the largest employer, followed by Spain (122 793), Italy (100 928) and Poland (89 895). France (65 975), Romania (62 145) and Hungary (46 587) also ranked among the top markets. By contrast, APPA (2025) reports 48 843 solar PV jobs for Spain, reflecting different scope and employment estimation methods. IRENA estimates solar PV employment in the European Union at 764 400 based on a combination of national and regional reports and employment factor calculations.

(SolarPower Europe, 2025) shows that Spain, Italy and France added jobs, with Italy moving past 100 000 FTEs on steady growth and a strong project pipeline, and France benefiting from a supportive rooftop policy, including the S21 feed-in tariff. Some of the

largest employment declines in 2024 were in Germany, the Netherlands and Poland. The German reduction in employment can be attributed to manufacturing job losses and a higher share of utility-scale builds. In Poland, the rooftop share of solar jobs fell from 66% in 2023 to 58% in 2024, signalling a shift towards less-labour-intensive, utility-scale activity.

Rooftop-linked jobs fell to a record-low share of about 59% in 2024 as the utility-scale builds expanded. In fact, (SolarPower Europe, 2025) expects a temporary slowdown in 2025 as the market contracts by about 1.4% and rooftop activity eases with normalising power prices and pared-back incentives, while productivity gains reduce labour per megawatt and manufacturing remains under pressure; even so, SolarPower Europe projects around 825 000 FTEs in 2025, with employment growing thereafter towards roughly 916 000 by 2029.

The EU's solar PV manufacturing profile remains unbalanced. It has 92.9 GW worth of inverter capacity and 26.1 GW of polysilicon, but module capacity stands at 11.7 GW, cell capacity at just 2 GW and wafer capacity at 0.3 GW (NREL, 2025a). According to SolarPower Europe (2025), half of the top ten global market leaders in PV tracker systems are based in Europe – primarily in Spain and Germany, along with some companies in Italy and France. European firms provided a quarter of global tracker shipments in 2023, compared with a 19% share for Chinese companies. Employment in the tracker value chain is created in the steel and aluminium sectors, metal processing, system manufacturing, distribution and installation. But European module production has decreased following several bankruptcies, and capacity utilisation stood at 50%, down from 59% in 2023 (Wood Mackenzie, 2025d). The bulk of Europe's solar panels are imported, principally from China (Ember, 2025).

According to EurObserv'ER (2025), the EU **bioenergy** industry employed 459 100 people in 2023 (the most recent year for which estimates are available). **Solid biomass** (for heating and electricity) had a workforce of 280 340 (down from 331 700 in 2022). Another 135 780 people were employed in **biofuels** (down from 149 700) and 43 000 in **biogas** (down from 49 300). Most solid biomass supply in the EU 27 is sourced from within the region, and feedstock operations thus offer substantial local employment. The largest bioenergy employers in 2023 were Germany (65 300 jobs), Poland (63 000), France (47 200), Spain (31 800),[22] Sweden (28 000) and Italy (26 800 jobs) (EurObserv'ER, 2025). Romania (20 700 jobs), Poland (19 100 jobs), France (18 600) and Germany (13 900) had the largest number of biofuel-related jobs in the EU-27 in 2023.

[22] *Based on APPA (2025).*

In the region, **Germany** has the largest cumulative solar PV capacity (89.9 GW). Annual additions have grown steadily over the past several years, and the 15 GW added in 2024 improved on the previous record of 13.7 GW in 2023 (IRENA, 2025b). However, Germany's residential solar distribution and installation sector confronted a downturn in consumer demand in 2024, partly caused by higher interest rates. The drop in the residential segment was offset by growth in commercial rooftop and utility-scale deployments (Pitel, 2025).

Solar manufacturers in Germany are facing difficulties. To cut costs, Meyer Burger, one of Europe's largest solar manufacturers, announced layoffs of about 200 workers or close to a fifth of its global workforce (it has factories in Germany and the United States), by the end of 2025. In Germany, it closed a panel assembly site in April 2024 but is still operating a cell manufacturing facility (Millard, 2024). German inverter manufacturer SMA Solar announced cuts of 1100 jobs in the face of a sustained slowdown in residential and commercial and industrial installations (Norman, 2024).

A relatively slow pace of wind additions reflects challenges like slow permitting processes and restrictions on project siting in some states. The 3.3 GW built in 2024 was about the same amount as the previous year but only about half of the 6.1 GW peak reached in 2017 (IRENA, 2025b). German wind energy employment remained steady at 110 000 in 2024, which is significantly lower than the 167 600 jobs in 2016. A reduced volume of new installations makes it more difficult to sustain a sizable domestic manufacturing industry.

According to EurObserv'ER (2024), bioenergy employed 65 300 people in Germany in 2023, down significantly from 76 300 in 2022. Employment numbers are much smaller for solar thermal energy (2 800 jobs) and hydropower (5 800 jobs).

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Germany's

solar PV installations are at record levels, but new wind power deployment is at half its previous peak.

Employment trends in **Spain's** renewable energy sector between 2017 and 2024 show substantial growth overall, though with a slight decline in 2024 compared to 2023 (APPA, 2025). Solar technologies are the largest employer. Grid-connected solar PV stood at roughly 41 000 jobs in 2024. However, after peaking in 2022 with over 14 000 jobs, employment related to PV self-consumption (residential and commercial) fell drastically in 2024 (APPA, 2025). According to the Spanish Photovoltaic Union (UNEF), self-consumption installations dropped by 31% in 2023 compared to the previous year (when 2.65 GW were added), due to supply chain tensions, rising financing costs and a petering out of the extraordinary boom triggered by incentives in 2021-2022. The self-consumption solar PV market continued to slow in 2024, with new additions falling to just 1.4 GW in 2024 from 1.9 GW in 2023 (UNEF, 2025; Touriño Jacobo, 2025a).

Spain remains a global leader in solar thermal power, with multiple concentrated solar power plants operating and ongoing investments that sustain employment in engineering, research and maintenance (Callau, *et al.*, 2024) with over 4 700 jobs (APPA, 2025). In addition, the sector has diversified beyond electricity generation, with low- and medium-temperature solar thermal systems increasingly deployed in residential buildings, hospitals, hotels and industrial processes such as food, chemical and textile production. These applications not only expand the employment base into installation and maintenance services but also strengthen Spain's progress towards its updated National Energy and Climate Plans (PNIEC in Spanish) targets for renewable heat (Polo, 2025). Solar thermal, together with other renewable heating technologies such as geothermal, accounted for nearly 2 000 jobs in 2024 (APPA, 2025).

Wind energy stands out with a steady increase from around 23 700 jobs in 2017 to nearly 37 000 in 2024 (APPA, 2025). Once a global leader, Spain still hosts a robust industrial

Women currently represent 26% of employment in renewable energy and related green sectors in

Spain.

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base for turbine manufacturing and export, as well as major offshore projects through companies such as Navantia Seanergies (González, 2024; ICEX - Invest in Spain, n.d.). This expansion explains the sector's capacity to create and maintain employment despite legal and social resistance in some regions (Lombardi, 2025).

Biomass, biogas and renewable waste employment has remained broadly stable in recent years. However, a closer look shows that employment in traditional solid biomass is beginning to decline, while biogas is gaining relative weight (APPA 2025). Renewable gases in Spain are on the rise: Biomethane production, though still modest at around 0.5 terawatt hours (TWh)/year, is expected to expand rapidly as Spain targets up to 20 TWh/year of biogas and biomethane by 2030 under its updated national plans (McKinsey & Company, 2024; Nedgia, 2024). With an estimated technical potential of more than 160 TWh/year, biomethane is increasingly seen as a strategic pillar for energy security and rural employment. Green hydrogen is rising with over 750 jobs in 2024, but the sector remains at an early stage of development (APPA, 2025). Major energy players such as Cepsa forecast up to 100 000 jobs by 2027, with most of this employment yet to materialise (Velasco, 2024).

Finally, it is essential to highlight the gender dimension of Spain's ecological transition. According to the Ministry for the Ecological Transition, women currently represent only 26% of employment in renewable energy and related green sectors, far below parity. The government has identified this gender gap as a challenge for an inclusive transition, emphasising measures to improve women's participation in technical and decision-making positions (MITECO, 2025).

A combination of modelling appearing in various reports as well as IRENA's employment-factor-based estimates, yields an overall figure of 174 000 renewable energy jobs in **France** in 2023[23] (EurObserv'ER, 2025; SolarPower Europe, 2025). For solar PV, SolarPower Europe estimates 66 000 jobs in 2024, following 4.1 GW of new installations in 2024, compared to just 2.7 GW in 2023. According to EurObserv'ER (2025), France's 47 200 bioenergy jobs in 2023 were down from 53 000 in the previous year. Employment is more limited in hydropower (12 700), solar thermal (3 400) and geothermal (900).

The pace of annual wind farm installations keeps fluctuating. France added 1.46 GW in 2024, down from a record 2.3 GW in 2023 (IRENA, 2025b). But France also has a growing industrial and engineering base in support of the wind sector. Estimates for wind jobs vary, reflecting different methodologies. Based on an input-output study, EurObserv'ER (2025) increased its estimate from 36 500 in 2022 to 40 200 in 2023.

The latest edition of the France Wind Observatory study (FEE and Capgemini Invent, 2024) offers detailed, granular data, and estimates 31 477 direct and indirect wind power jobs in 2023, up from 28 266 in 2022 and 20 200 in 2019. Three-quarters were in onshore wind, but offshore jobs almost doubled in the last five years. By segment of the value chain, 35% of wind employment was in planning and development – and this segment had by far the strongest growth rate, 15%, in 2019-2023. Another 26% was in engineering and construction (growing by an average of 8%), 22% in component manufacturing (growth of 12%) and 17% in O&M (growth of 8%). Close to a third of all wind jobs, 32%, were held by women. The share in planning and development was more than 35%, whereas in manufacturing and construction it was less than a quarter. The Île-de-France capital region continues to account for a quarter of all French wind jobs, based on its commanding lead in project design and planning work, as well as in engineering. Normandy saw wind jobs expand by 45% in 2023 and accounts for 40% of the country's manufacturing employment, while Pays de la Loire leads in O&M jobs.

[23] *The most recent year available for all technologies, except for solar PV, wind and hydropower, for which 2024 data is available.*

CHAPTER 3

3 RENEWABLE ENERGY JOBS IN SELECTED OTHER COUNTRIES, BY REGION

This chapter offers short profiles of selected countries, presented by region and moving geographically from west to east. Unless indicated otherwise, all employment estimates in this chapter were received from IRENA members' designated national focal points (typically the ministry of energy, mining or similar portfolio).

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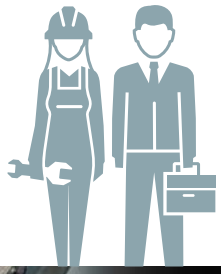
3.1 North America

Canada saw strong employment growth. Based on surveys, modelling, and employment factor analyses, Natural Resources Canada compiled an estimate of 113 610 direct and indirect jobs in renewable energy, up from the previous estimate of 86 430. The estimate was based on a mix of figures for 2024 and 2023. Hydropower is the largest employer among renewable energy industries, with 58 533 jobs (and close to 23 000 induced jobs, both figures are as of end 2023). IRENA estimates the direct hydropower workforce to have been 31 800 jobs in 2024. Canada's solar PV sector was estimated to have provided 27 868 jobs in 2023. Wind was next with close to 19 600 jobs. Other renewable energy technologies weigh in much less prominently, but there were some 4 420 bioenergy (heat and power) jobs in 2023.



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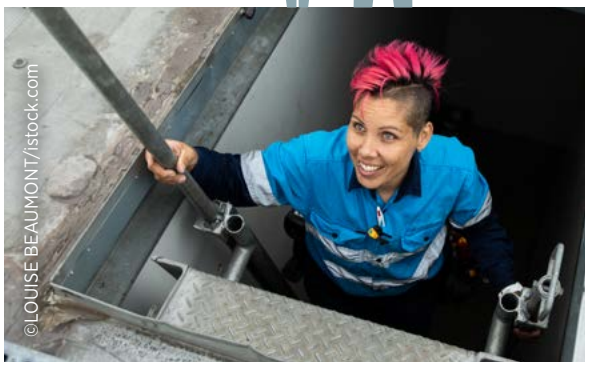

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3.2 Central America and the Caribbean

Costa Rica's share of electricity generation from renewables averaged 98% between 2015 and 2022. Hydropower remains the backbone of the grid, especially during the rainy months, but is complemented by geothermal and wind in the dry season, while solar still accounts for less than 1%. Seasonal balancing has allowed Costa Rica to operate on 100% renewable electricity for extended periods (Tico Times, 2024). However, climate variability, especially droughts linked to El Niño, has reduced hydropower output, lowering renewables' share. To address this, the country is investing in 166 MW of new solar and wind by 2026 (Renewables Now, 2024). This effort has yet to translate into new jobs, but the other technologies supplied an estimated 426 workers in 2024, of which 321 were in geothermal power. Employment is concentrated in operations and maintenance (O&M) and professional engineering roles, with most workers in permanent positions. However, the workforce remains overwhelmingly male (98–100% in most segments), with limited participation of women and only a handful of cases involving persons with disabilities.

Employment in the renewable energy sector of **El Salvador** reached an estimated 4 614 jobs in 2024. The main sources of employment are solid biomass with around 2 527 jobs, followed by biogas (549 jobs), geothermal power (377 jobs), solar PV (373 jobs) and, to a much lesser extent, wind energy (27 jobs). In terms of diversity, men made up the majority of workers in most technologies. However, there are exceptions such as biogas,

where women account for 65% of the workforce. People with disabilities are represented in a small proportion in biomass (1.4% of total jobs) and hydropower (1%). In terms of job security, 91% of geothermal power workers have permanent jobs, while in solar PV a significant share is temporary (47%) or subcontracted (25%).

Panama is ramping up renewables, with over 1 870 people working directly and indirectly in wind and solar PV in 2024. The country also has initiatives, including a 2023 strategy to become a Green Hydrogen Hub, targeting production of 500 000 tonnes of green hydrogen and derivatives by 2030 (Secretaría Nacional de Energía de Panamá, 2023). While no employment projections are available, the ambitious strategy portends growing demand for skilled labour in energy infrastructure, technology and related services.

While the **Dominican Republic's** energy mix remains heavily reliant on fossil fuels, renewable energy technologies (excluding hydropower) supported approximately 9 214 jobs in 2024. The vast majority of these positions were in solar PV construction (7 800 jobs), reflecting the country's strong investment in utility-scale solar deployment. An additional 696 jobs were in O&M for solar PV. Wind power had 400 construction jobs and 198 O&M jobs, while solid biomass fuels contributed 120 jobs. Gender inclusion remains a significant challenge, with men representing between 70% and 96% of the workforce, indicating limited access for women and marginalised groups.

The renewables workforce in
Central America and the Caribbean
is heavily male-centric.


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3.3 South America

Ethanol production in **Colombia** is rising again, following a multi-year decline after the 2018 peak. In 2024, output was estimated at 405 million litres. Biodiesel production fell slightly from the previous year's peak, reflecting lower palm oil yields, adverse climatic conditions and other issues. Sugarcane production and ethanol plants – and thus jobs – are located in the western Cauca River Valley, while palm oil plantations and biodiesel plants are mostly in the north and centre of the country (USDA-FAS, 2025b). Increasing mechanisation in sugarcane cutting and palm fruit collection is reducing the need for field labour. IRENA's employment factor calculation for this edition assumes a steady annual decrease in labour needs per volume of output. Accordingly, in 2024, there may have been some 70 200 jobs in bioethanol (up from about 58 611) and 88 950 jobs in biodiesel (down from 93 340 the previous year). Combined, this would mean 159 150 jobs, by far most of them in harvesting and transporting feedstock.[24] Harvest work is typically seasonal, but in Colombia sugarcane is harvested continuously through most of the year.

A government programme to support rooftop solar for

1.3 million

low-income households could create more than 25 000 direct and indirect jobs by 2030.

Colombia is also stepping up its solar PV deployment. Cumulative installations almost doubled in 2024, from 716 MW to 1.39 GW (IRENA, 2025b). The government has authorised COP 8.35 trillion (USD 2.25 billion[25]) in funding for 2026–2030 to support rooftop solar for 1.3 million low-income households, under the Colombia Solar programme. The plan could also create more than 25 000 direct and indirect jobs (though no details on the projection are available) and offers technical training in renewable energy across prioritised parts of the country (Ini, 2025).

Ecuador's renewable energy employment in 2024 is estimated at around 8 210 jobs, the majority linked to hydropower, which remains the backbone of its electricity mix. Large hydropower accounts for about 1 901 direct jobs, while small hydropower provides an additional 231. IRENA's employment-factor approach, however, estimates 8 019 hydropower jobs in 2024. Beyond hydropower, employment opportunities arise in solar PV (89 jobs, mainly in O&M), wind power (40 jobs, also in O&M), biogas (10 jobs), solar thermal (10 jobs), and municipal and industrial waste (20 jobs). Geothermal for electricity is still in its early stages, with marginal employment contributions. Overall, the renewables sector is still dependent on hydropower, with non-hydropower technologies representing less than 2% of jobs. Most reported employment is in direct O&M positions, reflecting Ecuador's mature hydropower fleet and the limited scale of new construction.

Uruguay's energy transformation has been impressive. By 2024, 98% of electricity came from renewables, predominantly hydropower, wind, solar and biomass. Employment, too, has increased, with over 10 630 people working. The highest share is in liquid biofuels (5 450), followed by biomass (2 550) and solar PV, which almost doubled from 770 people in 2023 to 1 400 in 2024.

[24] A different estimate was presented by Carolina Rojas Hayes, executive director of the Colombian Biofuels Federation. In an interview, she referenced estimates of the biofuels industry directly creating about 90 000 jobs and indirectly supporting 450 000 jobs in related agro-industries in the palm oil and sugarcane sectors (The Energy Year, 2025). But the methodology for this estimate was not specified.

[24] Exchange rate for Colombian Peso: COP 1 = USD 0.000269 as of 19 November 2025.

3.4 Non-EU Europe and Eurasia

Wind power capacity in the **United Kingdom** rose to 32 GW in 2024, following net additions of 812 MW onshore and 1.2 GW offshore (IRENA, 2025b). But difficulties remain in the offshore segment. In May 2025, Ørsted halted the 2.4 GW Hornsea 4 offshore wind project off the British coast. Factors including rising supply chain costs and higher interest rates were behind this decision (Barlow, 2025).

A joint report by RenewableUK and the Offshore Wind Industry Council estimates the UK's total wind industry workforce at 55 071 in 2025. Covering both the offshore and onshore segments, the report draws on jobs data collected from 20 companies and extrapolated to the industry at large. The offshore sector saw an increase of 24%, from 32 257 jobs in 2023 to an estimated 39 898 in 2025. Women held just 21.9% of all jobs, up slightly from 20.6% in 2023 (RenewableUK and OWIC, 2025).

The UK's wind industry also saw notable supply-chain progress. In late 2024, Siemens Gamesa's Hull plant produced its first 108-metre blades for the Sofia offshore wind farm (Offshorewind.biz, 2024). In early 2025, SeAH Wind's new monopile factory at Teesside began commercial production, supplying foundations for the Hornsea 3 offshore wind farm (Teesworks, 2025). Despite these advances, the United Kingdom still relies heavily on imports for key turbine components and captures only a modest share of value added beyond O&M and services.

Solar PV deployment in the UK accelerated in 2024, with 1.6 GW of new capacity added, up from 1.3 GW the year before (IRENA, 2025b). More than 40% of these additions came from small- and medium-sized systems below 5 MW, including both residential rooftops and commercial installations, which are typically more labour intensive (DESNZ, 2025). As a result, solar PV employment is estimated at 32 600 jobs in 2024, up from the previous year. Most of these jobs were concentrated in installation and operations, underscoring the strong role of distributed PV in driving both capacity growth and employment.

In Balkan states such as **Bosnia and Herzegovina** and **Serbia**, renewable energy jobs remain modest compared to coal-related employment. Recent studies underline the scale of this challenge: coal-dependent economies in the Western Balkans still employ tens of thousands of workers in mining and power generation, which will necessitate comprehensive strategies to bring about a just transition (GIZ, 2024). Multilateral initiatives are beginning to address the social dimension of this transition, such as the programme in **North Macedonia** supported by the European Bank for Reconstruction and Development. That programme aims to re-train over 4 000 workers from the coal value chain (Vanora Bennett, 2023). Taken together, these examples highlight the region's growing renewable energy footprint and its potential to transform the employment landscape, positioning renewable expansion not only as a shift in energy sources but as a broader vehicle for sustainable regional development.

The **Republic of Moldova** presents one of the more detailed labour market snapshots: in 2024, biomass supported about 290 jobs, solar PV around 1 203 direct jobs, wind power 376 jobs and small hydropower 26 jobs, according to industry and installer registry data.

Türkiye's installed solar PV capacity expanded from 11.3 GW to 19.9 GW in 2024, an impressive growth of 76% (IRENA, 2025b). Commercial and industrial projects account for most new installations. At the same time, the country is confronting grid connection bottlenecks (Çeliköz, 2025). Türkiye has used anti-dumping duties and local content requirements to build a domestic solar PV manufacturing industry. Its module production capacity has surged from 3.1 GW in 2020 to 17.1 GW in 2024, but cell production capacity has remained much more limited at 1.5 GW (Wood Mackenzie, 2025d). In 2023, direct employment was estimated at more than 40 000 jobs, including about 15 000 in module manufacturing, 8 000 in production of other panel components, 5 000 in the construction and aluminium sectors, and 15 000 in installations (SolarPower Europe, 2024). Given the rapid expansion, IRENA estimates some 122 000 jobs in 2024, including 28 600 in manufacturing, 71 900 in construction and installation, and 22 000 in O&M.

Türkiye's wind power capacity grew by 1 167 MW in 2024 to reach a total of 13 GW (IRENA, 2025b). Employment in the wind sector rose from 5 100 jobs in 2023 to 10 900 in 2024, according to IRENA's employment-factor-based estimate. This doubling reflects not only higher installations but also the maturing of the domestic value chain. The Nordex Group, for example, reported by late 2024 that it had exceeded 4 GW of installed capacity in Türkiye, supported by local sourcing of towers, blades and nacelles. Similarly, LM Wind Power's Bergama plant had produced over 1 100 blades by mid-2025 and employs more than 800 people, with women making up around one-quarter of its workforce (LM Windpower, 2025).

In the Caucasus, **Armenia's** 55 MW "Masrik-1" industrial solar plant employed 286 people in 2024. Large hydropower operations accounted for roughly 120 jobs. Studies are assessing Armenia's wind potential, with the aim of developing small projects that could diversify the country's energy supply and create additional employment opportunities. Based on a survey of enterprises, **Azerbaijan** reports a total of 1 547 people directly employed in renewable energy. The largest number is found in hydropower (617 jobs) and in municipal and industrial waste (615), followed by wind (267), solar PV (36) and biogas (12). **Georgia** reports interest in solar PV projects alongside long-standing employment in hydropower, the technology that anchors the country's renewable energy workforce with 3 170 people employed directly and indirectly.


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Türkiye's solar PV capacity expanded by

76%

in 2024 and industrial policy measures have created thousands of jobs in module manufacturing.

3.5 Africa

Nigeria aims to promote domestic production of solar panels. Two planned assembly plants are to support rural electrification programmes.

Nigeria's installed solar PV generating capacity stands at just 197 MW, with 124 MW of off-grid capacity (IRENA, 2025b). Yet imports of panels from China have soared from 861 MW in 2023 to 1.33 GW in 2024 (Ember, 2025). The 2024 imports alone are close to seven times the cumulative capacity installed according to official statistics, which appear not to capture some significant rooftop installations. The expansion is driven by frequent blackouts and the end of fuel subsidies (Jones *et al.*, 2025). The government has announced plans to ban solar panel imports amid efforts to promote domestic production. An agreement for a 1.2 GW solar assembly plant was signed in March 2025 by the Rural Electrification Agency (REA) with Lagos-based renewables developer Oando Clean Energy (Jowett, 2025a). REA has also partnered with the Infrastructure Corporation of Nigeria and Dutch solar manufacturer, Solarge BV, to establish and operate a 1 GW solar panel manufacturing facility, with a target of 50% local content within the first three years. The modules are to support public electrification programmes (Jowett, 2025b).

In **South Africa**, the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) has attracted investments of about ZAR 239 billion (USD 13.8 billion[26]), including all projects that have reached financial close. As of March 2025, a cumulative 7.8 GW had been procured from 104 independent power producers. This is up from 7.5 GW the previous year, but operational grid-connected capacity remains at 6.2 GW. To date, 86 531 job-years[27] in cumulative direct employment have been created, in construction and operations. This is up from 78 075 a year earlier. Of the current cumulative total, 57 952 job-years (two-thirds) relate to construction work and 28 579 to operations. Employment opportunities for women remain scarce, at 15 350, or 18% of the total (IPPPP, 2025).

Regional imbalances across the country remain, with the Northern Cape enjoying 3.9 GW of procured capacity distributed across 51 projects. The Western and Eastern Cape together had 2.8 GW in 35 projects. Free State and the North West together had 918 MW in 13 projects. In sharp contrast, the northeastern part of the country (Limpopo, KwaZulu-Natal, Mpumalanga and Gauteng, with 63% of the population) had only 156 MW in five projects. This imbalance is even more pronounced in employment terms, where 52 705 job-years, or 61%, are in the Northern Cape alone, compared with 3 458 in the northeastern provinces, including *zero* projects and jobs reported in KwaZulu-Natal (IPPPP, 2025).

While REIPPPP remains central for utility-scale projects, the country's recent solar PV deployment and employment gains reflect the rapid uptake of distributed and behind-the-meter systems, spurred by a lack of reliable power, rising electricity costs and declining solar PV prices. Despite a slight decline in new solar PV installations in 2024 compared to the previous year, IRENA estimates that South Africa still supported about 33 800 solar PV jobs, the vast majority of which were linked to rooftop and other private systems. Employment in wind remained limited at about 2 500 jobs in 2024. Activity in the sector was largely confined to O&M; however, that is likely to change as several wind projects (Enel's Impofu, Umsinde Emoyeni, Seriti Wind, *etc.*) entered the construction phase in 2024.

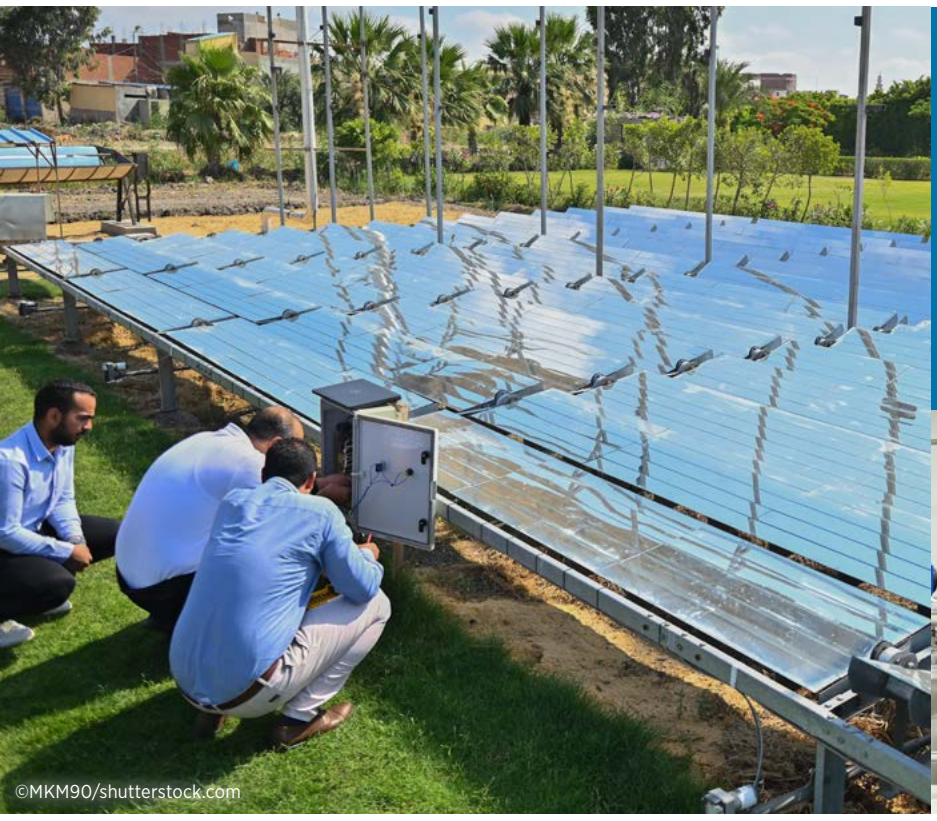
[26] *Exchange rate of South African rand: ZAR 1 = USD 0.06 as of 19 November 2025.*

[27] *A job-year is the equivalent of a full-time employment opportunity for one person for one year.*

3.6 Middle East and North Africa

Egypt added 734 MW of solar generating capacity and about 300 MW of wind power in 2024, a much faster pace than in recent years (IRENA, 2025b). IRENA's estimates show that solar PV employment more than doubled to reach 5 900 in 2024, reflecting the pickup in new installations and the country's growing role as a manufacturer. Jobs in wind energy also expanded, from 4 000 in 2023 to 5 200 in 2024, in line with capacity additions during the year and the steady build-up of O&M needs across Egypt's fleet.

Beyond project deployment, Egypt is also positioning itself as a manufacturing hub for solar technologies. The country has a 100 MW PV module assembly plant, but a number of manufacturing facilities are planned or under construction in the Suez Canal Economic Zone. Sunrev Solar, a Chinese company, is building factories with 2 GW of capacity each for cells and modules, with the intent to localise inputs of silicon ingots and wafers down the line. The project is expected to create more than 1 800 direct jobs, many presumably in construction (Jowett, 2025c). In August 2025, plans were announced for another manufacturing complex to produce 2 GW of solar cells, 2 GW of solar panels and 1 gigawatt hour of energy storage, with financing from companies in Egypt, China, Bahrain and the United Arab Emirates. The output is destined for both domestic and export markets. Over time, the project will increase the share of local components, such as aluminium and glass, and is expected to provide 841 direct jobs (Jowett, 2025d).



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Solar PV employment in

Egypt

more than doubled in 2024, reflecting growth in new installations and in manufacturing.

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3.7 South Asia

Solar PV and hydropower are driving most of the recent momentum in renewable employment in **Pakistan**. Solar PV has expanded faster than any other renewable technology, with distributed systems (rooftop, captive and off-grid) estimated by experts at around 15 GW by 2024, while utility-scale projects remained just above 1 GW (Isaad and Shah, 2025). IRENA estimates that this rapid growth, driven largely by net-metering as well as behind-the-meter installations, has created about 180 000 jobs, mostly in sales and distribution and installation of new projects. Recent policy shifts such as lower buyback rates for new net-metering users, as well as a sales tax on panel imports, may result in slower growth in the coming year.

Hydropower, at over 10 GW, remains the most significant source of renewable power, with major projects like Dasu (under construction) and Neelum-Jhelum. Hydropower supported around 111 400 jobs in 2024, spanning plant operations and large-scale civil works. Pakistan's biomass deployment is concentrated in sugar-mill bagasse co-generation, with about 278 MW connected to the grid and 830 MW used off-grid within sugar mills. No new plants were commissioned in 2024, so the overall scale remains small relative to the power mix (NEPRA, 2025). These facilities provide steady employment mainly in O&M and feedstock handling/logistics, together supporting an estimated 5 000 people nationwide in formal roles.[28] Pakistan's wind sector has stood at 1.8 GW since 2022. Employment, estimated at around 1 000 people, is concentrated in O&M and related service roles.

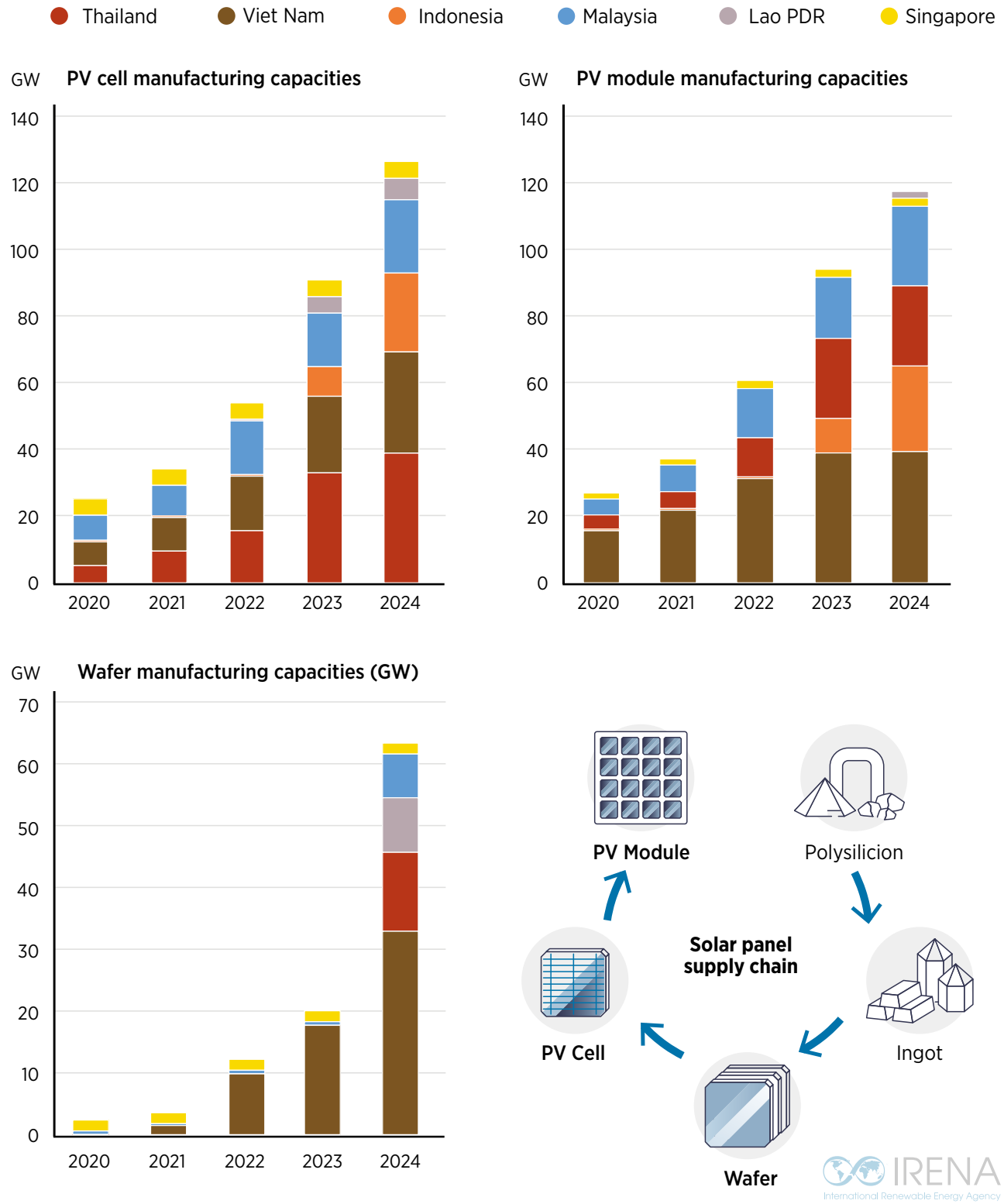
3.8 East Asia and Southeast Asia

Japan's solar PV capacity rose to around 89.6 GW in 2024, with new installations slowing to 2.5 GW, down from 4 GW in 2023 (IRENA, 2025b). Employment in the sector declined by 17% to settle at 95 000 jobs in 2024. Most jobs continue to be concentrated in installation and O&M, as domestic panel production remained limited, at less than 300 MW in 2024, compared with overseas production of nearly 1.6 GW by Japanese firms (JPEA, 2025). In wind power, cumulative capacity reached 6.1 GW, but, with no major acceleration in deployment, employment is estimated to have fallen to about 6 100 jobs in 2024.

Southeast Asia has substantial solar PV manufacturing capacity, and the region also has significant liquid biofuels production. In the **solar PV** industry, several countries in the region are important cell and module producers, with output principally destined for export. Since 2023, **Indonesia** and **Lao PDR** have joined this club (see Figure 10). The region's module manufacturing capacity expanded to 130 GW in 2024 from 38.7 GW in 2020, though only half or less of it is utilised; module production stood at 62 GW in 2024. Cell production capacity has grown fivefold to 135 GW since 2020 (Wood Mackenzie, 2025a).

[28] *Assuming 3-5 jobs per megawatt in feedstock handling and transport.*

Figure 10 Solar cell, module and wafer manufacturing capacities in Southeast Asia, 2020-2024

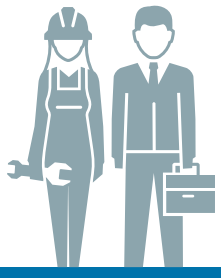


Source: (Wood Mackenzie, 2025a).

Notes: Countries are shown in order of the size of their capacities in 2024.
GW = gigawatt; PV = photovoltaic.

Viet Nam has the region's largest module and wafer capacities and the second-largest cell capacity (Wood Mackenzie, 2025a). However, domestic deployment of solar panels remains at a standstill, at around 18.7 GW, following the massive surge in 2019-2020 and unresolved grid bottlenecks (IRENA, 2025b). The solar PV industry remains dominated by manufacturing for export rather than the domestic market. In 2024, the country exported at least 19.3 GW of modules to the United States alone, with total exports likely exceeding 20 GW once other destinations are included (Thomas, 2025). By contrast, the domestic market has contracted sharply, with new installations falling to negligible levels after the post-2019 policy boom. According to IRENA estimates, the sector supported about 135 000 jobs in 2024, nearly four-fifths of which were in manufacturing, with the remainder concentrated in O&M. However, the industry's reliance on exports makes it vulnerable, and new trade duties in the United States – as well as production cutbacks announced by LONGi, Trina Solar and First Solar towards the end of 2024 – could weigh on manufacturing employment going forward (Jackson *et al.*, 2025; Howe, 2024; Touriño Jacobo, 2025b). In the wind sector, Viet Nam added only 297 MW in 2024, bringing the total capacity to 6.2 GW (IRENA, 2025b). This marks a continued slowdown in deployment after the high of 3.6 GW installed in 2021. IRENA estimates that Viet Nam may have 6 000 wind jobs.

In **Malaysia**, domestic solar PV installations have remained limited (a cumulative 2.3 GW in 2024), compared to the country's export-oriented PV manufacturing capacity (IRENA, 2025b). It hosts nearly 45 900 solar PV jobs, almost all of which are in manufacturing. Most of this module production is destined for the United States, where Malaysia was ranked as the third-largest supplier in 2024, with about 7.6 GW of modules shipped, just behind Viet Nam and Thailand.

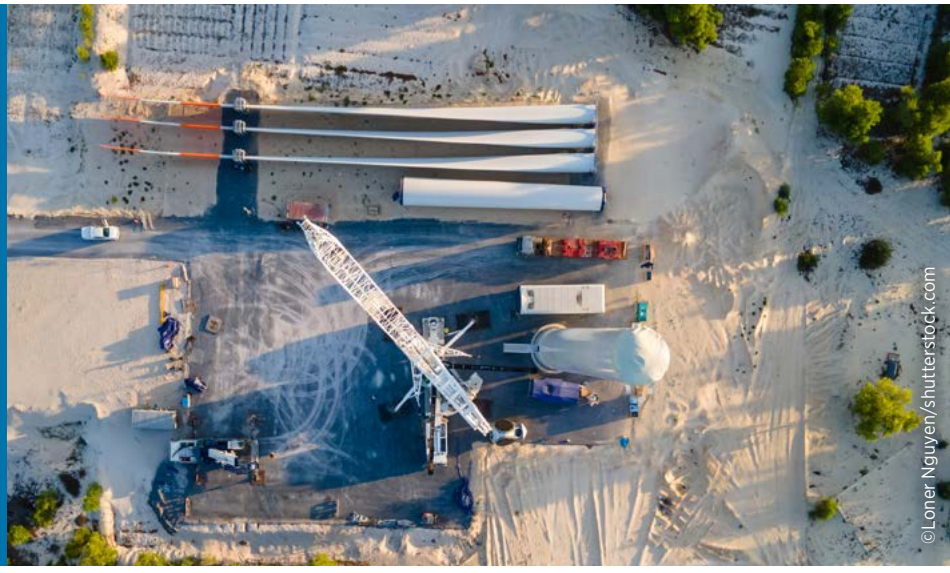


According to inputs from the national focal point designated by **Thailand**, the country's solar PV industry directly supports around 13 500 jobs, but IRENA's employment-factor-based estimates indicate that the country's export-oriented solar PV manufacturing sector could account for a far larger workforce, bringing total solar PV employment to an estimated 85 000 direct and indirect jobs.

Around 80% of

Viet Nam's

solar PV employment is in panel manufacturing, which is mostly focused on export markets.



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Even as the country is joining the club of PV manufacturers, **Indonesia's** domestic solar installations remain quite small for the time being, though they have tripled in the last two years to approach 1 GW (IRENA, 2025b). The government had established a minimum local content of 60% for solar power plants financed by foreign investors but relaxed the rules in 2024 in an effort to secure concessional loans for solar development from international development banks. The panels must still be sourced from companies that commit to establishing factories in Indonesia (Suleiman, 2024).

Employment in the region's agricultural supply chain for **biofuels** is labour intensive but often seasonal and possibly temporary. IRENA's employment-factor-based calculations provide rough estimates that are built on different assumptions for plantation- and small-scale feedstock operations. Indonesia is Southeast Asia's most prominent biofuels producer, with relatively smaller volumes in Malaysia, Thailand and the Philippines, among others.

Indonesia's production of biodiesel was estimated at a record 13 billion L in 2024, up from 12.6 billion L in 2023. The vast majority of output is consumed domestically, with exports playing a limited role (USDA-FAS, 2024b). IRENA estimates biodiesel employment at 750 600 jobs in 2024, up from 737 200 in 2023. **Malaysia's** biodiesel production in 2024 (1.58 billion L) was roughly at par with the previous year, but output remains below the 2019 peak value of 1.8 billion L (USDA-FAS, 2024c). IRENA estimates the biodiesel sector to have provided about 89 700 jobs in 2024, compared to the peak of 106 200 jobs in 2019. **Thailand's** biodiesel output is rising, but the volume of 1.77 billion L remains below the 2019 peak of 1.85 billion L. At 1.34 billion L, bioethanol output also lags behind the 2019 record (USDA-FAS, 2025c). IRENA estimates some 120 400 biofuel jobs in Thailand in 2024, up slightly from 114 500 in 2023.

In the Philippines, ethanol and biodiesel production is much smaller, with a combined 648 million L in 2024 – a new record after four years of continuous increases (USDA-FAS, 2024d). A rough estimate by IRENA suggests biofuels may employ 13 200 people.


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Rising biofuel

output in Southeast Asia is leading to growing employment in agricultural supply chains.

CHAPTER 4

4 TOWARDS AN INCLUSIVE RENEWABLE ENERGY WORKFORCE

The global transition to renewable energy is not only the key to reducing greenhouse gas emissions and mitigating climate change, but also can create millions of jobs and improve livelihoods while increasing energy security. Whether the Paris Agreement's 1.5°C climate target remains achievable is increasingly in question. But if the right policies are put in place with the utmost urgency, a pathway aligned with that goal could, according to IRENA modelling, expand the global renewable energy workforce from today's 16.6 million to 30 million jobs by 2030 and nearly 40 million by 2050 (IRENA *et al.*, 2025). This expansion would require concerted policies to step up education and skills training (including upskilling and reskilling), in conjunction with labour market measures, industrial policies, public investment strategies and other efforts.

Beyond the *number* of jobs, their quality and equitable access to opportunities matter. A just transition must have inclusion and equity at its core, ensuring that benefits extend to groups that have historically been excluded. Two such groups are the focus of this section: women and people with disabilities, the latter having so far received limited attention. The potential of both groups, which of course have some overlap, remains underutilised, highlighting the need for deliberate, systemic action. Section 4.1 considers how best to move from barriers women face to opportunities, discussing measures and good practices by governments, employers and society at large to ensure inclusion. Section 4.2 takes a similar approach to people with disabilities, examining the roles and perspectives of governments, employers and labour unions. Section 4.3 proposes priority actions to ensure an inclusive renewable energy workforce.

4.1 Women in the renewable energy workforce

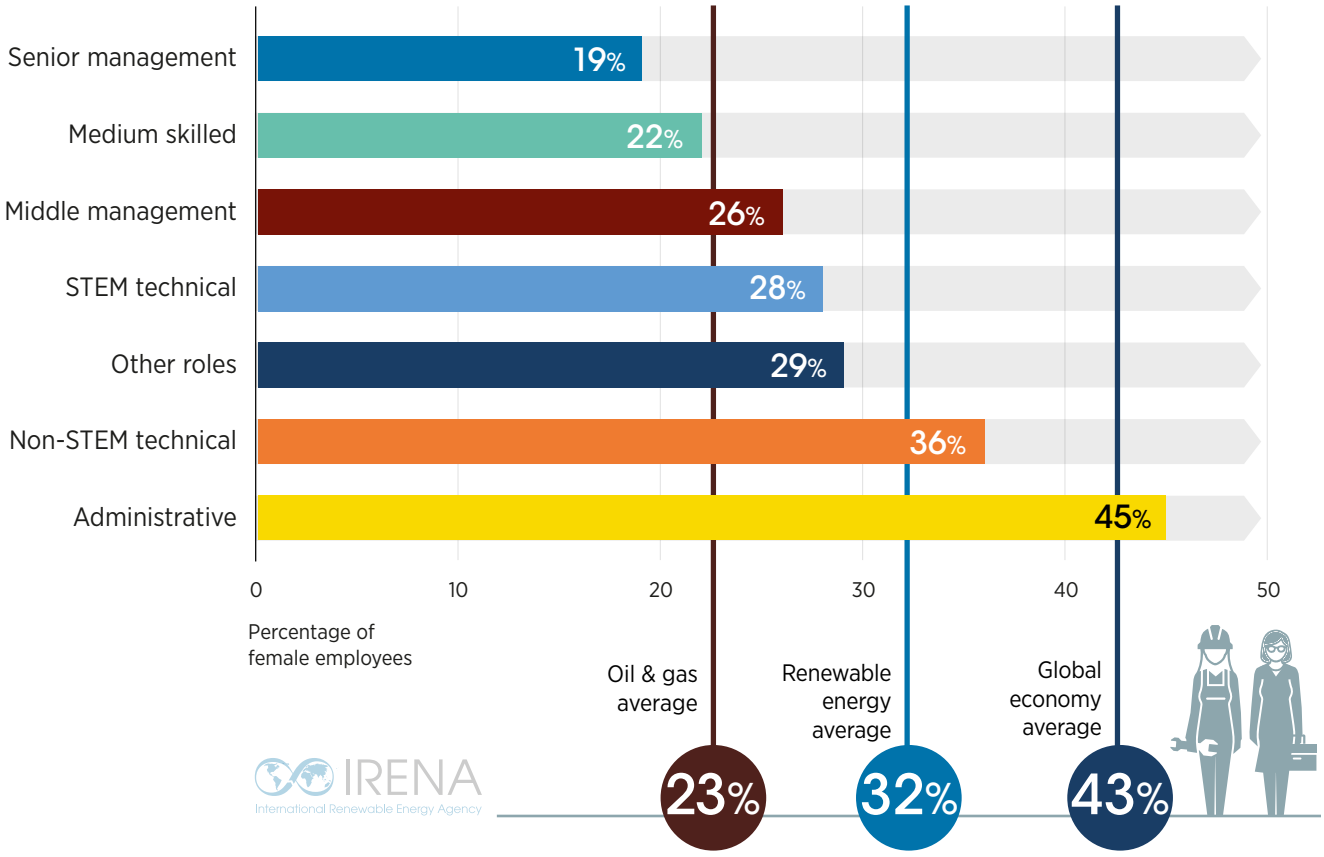
Despite some progress, women continue to be under-represented in the renewable energy industry. This situation still mirrors many of the inequalities that pervade the global economy. IRENA's new report, *Renewable energy: A gender perspective (Second edition)* (IRENA, 2025a), offers an updated picture of women's roles in renewable energy, the barriers they face and the measures needed to enable their full participation. The new analysis shows that women hold 32% of full-time jobs. This is higher than in oil and gas (23%) or nuclear energy (25%), showing that renewables are comparatively more inclusive. However, it is still far below the global workforce average of 43.4%.

Jobs held by women are significantly concentrated in administrative roles, which account for 45% of female employment in renewable energy, and in technical positions not related to science, technology, engineering and mathematics (STEM) – such as legal roles, where women make up 36% of the workforce. By contrast, women comprise only 28% of STEM-related roles (such as engineers, data scientists and technical specialists) and just 22% of medium-skilled jobs like solar installation or construction. At the highest levels of decision making, women are even scarcer: 26% of middle managers are female, but women make up only 19% of senior managers or board members. This imbalance illustrates the persistence of a glass ceiling[29] that limits women's influence on strategic and technical aspects of the energy transition (see Figure 11) (IRENA, 2025a).

Jobs held by women are concentrated in administrative roles, whereas few women are in high-level decision-making positions.

[29] *The term "glass ceiling" is a metaphor for an invisible barrier that prevents a given group of people from advancing professionally beyond a certain level in the hierarchy of a company or other organisation.*

Figure 11 Female share of employment in renewable energy, oil and gas, and economy



Source: (IRENA, 2025a).
Note: STEM = science, technology, engineering and mathematics.

From barriers to opportunities

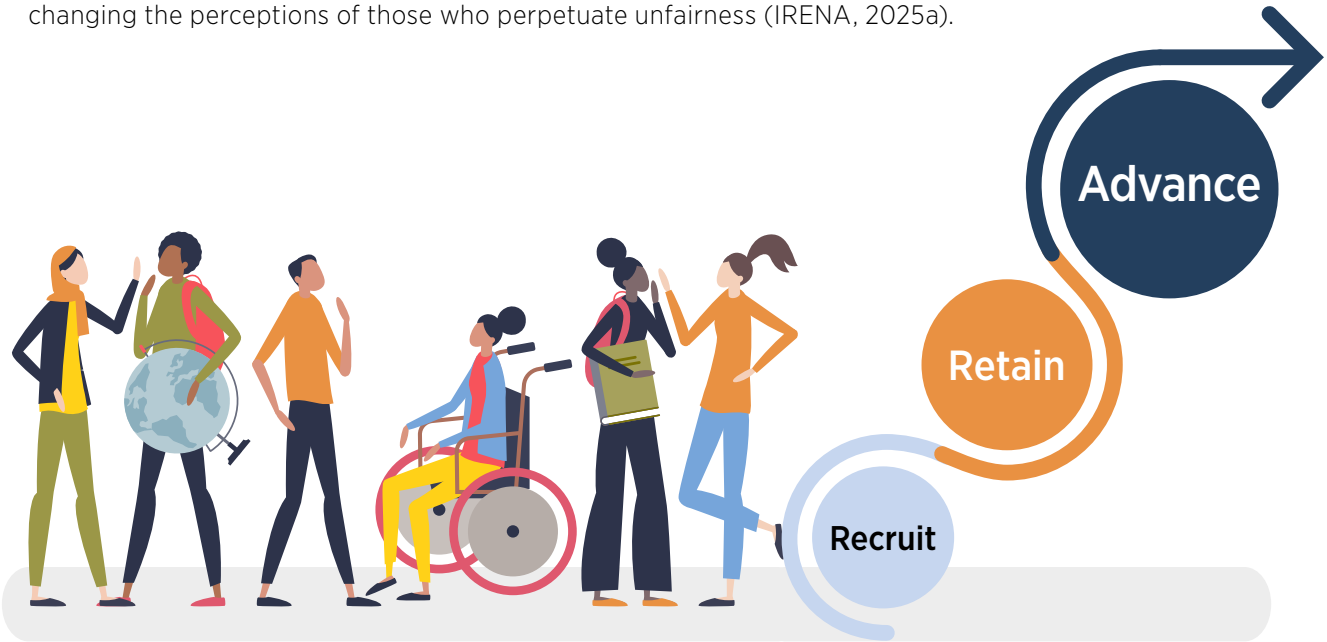
This under-representation does not reflect a lack of interest or ability, but rather the presence of systemic barriers at different stages of education and careers. Encouragingly, these challenges also highlight where the greatest opportunities for change exist. Respondents to IRENA's survey identified three main types of barriers: workplace, societal and academic (IRENA, 2025a).

Workplace dynamics are the most significant barrier, with many women citing the glass ceiling as the main obstacle to reaching leadership positions. Other issues include bias in recruitment, limited flexibility, mobility requirements and workplace policies that are insufficiently family friendly. Almost half of survey respondents reported experiencing discrimination, even though few cases were officially reported due to employees' low level of confidence in reporting systems. The survey also found that larger organisations, typically with stronger policies and more resources, tend to provide more inclusive environments. Expanding such practices across the sector, along with tailored career development programmes, can open pathways for women to thrive and support the expansion of renewable energy at all levels (IRENA, 2025a).

Societal expectations were flagged by survey respondents as the second-most prominent set of obstacles, with caregiving roles, stereotypes and legal restrictions in some regions limiting women's participation. Yet, the survey also highlighted how progress in cultural norms, legal frameworks and visible female role models can shift perceptions and inspire women to pursue technical and leadership roles (IRENA, 2025a).

Education and academic pathways shape opportunities early on. Gender gaps in STEM education, vocational training and limited access to leadership programmes contribute to a "leaky pipeline". However, respondents pointed out that access to mentorship and belonging to professional networks provide significant help in overcoming barriers. Strengthening girls' education, broadening STEM engagement and expanding mentorship and leadership programmes offer clear avenues to foster the next generation of women leaders in renewable energy (IRENA, 2025a).

The survey analysis also shows that barriers often intensify over time, as women progress in their careers. This makes retention and advancement policies especially powerful tools for change. By investing in inclusive workplaces, reforming societal norms and expanding academic opportunities, the renewable energy sector can turn today's challenges into tomorrow's solutions, unlocking women's full potential while changing the perceptions of those who perpetuate unfairness (IRENA, 2025a).



While public and private sector

decision makers

are key to promoting inclusion, society at large also plays an important role.

Measures and good practices to ensure inclusion

Public and private sector decision makers have a unique opportunity – and responsibility – to accelerate this transformation by promoting inclusive policies, education and visibility for women in the sector. Society at large also plays a role.

Governments have the responsibility to enact and enforce laws on non-discrimination, equal pay for work of equal value, and equitable access to land, finance and education. Such measures can facilitate and enable women's access to the renewable energy sector, adding to the talent pool and advancing progress. Key practices include institutionalising sex-disaggregated data collection, adopting gender audits, and instituting gender-responsive budgeting to align financial decision making with equality objectives. Nationally Determined Contributions under the 2015 Paris Agreement on Climate Change and related climate policies need to go beyond symbolic mentions of gender and instead embrace concrete, measurable actions. At the same time, governments can raise awareness, support advocacy and safeguard against violence perpetrated on marginalised groups, including women, indigenous peoples, ethnic minorities, LGBTIQ[30] individuals and people with disabilities (IRENA, 2025a).

Employers are central to advancing equity in the workplace, though this will likely be harder to achieve under conditions of informal employment. Advancing equity begins with practices that enable an effective work-life balance, such as flexible hours, remote work options, parental leave and childcare support, ideally even where national laws do not require such measures. It is equally important to create safe and respectful environments, built through zero-tolerance harassment policies, gender sensitivity training and accessible and reliable reporting mechanisms. Fairness and inclusion need to be embedded across all employment processes and stages, from recruitment and pay structures to pathways to promotion. Employers also play a vital role in women's career advancement by ensuring access to mentorship, sponsorship, leadership development and targeted resources to strengthen participation in technical and leadership roles. These measures should apply equally across full- and part-time positions to ensure that flexible work does not become a source of disadvantage (IRENA, 2025a).

Society at large also plays a decisive role in breaking down systemic barriers and cultural norms that restrict women's participation in energy. Civil society organisations, women's networks and grassroots movements are essential in amplifying voices, fostering solidarity and holding institutions accountable. International organisations can contribute by setting standards, funding initiatives and promoting gender-responsive approaches globally, while trade unions can strengthen women's representation and advocate for inclusive workplace policies. Education systems should try to dismantle stereotypes early, encourage girls and women to enter STEM fields, and provide scholarships, mentorship and training opportunities. Beyond institutions, cultural transformation is indispensable: campaigns that promote shared domestic responsibilities, celebrate women leaders and challenge stereotypes can shift social expectations. True progress relies on collective responsibility, with men acting as allies, women supporting one another and individuals across society questioning biases and championing equality in everyday life (IRENA, 2025a).

[30] *Lesbian, gay, bisexual, transgender, intersex and queer/questioning.*

Gender mainstreaming needs to be much more than a checkbox exercise. It requires a fundamentally transformative agenda – one that is top-down, through political leadership and regulatory reform; bottom-up, through community empowerment and inclusive programming; and cross-cutting, embedded across all stages of energy policy, planning, finance and implementation. Likewise, other marginalised groups, such as people with disabilities (visible or not),[31] must also be covered by this approach (IRENA, 2025a).

4.2 People with disabilities in the renewable energy workforce

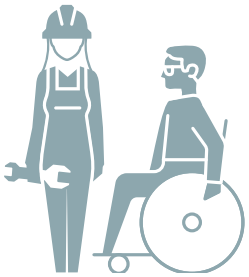
People with **disabilities** have a low workforce participation rate, but those who are employed often face a significant wage gap.

According to World Health Organization estimates, 1.3 billion people – roughly one in six of the global population – experience significant disability. However, only three in ten people with disabilities are active in the labour market, reflecting both a low participation rate and slow progress towards greater inclusion (WHO, 2022).

Beyond low employment rates, employed people with disabilities often earn significantly less. On average, they receive 12% lower hourly wages than other employees, with three-quarters of the gap unexplained by differences in education, age or type of work. In low- and lower-middle-income countries, the disability wage gap is even more pronounced at 26%, with nearly half of the disparity remaining unexplained by socio-demographic factors (ILO, 2024).

From barriers to opportunities: A framework for action

Barriers to inclusion begin with education and training. Many persons with disabilities face challenges in accessing vocational programmes due to physical inaccessibility, limited availability of assistive technologies or teaching methods that fail to accommodate diverse needs. Discrimination, both overt and structural, continues to affect hiring and promotion in energy-related industries.



The energy transition presents a unique opportunity to proactively create jobs in the renewable energy sector (and green jobs generally) for persons with disabilities, rather than adapting roles as an afterthought. According to the International Labour Organization (ILO), green jobs can be designed from the outset to be inclusive, especially in emerging areas such as solar panel assembly, environmental monitoring, waste management and e-waste recycling. Many of these roles can be adapted to a wide range of abilities with a modest amount of support.

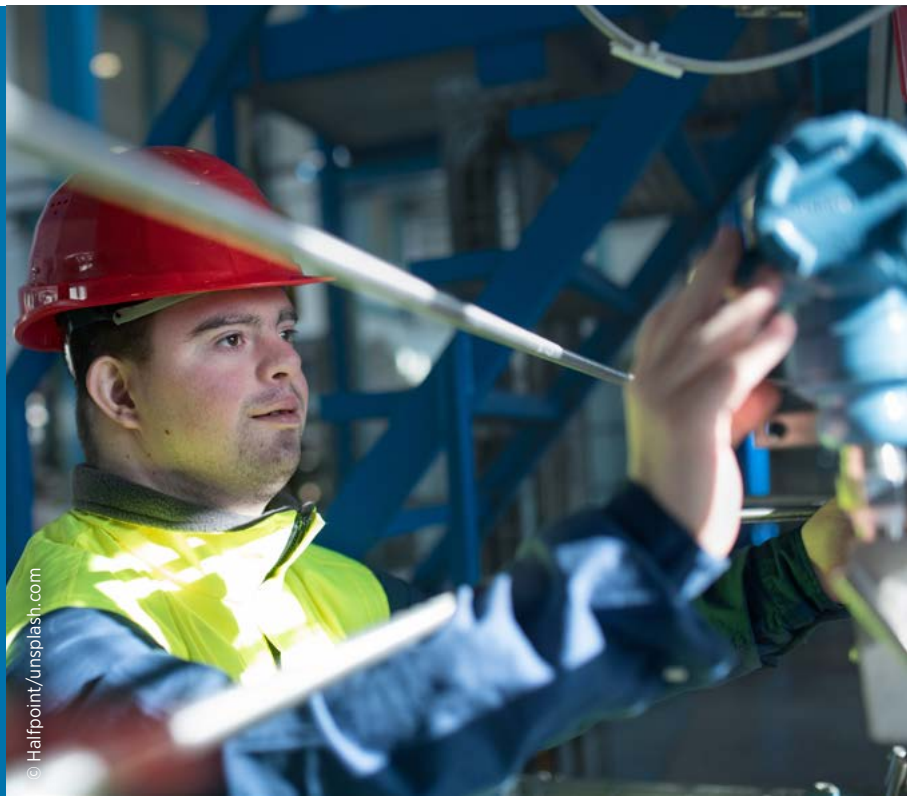
[31] *Disabilities may be visible, like an amputation or a wheelchair, or invisible/non-visible, such as mental health conditions, chronic pain or neurodevelopmental conditions. While visible disabilities are apparent to others, invisible disabilities are not immediately apparent but can significantly affect a person's daily life.*

Investing in accessible skilling, reskilling and upskilling programmes is central to this transformation. The ILO emphasises the need for curricula that integrate universal design, training environments that are physically and digitally accessible, and partnerships with organisations of persons with disabilities to ensure outreach and relevance. New digital platforms – if inclusively designed – can allow persons with disabilities to train for technical and knowledge-based green jobs, such as energy auditing, geographic information system (GIS) mapping, and data analysis (ILO, 2023).

National energy and employment policies should embed disability inclusion across green job strategies. Public procurement and investment incentives can drive inclusive hiring and accessible infrastructure (ILO, 2015). A critical pillar of this work is tripartite social dialogue. The dialogue should include organisations of persons with disabilities alongside trade unions and employers, ensuring that sectoral training strategies and employment standards reflect the needs and contributions of disabled workers. Workers with disabilities and their representative organisations must be involved in shaping the policies and practices of the transition to sustainable economies and societies.

The text that follows is structured to discuss the activities and perspectives of the tripartite partners – *i.e.* governments, employers and trade unions. In addition, it should be remembered that a number of international labour conventions and other legal instruments exist to protect the rights of women and persons with disabilities (see Box 2). All countries have an obligation to implement these in law and practice.

Energy and employment policies, public procurement and investment incentives, and social dialogue are essential to driving **inclusive hiring processes.**



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Box 2
International labour standards to protect the rights of women and persons with disabilities

International labour standards[32] offer a common framework that helps governments, employers and workers' organisations strengthen labour governance and promote decent work. By defining clear rights and responsibilities, they support governments, employers and trade unions in creating fair, safe and inclusive workplaces, particularly in sectors undergoing rapid transformation.

Key standards advancing gender equality include the Violence and Harassment Convention, 2019 (No. 190); the Maternity Protection Convention, 2000 (No. 183); the Workers with Family Responsibilities Convention, 1981 (No. 156); the Discrimination (Employment and Occupation) Convention, 1958 (No. 111); and the Equal Remuneration Convention, 1951 (No. 100). These instruments guide constituents in preventing discrimination, ensuring maternity protection, addressing unequal care responsibilities and securing equal pay, thereby supporting more equitable and respectful work environments.

International instruments also strengthen inclusion for persons with disabilities. The ILO code of practice includes: Managing Disability in the Workplace; the Vocational Rehabilitation and Employment (Disabled Persons) Convention, 1983 (No. 159); the Vocational Rehabilitation and Employment (Disabled Persons) Recommendation, 1983 (No. 168); the Discrimination (Employment and Occupation) Convention, 1958; and the United Nations Convention on the Rights of Persons with Disabilities. All guide constituents in removing barriers, ensuring non-discrimination and promoting equal participation. Together, these standards help build workplaces where all workers can contribute, develop and thrive.

[32] *A list of all international labour standards can be found at https://normlex.ilo.org/dyn/nrmlx_en/f?p=NORMLEXPUB:1:0::NO:::*

Measures and good practices to ensure inclusion

Several promising examples are beginning to emerge in diverse contexts. In **Brazil**, national legislation requires companies with more than 100 employees to reserve 2-5% of jobs for persons with disabilities, including those in renewable energy.[33]

In **Germany**, the dual vocational training system includes support services for trainees with disabilities, enabling more equitable access to green sector jobs (Federal Institute for Vocational Education and Training [BIBB], 2022).

In **Spain**, a public-private initiative between the utility company Endesa and local municipalities created a programme that trained over 300 persons with intellectual and psychosocial disabilities in tasks such as vegetation management and composting at solar energy sites. Almost 40% of trainees managed to secure jobs after six months, illustrating the power of targeted partnerships in their ability to create inclusive green jobs (Endesa, 2024).

South Africa's skills development legislation requires inclusive training opportunities, including in the green economy. This is operationalised through initiatives like the learnership programme led by the Energy and Water Sector Education and Training Authority, in partnership with renewable energy providers, which trains youth with disabilities in technical skills such as electrical network control (EWSETA, 2023).

In the **Philippines**, waste-to-energy programmes have included persons with intellectual and psychosocial disabilities (UNDP, 2024).

In **Yemen**, an initiative supported by the UN Development Programme (UNDP) provides hands-on training in solar panel maintenance to young people with disabilities. With assistive tools and peer learning support, graduates have begun launching small-scale solar repair services. This shows that inclusion is feasible even in fragile contexts (UNDP, 2023).

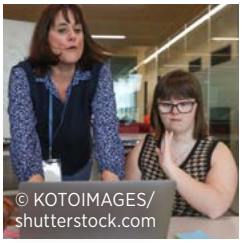
[33] *In the past, quotas have been the subject of controversy about whether they represent a valid policy option, or whether they reinforce negative stereotypes about the working capacity of persons with disabilities. The ILO publication Promoting Employment Opportunities for People with Disabilities: Quota Schemes (Vol. 1) (ILO, 2019) points to an emerging trend, with quotas being seen as a form of affirmative action in the framework of anti-discrimination legislation, and therefore being compatible with the UN Convention on the Rights of Persons with Disabilities and with the earlier ILO Convention on Vocational Rehabilitation and Employment of Disabled Persons (C. No. 159). Quota systems are not one-size-fits-all; their design and implementation should consider multiple factors.*

As part of a joint initiative with the UNDP and the Office of the United Nations High Commissioner for Human Rights under the UN Partnership on the Rights of Persons with Disabilities, the ILO is contributing its expertise to ensure that climate action is inclusive of persons with disabilities, particularly in the world of work. The ILO's contributions focus on mainstreaming disability inclusion into just transition frameworks, national climate strategies and green jobs policies. The effort includes developing guidance on integrating the rights and needs of persons with disabilities into Nationally Determined Contributions and National Adaptation Plans, as well as capacity building for policy makers, workers' and employers' organisations and organisations of persons with disabilities. Through this initiative, the ILO is advancing a rights-based and inter-sectional approach to climate action that promotes equal access to emerging employment opportunities in the green economy for persons with disabilities (ILO, 2022).

Inclusive employment is emerging as a cornerstone of both economic sustainability and the transition to renewable energy. As enterprises across sectors, including renewables, strive to develop resilient and innovative workforces, many employer and business membership organisations are promoting disability inclusion. These organisations are helping their members adopt practical inclusion strategies through initiatives such as national business and disability networks, recruitment toolkits, training programmes and policy engagement. These efforts support enterprises in creating inclusive workplaces, expanding their talent pool and strengthening long-term competitiveness.

For example, in **Mexico**, the National Business Council launched the Éntrale alliance to promote inclusive recruitment practices. This employer-led network has grown to comprise over 700 member companies, facilitating employment for more than 50 000 people with disabilities by 2022. Éntrale provides tools such as annual inclusion indices, training workshops and peer learning forums to help companies improve accessibility and recruitment practices (Éntrale, n.d.). The initiative emphasises that hiring people with disabilities is a business strategy. Member enterprises report that greater workforce diversity enhances innovation and productivity, thereby strengthening the economic sustainability of inclusion efforts. The success of Éntrale has earned it international recognition, including a Zero Project award in 2019, and highlights how a company's commitment to disability inclusion can have a positive social impact and provide a competitive advantage.

In **Chile**, Red de Empresas Inclusivas (ReIN), an initiative of the Sociedad de Fomento Fabril (SOFOFA), brings together companies committed to promoting the social and labour inclusion of people with disabilities. Established in 2015 with the support of the ILO and having become a member of the ILO Global Business and Disability Network, ReIN fosters collaboration between the public and private sectors to strengthen inclusive employment practices nationwide. The network provides more than 110 member companies with technical guidance, self-assessment tools and training programmes on inclusive recruitment, accessibility and workplace culture. Through peer learning and shared experience, ReIN has become a key national platform for advancing disability inclusion within corporate strategies. Its members, which span diverse industries, exchange good practices and measure progress, demonstrating that inclusive employment not only fulfils a social responsibility but also enhances innovation, engagement and organisational resilience.



Inclusive

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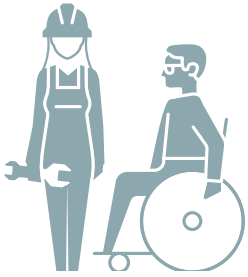


In Africa, the **Nigeria** Business Disability Network (NBDN), an offshoot of the ILO's Global Business and Disability Network launched by Sightsavers and the Chartered Institute of Personnel Management in 2020, is transforming hiring practices in Nigeria by working with civil society organisations to revise recruitment policies – shifting the focus from traditional formal qualifications to a candidate's unique strengths and problem-solving skills. This strategic shift not only broadens the talent pool by tapping into the potential of more than 30 million Nigerians with disabilities, but also builds confidence among employers, enabling them to invest in tailored training and reasonable accommodations that enhance job readiness. Recognising that disability inclusion makes good business sense by increasing revenue, driving growth and enhancing brand reputation, NBDN organised the 2024 Nigeria Diversity and Inclusion Conference on Disability Inclusion in Corporate Sustainability. The conference brought together private companies, civil society, public sector organisations and the community of persons with disabilities to reposition the private sector as an active driver of inclusive economic growth by harnessing the opportunities offered by the disability community as customers, employees and business leaders.

The Federation of **Kenya** Employers (FKE) has spearheaded initiatives to promote disability inclusion among its member companies by partnering with the Innovation to Inclusion (i2i) programme to increase the number of employees, interns and trainees with disabilities in the private sector – including renewable energy enterprises – thereby fostering more diverse and innovative workplaces. As part of this effort, FKE launched the Kenya Business and Disability Network, an employer-led initiative that not only demonstrates the tangible business benefits of employing people with disabilities, but also creates an ecosystem where private sector employers share best practices and support each other in their inclusion journeys through targeted training, policy reform and accessibility improvements.

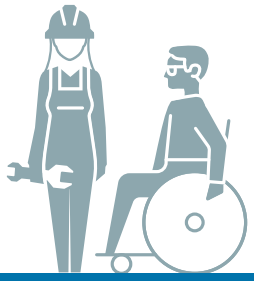
In **Bangladesh**, the Bangladesh Business and Disability Network, a member of ILO's Global Business and Disability Network, has become a leading force in advancing disability inclusion in the private sector. Established in 2016 as a voluntary platform of employers under the Bangladesh Employers' Federation, with support from the ILO, the network promotes equal employment opportunities for persons with disabilities through awareness raising, capacity building and strategic partnerships. The network brings together businesses, government agencies, and organisations of persons with disabilities to identify barriers, share good practices, and develop inclusive recruitment and retention strategies. Through awareness-raising workshops for employers, workplace accessibility audits and targeted skills development programmes, the Bangladesh Business and Disability Network has enabled hundreds of job seekers with disabilities to access training and employment across diverse sectors. Projects in which it is involved, such as ProGRESS and Social Protection for Workers in the Textile and Leather Sector, are helping member companies assess their readiness for disability inclusion, adopt practical measures for inclusive hiring, build employers' capacity in return-to-work strategies and create awareness about occupational diseases and medicine. The network also organises annual job fairs and business dialogues to connect talent with employers and foster a culture of openness and respect. By integrating advocacy, technical assistance and business leadership, it is demonstrating that inclusion strengthens productivity, innovation and organisational reputation, positioning Bangladesh's private sector as a regional example of inclusive growth.

Finally, an example of a policy-level partnership in **India** is the establishment of the Skills Council for Persons with Disabilities, a collaboration among the National Skill Development Corporation, the Ministry of Social Justice and Empowerment, and the Confederation of Indian Industry. This employer-backed council develops training standards and certifications relevant to specific industries for workers with disabilities. By giving employers a direct voice in shaping training curricula, the council ensures that skill development programmes align with actual business needs, thereby improving the employability of graduates with disabilities.

Such initiatives demonstrate how employer and business membership organisations in Asia are encouraging companies to make their hiring practices more inclusive, thus influencing the broader ecosystem (education, skills and policy frameworks) to support disability inclusion in an economically viable way. These examples, ranging from job fairs and toolkits to policy advocacy, demonstrate the practical steps that employer organisations in emerging economies are taking to make workplaces more inclusive. Moreover, they all highlight that disability inclusion can go hand in hand with business development and sustainability, creating a win-win situation for enterprises and communities alike.

The examples discussed above are at the level of industry associations and networks. However, individual companies are also taking action, as Box 3 indicates.

Trade unions may have varying perspectives on the energy transition, but most emphasise that the transition should be inclusive of all workers, including those with disabilities. While data and good practices in the renewable energy sector are still limited in this area, the principles of equity and non-discrimination are fundamental. The growth of the green economy should avoid replicating existing patterns of exclusion and instead serve as a lever to transform labour markets and workplaces into spaces that are accessible, fair and inclusive for all. As such, trade unions put forward the following priorities to ensure that people with disabilities are not left behind in the energy transition (IndustriALL-union, n.d.).



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Disability inclusion

can go hand in hand with sustainable business development.

Box 3
Corporate initiatives in support of disability inclusion

ENGIE and Siemens Energy, two of the more than 40 company members in the ILO Global Business and Disability Network (GBDN), have been proactive in promoting the inclusion of persons with disabilities.

ENGIE's commitment to diversity and inclusion

In 2024, ENGIE Renewables marked a major milestone by signing its first agreement in support of individuals with disabilities within the organisation, thereby underscoring the company's commitment to fostering a more inclusive and diverse work environment. The agreement introduced several key initiatives, with a strong emphasis on awareness raising and capacity building. "Sensi'play" workshops were designed to increase understanding of both visible and invisible disabilities and to challenge persistent stereotypes. Diversity "fresco workshops" enabled participants to explore and reflect on the conscious and unconscious biases that contribute to exclusion and discrimination.

These workshops were implemented for all interns and apprentices in 2024 and are set to be scaled up in 2025 to include all employees at the headquarters in Paris. As part of European Disability Employment Week, ENGIE Green also participated in DuoDay on 21 November 2024, the seventh edition of the event in France, which aims to promote the inclusion of persons with disabilities in the labour market. Further, ENGIE engaged in a solidarity hackathon benefiting APF France Handicap. Twenty employees contributed to a skills-based volunteering initiative that involved a full innovation cycle – needs analysis, beneficiary interviews, ideation, prototyping and final presentations – carried out in partnership with other companies and co-financiers.

Driving disability inclusion through data and action: Siemens Energy's holistic approach

Data are critical for fostering inclusion in the workplace. They provide critical insights needed to identify gaps, measure progress and drive meaningful change. Recognising this, in 2024, Siemens Energy undertook a voluntary and anonymous self-identification survey.

The survey revealed that 51% of respondents who self-identified as having a disability reported a physical disability, while 11% disclosed sensory disabilities. Importantly, 25% of respondents with disabilities indicated that their access to the resources they needed for success could be improved. These findings became a catalyst for action.

In line with its broader commitment to evidence-based inclusion, Siemens Energy is also a strong endorser of the ILO GBDN Self-Assessment Tool, which helps organisations evaluate and strengthen their disability inclusion strategies. Insights from both the self-ID survey and the ILO GBDN framework have guided Siemens Energy in identifying concrete areas for improvement and advancing global alignment on accessibility and inclusion standards.

In response to these findings, Siemens Energy prioritised upgrades to office locations where employees reported physical impairments. Beyond physical spaces, Siemens Energy has expanded its SharePoint page on accessibility and promoted awareness of built-in tools like Microsoft's accessibility features.

Additionally, the company introduced instruction on "Preventing Harassment and Discrimination at Work" and developed inclusive communication guidelines. These efforts are complemented by the addition of sign language interpretation at company-wide town halls.

Siemens Energy has also created an internship programme for students with disabilities, allowing selected students to gain hands-on experience in areas like document digitalisation, mailroom support and sustainability projects – building their confidence and essential job market skills.

By combining data from the self-ID survey and the ILO GBDN self-assessment tool with grassroots advocacy, inclusive design and cultural transformation, Siemens Energy is proving that accessibility is not a checkbox – it is a mindset and a cultural shift.

Source: (Engie, 2023; Siemens, n.d.)

A number of
priorities
can help ensure that labour markets and workplaces are accessible, fair and inclusive for all, including people with disabilities.

Use inclusive language and promote visibility in all sector policies, training and employment frameworks. Adopting the terminology "persons with disabilities", aligned with the 2006 UN Convention on the Rights of Persons with Disabilities and across just transition strategies ensuring respectful, dignified and legally consistent representation. Language is not neutral – shifting terminology away from stigmatising expressions helps break social and workplace barriers.

Guarantee equal treatment and non-discrimination in employment through collective bargaining agreements, just transition frameworks and renewable energy job strategies. Equal treatment ought to be a binding principle, not a voluntary practice. This includes equal access to hiring, promotion, skills development and job security for workers with disabilities.

Implement awareness and training campaigns. Employers in the renewable energy sector often cite lack of knowledge or perceived cost burdens as reasons for not hiring persons with disabilities. Workplace-wide awareness and sensitisation campaigns can debunk myths, highlight the capabilities of disabled workers and foster inclusive work environments. These actions should be part of broader inclusion plans negotiated through social dialogue.

Ensure access to employment and inclusive hiring policies with the help of quota systems, affirmative action measures and inclusive recruitment policies. These hiring commitments should be reflected in both public and private sector employment, especially as many renewable energy projects are publicly financed or supported. Where feasible, companies should also prioritise candidates from among those with greater barriers to entry, such as persons with intellectual or psychosocial disabilities.

Promote accessible training and skills development. A universal design of training programmes in renewables ensures that learning environments are accessible in both physical and cognitive terms. This includes the use of easy-to-read materials, sign language interpretation, adaptive tools and formats that allow persons with disabilities to engage fully in technical training, from solar installation to energy auditing and maintenance. Special consideration must be given to the needs of workers who acquire disabilities over the course of their careers.

Incorporate disability inclusion into collective bargaining. Collective bargaining should include disability-specific clauses in agreements with renewable energy employers, addressing recruitment, accessibility, reasonable accommodation, working conditions and career development. Inclusion should be contractual.

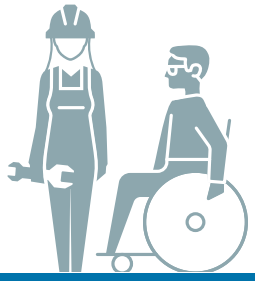
Secure workplace accessibility and reasonable accommodations. Trade unions insist that renewable energy facilities, offices and project sites comply with universal accessibility standards. Reasonable accommodations, including assistive technologies and adapted workstations, should be made available without undue burden. These adaptations are often minor, but their impact on dignity and productivity can be significant.

Strengthen public policy and social protection. Ideally, renewable energy employment programmes should be accompanied by inclusive social protection, disability benefits, transport allowances and supported employment services. Where national employment legislation lacks enforcement mechanisms for disability inclusion, trade unions can work with civil society and international organisations to close these gaps.

Combat stigma and promote workplace dignity. Stigma and ignorance continue to hinder the full participation of persons with disabilities. Cultural change in the workplace aims to bring about a situation where disability is no longer associated with limitations, but with rights, talent and potential. Anti-harassment protocols, inclusive communication strategies and peer-support mechanisms are essential in fostering an inclusive culture within renewable energy companies.

Include disability in just transition monitoring and reporting. Social dialogue mechanisms overseeing the just transition should explicitly include indicators on disability inclusion. Trade unions request that governments and employers collect disaggregated data on recruitment, retention, promotion and workplace accessibility of persons with disabilities in the green economy. Transparent reporting will help track progress and identify areas for improvement.

Disability inclusion is not a marginal issue. It is a test of the degree of justice and credibility of transition pathways. Tripartite social dialogue – among governments, employers and trade unions – centres the voices of workers with disabilities and their representative organisations.



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Disability inclusion

is a test of the degree of justice and credibility of energy transition pathways.

4.3 Priority actions for an inclusive renewable energy workforce

diversity

equity

inclusion

justice

With the renewable energy workforce possibly doubling by 2030, the industry faces a pivotal decision: to expand in an inclusive manner or risk leaving people behind. For reasons of both fairness and pragmatism, the future of renewable energy should be grounded in *diversity* (bringing together people from different backgrounds and viewpoints across the entire value chain); *equity* (ensuring fair access to opportunities, resources and leadership positions); *inclusion* (fostering a culture that respects every individual's voice, participation and sense of belonging); and above all *justice* (securing equal rights and fair outcomes for communities that have historically been disadvantaged not only in the renewable energy sector, but in the overall economy).

To promote the inclusion of women and persons with disabilities in the renewable energy sector, a multi-faceted approach is essential:

- **Inclusive policy frameworks.** Governments should adopt policies that mandate inclusive hiring, training and workplace accommodations in the green economy.
- **Accessible training and education.** Institutions should ensure that renewable energy programmes are physically, digitally and pedagogically accessible.

Particularly for people with disabilities, the following actions could also be beneficial:

- **Employer incentives.** Offering tax breaks or subsidies to employers who recruit and retain persons with disabilities can foster inclusive workplaces.
- **Partnerships with disability organisations.** Engaging with representative organisations ensures that training and workplace adaptations are relevant and effective.
- **Assistive technologies.** Investing in adaptive tools and technologies expands the scope of the roles that persons with disabilities can pursue.

Inclusion of persons with disabilities in the renewable energy workforce is not just a question of rights – it is a question of sustainability. A truly just transition must create space for all workers, including those too often left on the sidelines.

CHAPTER 5

5 HOLISTIC POLICY MAKING FOR A JUST AND INCLUSIVE TRANSITION

At its core, the energy transition is about ensuring that energy use does not push the world irreversibly past the 1.5°C climate change threshold. To preserve a stable climate for future generations requires accelerating the shift to renewable energy sources, accompanied by related actions such as pursuing energy efficiency and sufficiency.

The
human dimension
of the energy transition is critical

All too often, however, the conversation around the energy transition is limited to matters such as technology, costs and capacity targets. While these are important metrics, on their own they are incomplete. The human dimension is just as critical because it is people who have to make a new energy system work and it is people who will experience the benefits of a more sustainable system. The central purpose of the transition to a renewables-centred future is to safeguard both planetary and human well-being.

Even when the socio-economic dimension is taken into account, it is often reduced to a single statistic: the number of jobs. Understandably, a large number is viewed as good news. But it is important to focus on job quality and security as well as occupational health and safety, and to make sure that job opportunities and career prospects are fairly distributed, both within and among countries.

The urgency of the transition is undeniable. For many years, IRENA and others have called for much greater ambition in energy and climate policy making, but progress is often painfully slow relative to the demands of climate science. There is no shortage of climate and energy conferences, but rhetoric typically outpaces action. Many initiatives are voluntary rather than binding, and partial rather than comprehensive.

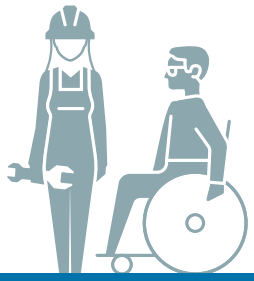
Meanwhile, the fossil fuel industry demonstrates remarkable staying power in national policy-making contexts, reinforced by mounting concerns over energy supply security. While renewable energy continues to grow, the energy transition is not getting enough of an assist from global climate diplomacy. Following virtually each of the to-date 30 annual climate conferences (COPs[34]) discussions persist whether enough has been achieved and whether the proverbial glass is half full or half empty. And, for a variety of reasons, the pace of renewables deployment still falls short of what is needed; to some extent the energy *transition* to date has been more an energy *addition* in which renewables are layered on top of the existing fossil fuel system. This of course limits the prospects for a speedy expansion of renewable energy employment and an equally speedy achievement of climate goals.

More than ever, there is a need to ensure that people experience tangible benefits of the energy transition. Adequate jobs and livelihood opportunities are major markers in this regard. People – families, businesses and communities – need to have confidence that the uncertainties inherent in this difficult transformation are proactively addressed, and in ways that do not unfairly burden them.

[34] *COPs refers to annual Conferences of the Parties to the United Nations Framework Convention on Climate Change.*

A just transition must deliver accessible and affordable energy services for all households and businesses. Energy is not a luxury good; in the modern world it is a pre-condition of being able to function and participate in society. It is, effectively, a basic human right. Secure, reliable, affordable and clean energy systems sustain jobs and livelihoods, while strengthening resilience and inclusion across societies.

Reliable information is essential, and this report series has sought to contribute insights on employment, a key socio-economic benefit of renewables. Contextual knowledge is key – an informed understanding of the factors that shape the further development of renewable energy; support or hinder job creation; influence where jobs are created (or lost); and determine who has access to job opportunities (through education, training and career networks). The goal should not be to generate just any kind of jobs, but good jobs: work that pays living wages, provides stability and strengthens communities rather than exploits them. This is especially vital for workers and regions historically dependent on fossil fuels, who must not be left behind.

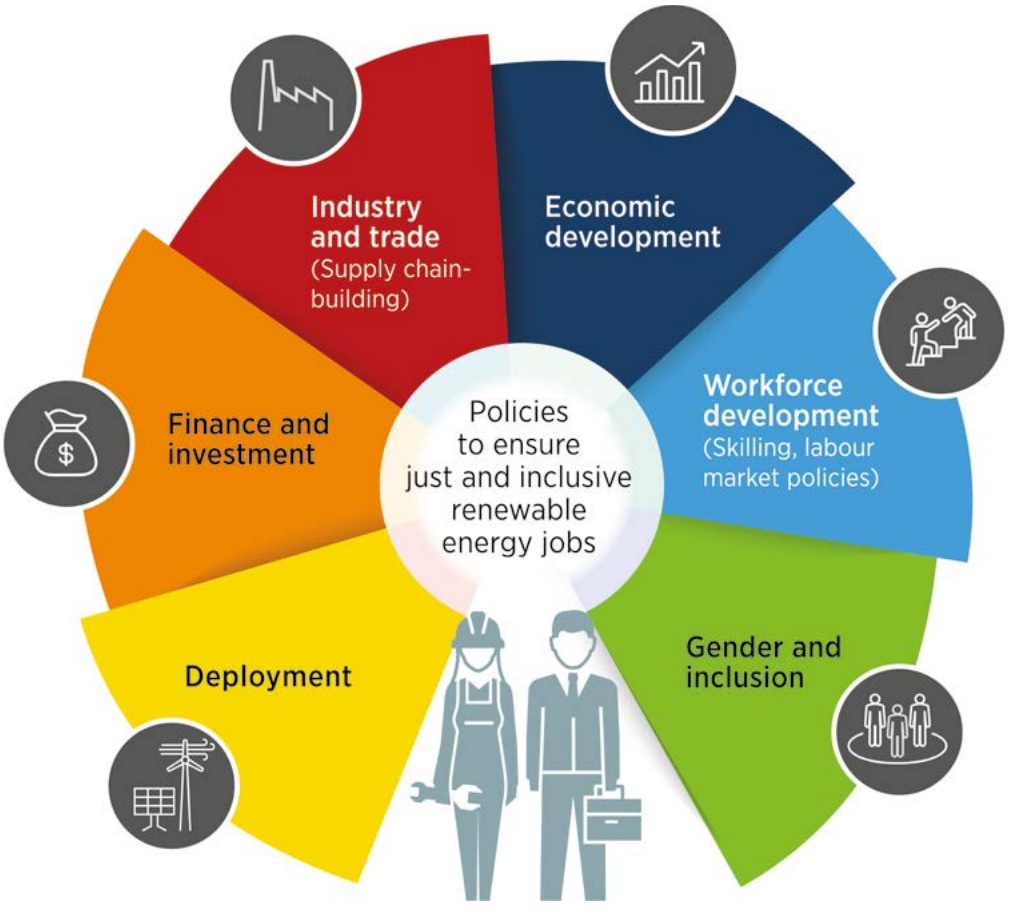


Secure, reliable, affordable and clean energy systems **sustain jobs and livelihoods**, while strengthening resilience and inclusion across societies.

Creating decent jobs and ensuring widely shared benefits will not happen automatically. As IRENA has long argued, a successful outcome requires a holistic approach to policy making. Most directly, this entails an array of well-designed deployment policies to enable and support the installation of renewable-energy-generating capacities and their integration into electricity grids and other energy delivery systems. Building the complex supply chains that provide critical inputs and manufactured components for the wind, solar, hydropower, bioenergy and other industries is also essential, requiring a mix of industrial and trade policy measures. No less important is workforce development (see Figure 12).

Workforce development must include stepped-up efforts in education and training (including reskilling and upskilling) – whether through university-level coursework, vocational training, apprenticeships or on-the-job learning – and co-ordination between educational providers and industry. Reskilling and upskilling programmes are essential to avoid leaving fossil fuel workers behind. Skilling needs to be paired with labour market services and regulations. Industrial policy making will be essential for building capable, diversified supply chains. Trade policy could supplement such efforts by temporarily protecting fledgling enterprises. Public finance and investment strategies will be key in supporting all these

Figure 12 Policies to ensure just and inclusive renewable energy jobs



measures, and will also be needed for economic development programmes undertaken in conjunction with the energy transition, whether focused on revitalising structurally weak, fossil-fuel-dependent regions and communities, rural electrification campaigns or other priorities.

Designing and shaping these policies for the common good requires that all stakeholders have a seat at the table. An important dimension of policy making is inclusion. Diversity matters. But inclusion is not merely granted; it is based on the fundamental rights of all peoples and communities. A just transition pushes back against discriminatory practices and outdated social and cultural norms, ensuring that new opportunities are accessible to people of all backgrounds. As such, efforts must go beyond token quotas or other measures that merely give the appearance of equity. Equity needs to become a lived reality, a genuine expansion of perspectives and talents that will ensure fairer, more inclusive, and ultimately, more successful economies.

Naturally, questions abound about the most effective policies and approaches. There is not a single energy transition that plays out the same way across the globe, but rather multiple transitions that are shaped by existing economic structures, social and economic priorities, and policy design (IRENA, 2026). Can a transition that is driven primarily by private enterprises – *i.e.* profit driven – be expected to accomplish goals that hew to the global public good? A strategy that exclusively looks to the private sector is bound to neglect many of these aspects, running the risk of failure. The importance of public policy cannot be overstated. Both the climate urgency and the goal of an inclusive transition imply the need for a much stronger public role (by governments and civil society alike) in guiding the energy transition, thus ensuring that investments and ownership of energy assets reflect fundamental public needs, and giving voice to diverse needs, ideas, talents and viewpoints.

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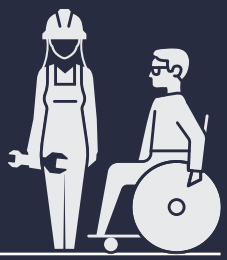

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