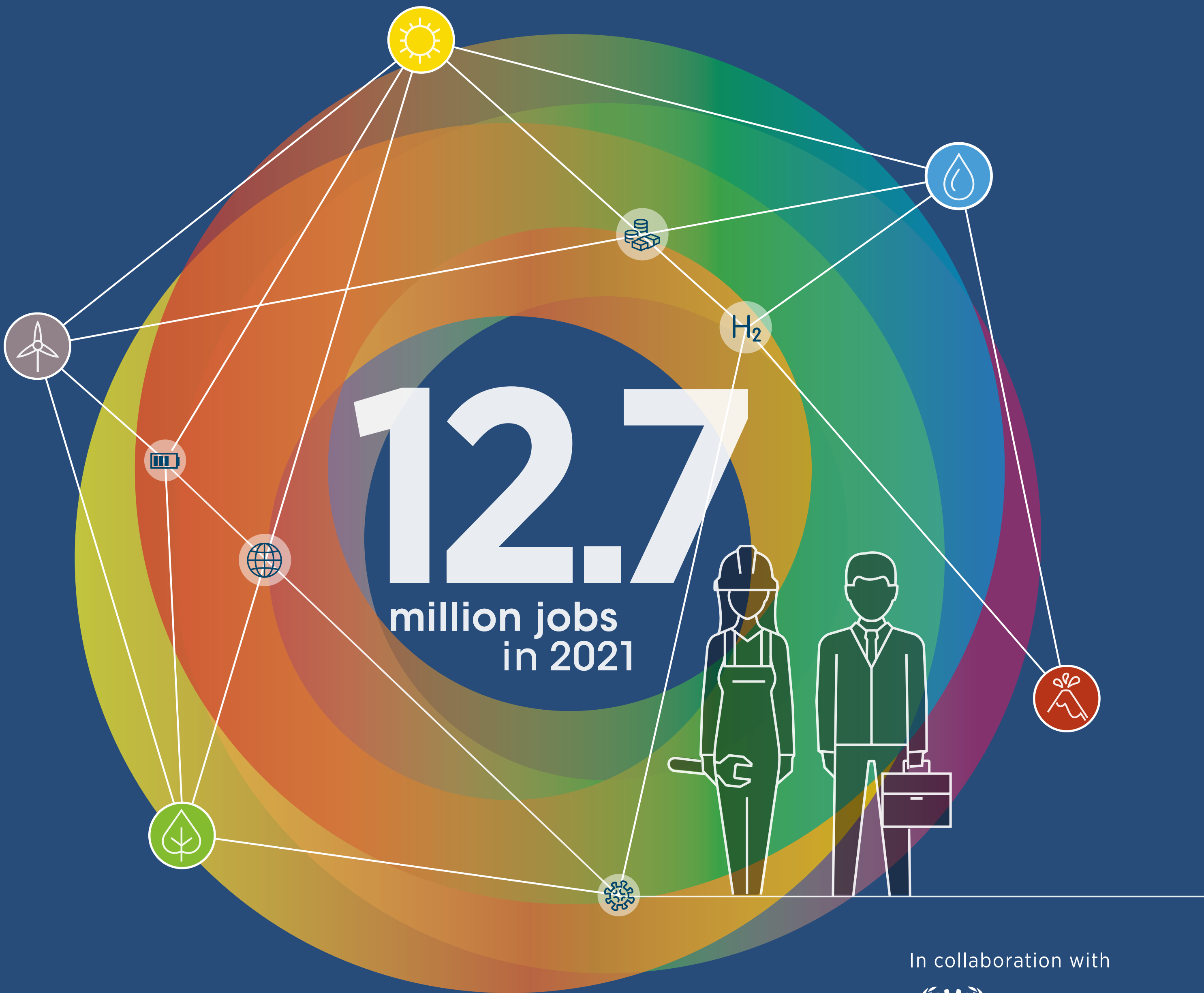
IRENA
International Renewable Energy Agency

Renewable Energy and Jobs
Annual Review 2022



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ABOUT IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

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ABOUT ILO

The only tripartite U.N. agency, since 1919 the ILO brings together governments, employers and workers of 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

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With the extreme weather events witnessed across the globe in recent years, the heavy costs of climate change are becoming increasingly visible to all, strengthening the already compelling case for our transition to a low-carbon future powered by renewable energy.

As with the global economy, the renewable energy sector faces lingering supply chain disruptions from the COVID-19 crisis and volatile energy prices stemming from trade disputes and geopolitical rivalries.

Our responses to these immediate and long-term challenges bring to the fore the role of workforce development. This remains an essential component of the energy transition that should be addressed in the context of a broad policy framework comprising industrial policies, education and skills training, labour market policies, enterprise development, diversity and inclusion strategies, regional revitalisation and social protection measures, based on social dialogue.

This ninth edition of IRENA's *Renewable energy and jobs: Annual review* shows that the number of people either directly or indirectly employed in the renewable energy sector has continued to grow, from 12 million in 2020 to 12.7 million in 2021. Solar photovoltaics, with a third of these jobs, remains the most dynamic renewable industry.

Close to two thirds of all renewable energy jobs are based in Asia, with China alone accounting for 42% of the global total. This reflects the region's strengths in installation markets and equipment manufacturing. To secure jobs and other socioeconomic benefits worldwide, more countries across the globe need to pursue policies to boost their domestic capabilities.

As the number of jobs in the renewable energy sector continues to rise, it is essential to ensure that these posts provide decent livelihoods in terms of wages, occupational health and safety and workplace conditions, job security and other rights at work.

A successful and just energy transition must reflect the needs and interests of communities and regions, offer social protection for those most affected, and ensure that poor households and the most vulnerable members of societies are not priced out of the energy market by measures intended to reflect the environmental costs of fossil fuels. Such a perspective can ensure that the move from old to new energy systems is just, both in terms of jobs and other pressing social and economic needs in societies around the world.

Encouraging advances have been made in workforce gender equity – with women accounting for one-third of all renewable energy jobs. Additional progress is essential. As the transition gathers pace our focus must remain on fostering workforce diversity in ways that offer equal opportunities across the board, not only in terms of gender but for youth, minorities and marginalised groups.

This report shines a spotlight on the extended renewables value chain. On the upstream side, growing scrutiny of industry practices in the mining and processing of commodities critical to renewable energy is required. This includes environmental and labour standards as well as impacts on local communities, local content, value added and domestic manufacturing. Meanwhile, at the other end of the value chain, measures are needed to handle decommissioned equipment and materials with greater care and responsibility.

As the transition gains momentum, the multiple benefits of pursuing renewable energy are becoming increasingly clear – ranging from greater climate stability to new economic opportunities and jobs. If we are to lock in these benefits for the long term, we must act with urgency to significantly ramp up the pace of our transition to a sustainable energy future.

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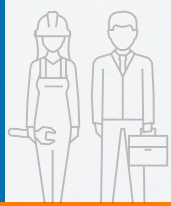

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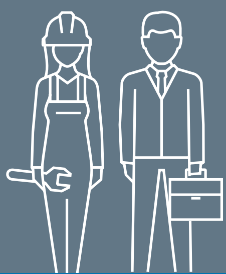


Abbreviations

ASM	artisanal and small-scale mining
CdTe	cadmium telluride
CSP	concentrated solar power
DRE	decentralised renewable energy
EOL	end-of-life
EU	European Union
EU-27	27 Member States of the European Union
GW	gigawatt
IEA	International Energy Agency
ILO	International Labour Organization
IREC	Interstate Renewable Energy Council
MW	megawatt
O&M	operations and maintenance
PV	photovoltaic
R&D	research and development
SGRE	Siemens Gamesa Renewable Energy
USDA-FAS	US Department of Agriculture Foreign Agricultural Service
US DOE	US Department of Energy

KEY FACTS

12.7 million — **Worldwide employment** in renewable energy in 2021, up from 12 million in 2020. Close to two-thirds of all jobs are in Asia, and China alone accounts for 42% of the global total. It is followed by the European Union and Brazil with 10% each, and the United States and India with 7% each.

4.3 million — **Jobs in solar photovoltaic (PV)** in 2021, the fastest-growing sector, accounting for more than a third of the total renewable energy workforce.

1.3 million — **Jobs in wind power** in 2021. Countries are building the industrial base and infrastructure needed to support growing offshore installations.

2.4 million — **Direct jobs in hydropower** in 2021. Two-thirds of these jobs were in manufacturing, 30% related to construction and installation and about 6% to operation and maintenance.

2.4 million — **Jobs in biofuels** in 2021, with the vast majority in feedstock operations. Biodiesel output and employment are rising while ethanol is ebbing.

38.2 million — **Worldwide employment in renewable energy in 2030** under an ambitious energy transition scenario with front-loaded investments. The number of jobs in the energy sector could rise to 139 million, including more than 74 million in energy efficiency, electric vehicles, power systems/flexibility and hydrogen.

IRENA
International Renewable Energy Agency

KEY OBSERVATIONS

› **MANUFACTURING HUBS:** At present, a handful of countries dominate the renewable energy landscape, reflecting their strengths in manufacturing, engineering and related services, reaping the majority of jobs. But some component production is shifting to other countries.

› **DOMESTIC JOB CREATION:** The lingering impact of the COVID-19 crisis has put a spotlight on the viability of far-flung supply chains. Rising concerns in the context of additional supply chain disruptions, trade disputes and geopolitical rivalries are reinforcing interest in localisation of supply chains, to enhance resilience, domestic value and job creation.

› **DECENT JOBS:** Jobs that pay good wages, adhere to occupational health and safety standards, and provide job security are essential for a just energy transition. Workers' rights are key to collective bargaining and effective social dialogue.

› **COMMODITIES:** Observance of labour and environmental standards is critical along the renewable energy supply chain. This includes the mining and processing of metals and other raw materials critical to renewable energy equipment. Industry practices vis-à-vis workers and local communities are receiving greater scrutiny.

› **CIRCULAR ECONOMY:** Once solar panels and wind turbines reach the end of their life, recycling, remanufacturing and reuse of embedded materials limit waste flows, reduce the extraction of virgin raw materials and offer greater employment opportunities than landfilling or incineration.

› **POLICY FRAMEWORK:** The continued expansion of decent renewable energy jobs requires a comprehensive approach comprising policies on deployment, integration and enablement, as well as industrial policies, education and skills training, labour market measures, diversity and inclusion strategies, and regional revitalisation and social protection measures.

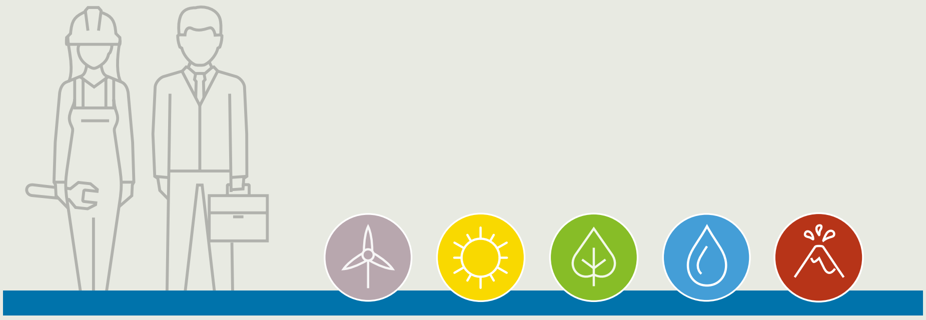
RENEWABLE ENERGY JOBS

Introduction

This ninth edition of IRENA's ***Renewable energy and jobs: Annual review*** series provides the latest estimates of renewable energy employment globally. In addition to IRENA's own calculations, the report is based on a wide range of studies and reports by government agencies, industry associations, non-governmental organisations and academic experts.

The report first surveys the global renewable energy employment landscape as of 2021. It then discusses employment results for selected countries with respect to deployment trends, policy contexts and pandemic impacts, with an eye to job quality as well as job numbers. It explores job quality and related issues in the upstream and downstream segments of the renewable energy supply chain. Throughout the report, particular attention is given to the regional distribution of employment within countries, to the gender dimension, and to trade.

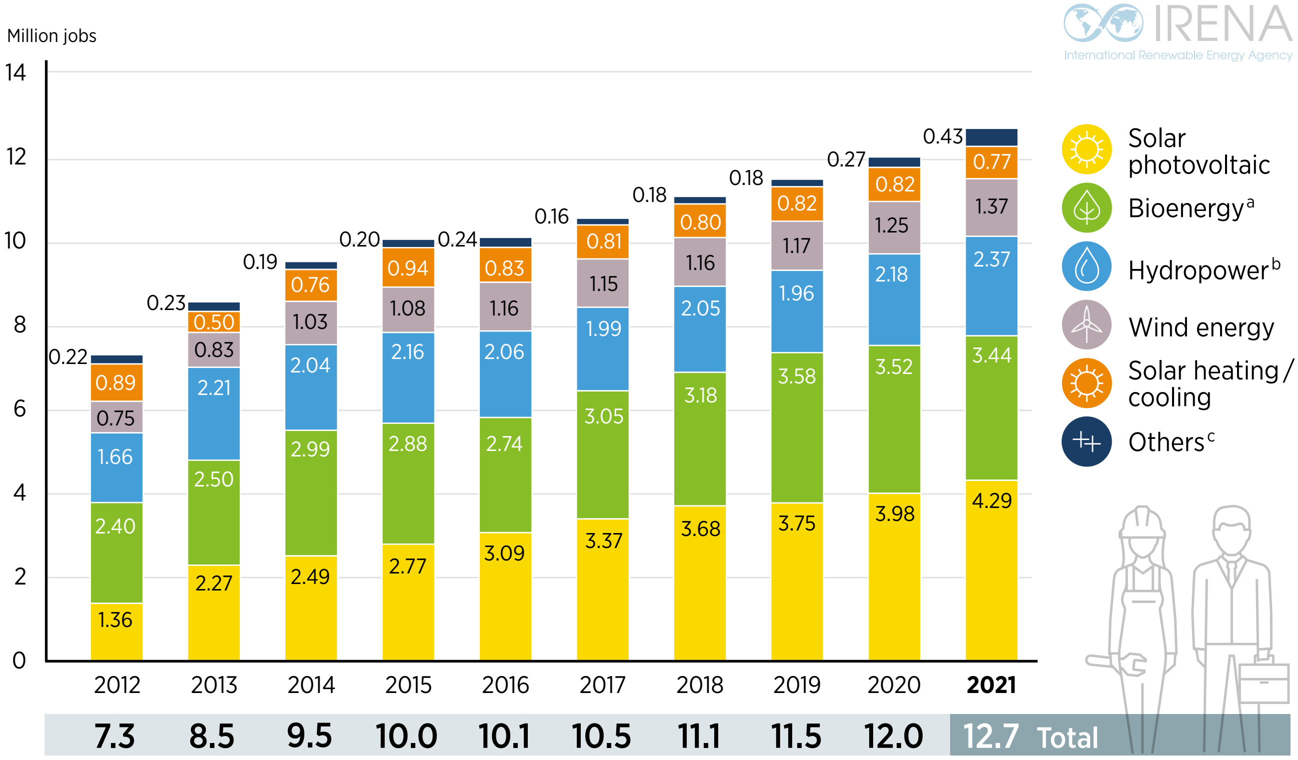
The renewable energy sector employed 12.7 million people, directly and indirectly, in 2021.[1] The number continued to grow worldwide over the past decade, with most jobs in the solar photovoltaic (PV), bioenergy, hydropower and wind power industries. Figure 1 shows IRENA's renewable energy employment estimates since 2012.[2]



[1] *Data are principally for 2021, with some dates for 2020 and a few instances in which only earlier information is available. The data for hydropower include direct employment only and for other technologies include both direct and indirect employment wherever possible.*

[2] *The job numbers shown in Figure 1 reflect the figures reported in earlier editions of this series. IRENA does not revise estimates from previous years in light of information that may become available after publication of a particular edition.*

Figure 1 Evolution of global renewable energy employment by technology, 2012-2021



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.

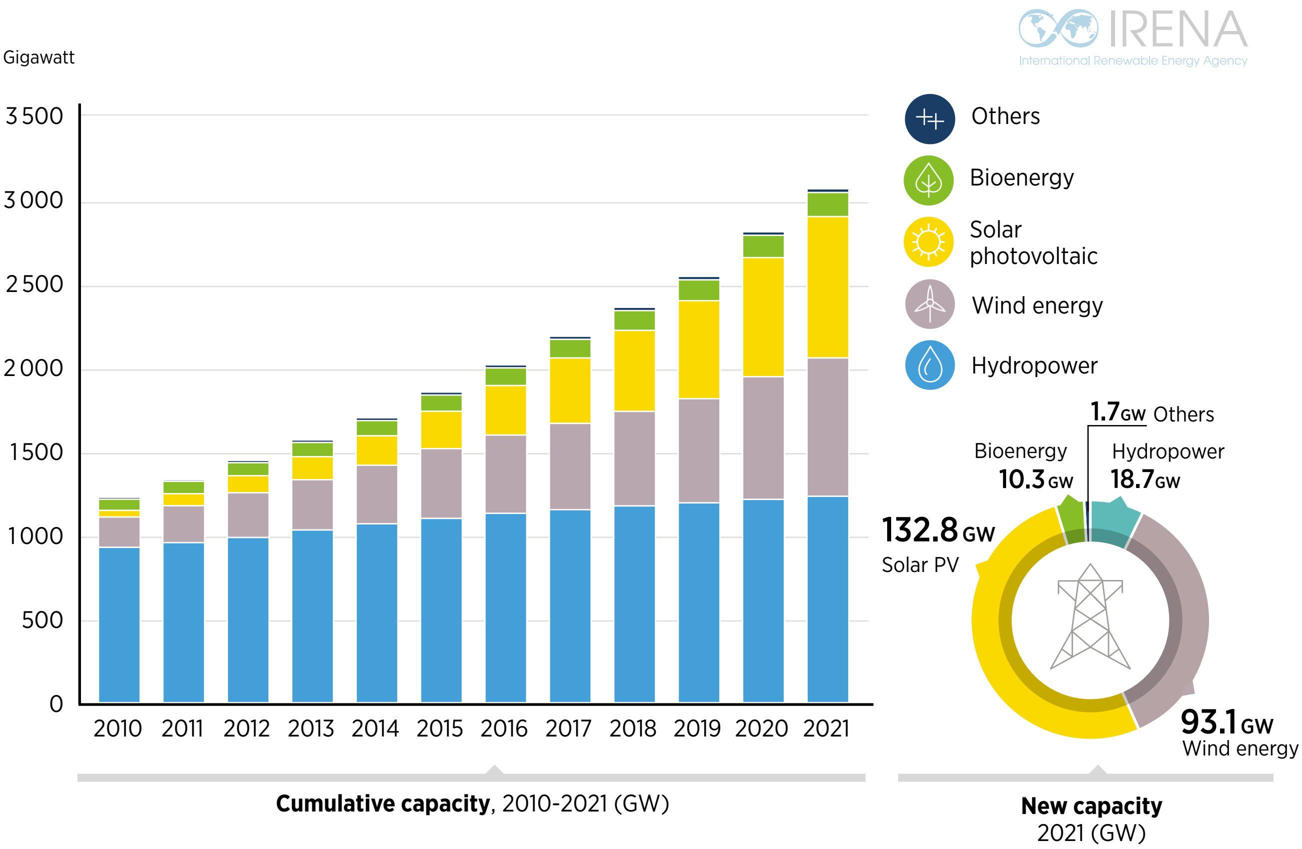
Source: IRENA jobs database.

These employment trends are shaped by a multitude of factors, including costs, investments, and new and cumulative capacities, and by a broad array of policy measures to enable renewable energy deployment, generate viable supply chains and create a skilled workforce. The COVID-19 pandemic continued to affect the global economy during 2021, altering both the volume and structure of energy demand.

Domestic market size is a major factor that affects employment generation in construction, installation, and operations and maintenance (O&M). Building or maintaining a strong equipment manufacturing industrial base also needs sufficiently large and steady domestic demand. Only a few countries have become significant equipment producers. Trade restrictions may be required to protect a fledgling local industry, but policy makers need to strike a careful balance between such efforts and minimising costs for renewable energy projects.

Worldwide, some 257 gigawatts (GW) of renewable electricity were installed in 2021, expanding cumulative capacity by 9% to a total of 3 068 GW (Figure 2). Solar and wind power together accounted for 88% of this expansion, at 133 GW and 93 GW, respectively. By contrast, hydropower grew by just 25 GW in 2021, the same pace as in 2020, and bioenergy power capacity expanded by 10 GW in each of the last two years (IRENA, 2022a). Solar thermal capacity grew by 31 million square metres or 21 gigawatt-thermal, continuing an upswing after several years of declining installations (Weiss and Spörk-Dür, 2022). Global biofuel output of about 160 billion litres matched the level reached in 2019, before the COVID-19 crisis (REN21, 2022).

Figure 2 World renewable electricity capacity, 2010-2021



Note: GW = gigawatt; PV = photovoltaic.

Source: IRENA, 2022a.

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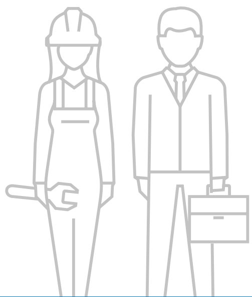
The majority of new capacity was installed in China, which continued to dominate renewable electricity and account for a large share of renewable energy employment. China installed 50% of the world's new installations in wind power and in solar PV it accounted for 40% (IRENA, 2022a). Collectively, the rest of the world added record amounts of wind and solar capacity in 2021. In the solar PV industry, the United States, India, Brazil, France and Italy added record amounts to their capacities. By contrast, some other leading countries remained behind the pace they had set in earlier years. In solar PV, the pace slackened for Germany, Spain, Türkiye, Japan, Australia and the Republic of Korea. In wind, Brazil, the United Kingdom, Sweden and Türkiye scored new annual records; Germany and India failed to match the pace of earlier years (IRENA, 2022a).

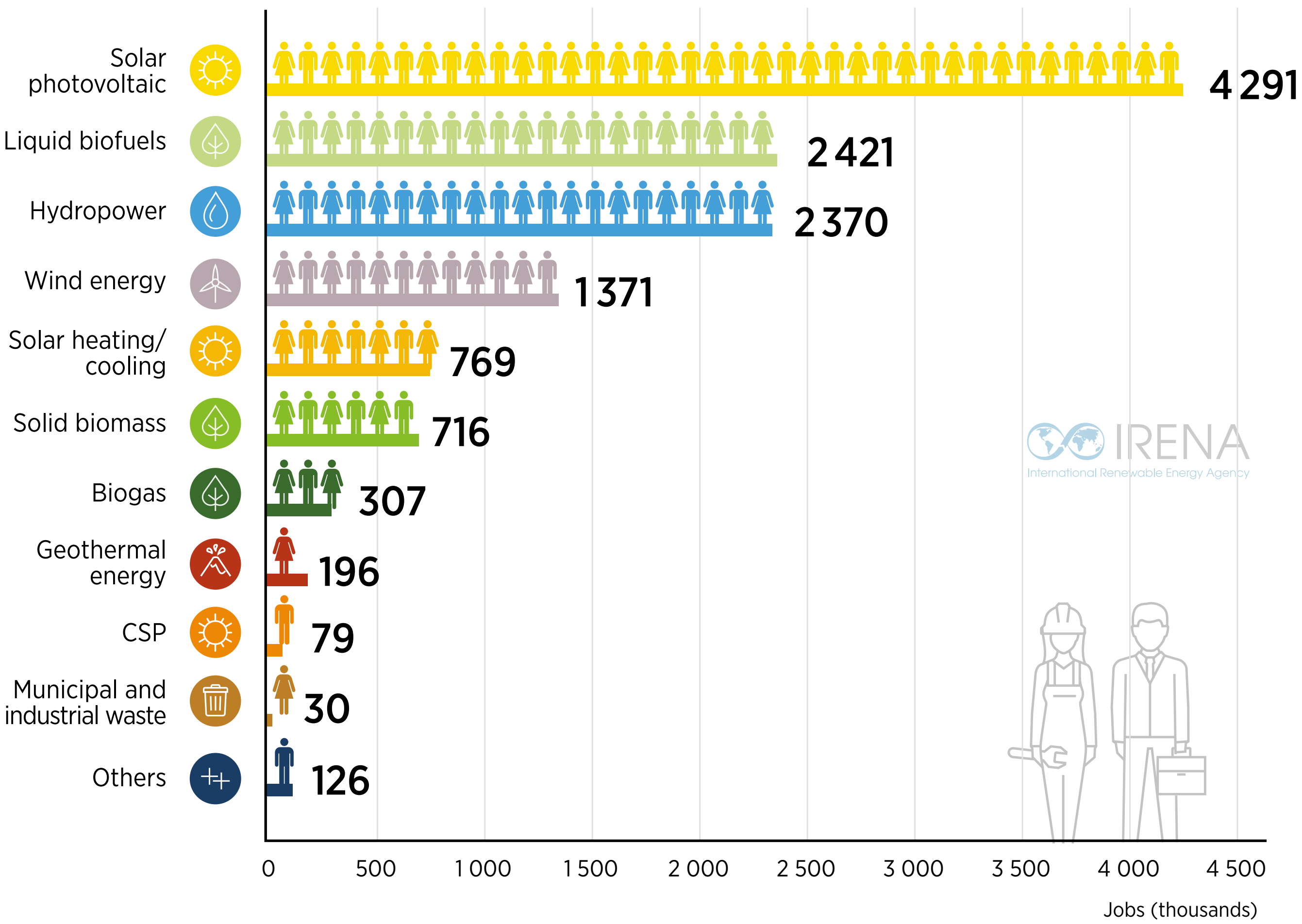
This report is organised as follows: **Chapter 1** discusses employment trends by major technology. **Chapter 2** explores the dynamics shaping job creation in several leading countries and presents findings for a number of additional countries in each region of the world. **Chapter 3** examines the upstream and downstream dimensions of renewable energy supply chains, including logging and mining aspects, and considers end-of-life issues after projects are decommissioned. **Chapter 4** emphasises the importance of a just transition for workers. **Chapter 5** provides key takeaways in the context of IRENA's work on the socio-economics of the energy transition.



Chapter 1 RENEWABLE ENERGY EMPLOYMENT **BY TECHNOLOGY**

This chapter presents estimates for employment in solar PV, wind, hydropower and liquid biofuels. Other renewable energy technologies included in Figure 3 employ fewer people, and there is typically less detailed information available on them. For any given technology, the main segments of the value chain include manufacturing of equipment, construction and installation, and O&M, plus a range of support services, enabling functions and governance aspects.

Figure 3 Global renewable energy employment, by technology, 2021



Note: CSP = concentrated solar power. "Others" include jobs not broken down by individual renewable energy technologies.
Source: IRENA jobs database.

4.3
million jobs

1.1 SOLAR PHOTOVOLTAIC

The world scored a new record in 2021, producing 132.8 GW of solar PV capacity installations, up from 125.6 GW in 2020. **China** accounted for 53 GW (40%) of the 2021 additions. It was followed by the United States, India and Brazil, all of which set new annual records. Germany, Japan, the Republic of Korea, Spain and the Netherlands were the next largest sites of PV solar installations, but all of them failed to surpass their earlier peak volumes (IRENA, 2022a).

Solar PV manufacturing is highly concentrated, at both the corporate and country level. Polysilicon is first processed into ingots and wafers, which are then manufactured into cells and assembled into modules. Among wafer producers, the market share of the top ten firms rose from 62% in 2016 to 95% in 2019 (USAID and Power Africa, 2022). The top ten solar PV module manufacturers shipped more than 160 GW in 2021, giving them a 90% share of the global market. There is a significant degree of vertical integration among wafer, cell and module manufacturing operations (Shaw and Hall, 2022).

The vast majority of global solar PV manufacturing takes place in China, supported by substantial government incentives and extensive research and development (R&D). For wafers, China has a near-complete monopoly, with 96% of global production in 2021. For cells, it commanded an 84% share of global capacities and 79% of production. For modules, the shares were 81% and 78%, respectively. Malaysia, Thailand and Viet Nam have become manufacturing and assembly hubs, principally for Chinese companies, together representing close to 9% of cell and module production. Elsewhere in Asia, India, Japan, the Republic of Korea, Singapore and Chinese Taipei account for another 10.5% of cell output and 7.6% of modules, respectively (Wood Mackenzie, 2022a).

Close to half of the world's module production in 2021 was exported, following a steep increase in international solar trade over the past decade (IEA, 2022b). Trade statistics echo the lopsided manufacturing landscape, with the bulk of the world's PV manufacturing jobs found in China and Southeast Asia. In 2020, two-thirds of China's total PV production of 124.6 GW was shipped abroad (Gulia *et al.*, 2022). By contrast, major solar installers such as Germany, Brazil, India and the United States are net importers (see Figure 4, which shows data for 2020, the most recent year available). The European Union imported 84% of the modules it installed between 2017 and 2021, more than the United States (77%) or India (75%) (IEA, 2022b).


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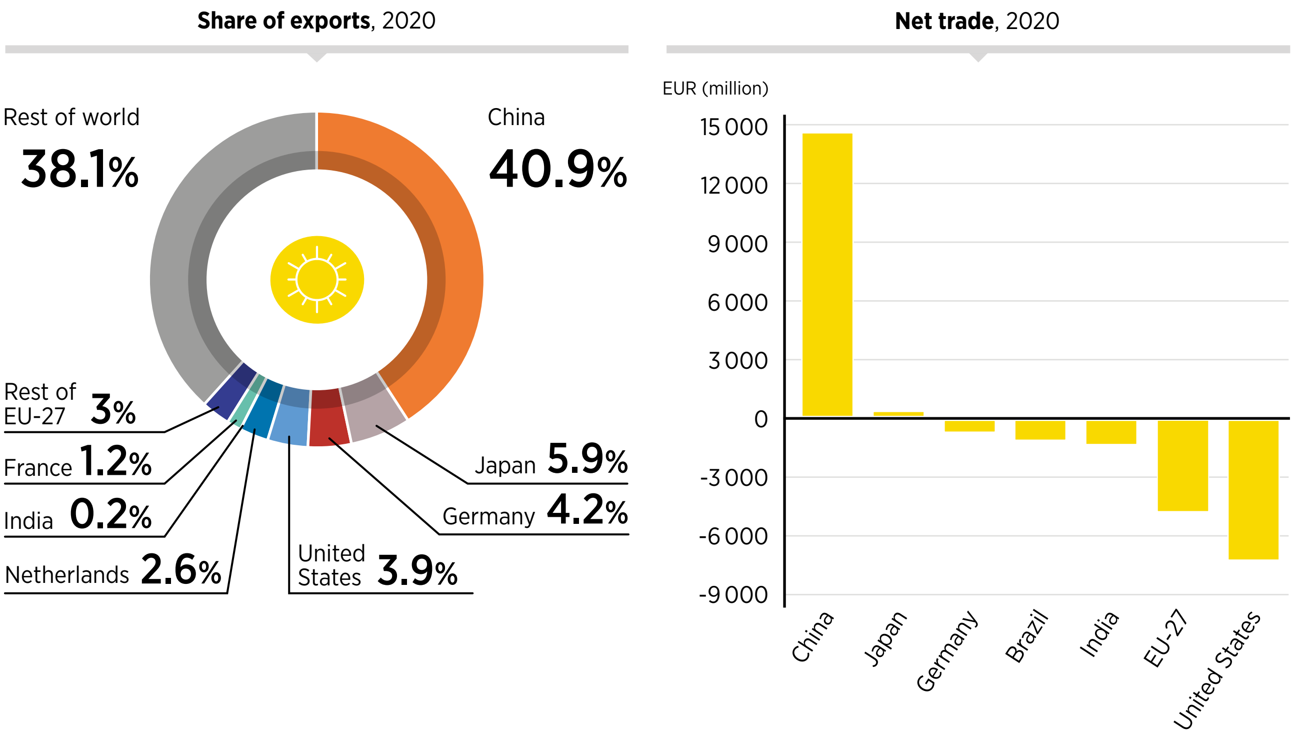
Figure 4 Exports and net trade in the solar PV sector, 2020: Selected countries



Note: PV = photovoltaic.

Source: EurObserv'ER, 2022.

Factors such as land, energy, capital and labour largely determine the location of segments of the solar PV manufacturing supply chain (and thus localisation possibilities and domestic job creation), but government industrial policies are a critical factor in shaping viable supply chains (US DOE, 2022b).

- **Polysilicon** production relies on large-scale capital investments; low-cost electricity and heat (given the energy-intensive nature of production, a big factor also in ingot and wafer production); and skilled labour.
- The growing automation of **cell** manufacturing requires access to state-of-the-art production equipment plus the engineers and skilled machine operators to run it. Tax breaks and low-cost land and electricity play a significant role in an industry with tight margins.
- The **module** production segment focuses on assembly and therefore does not require the same level of technical skill as cell fabrication.

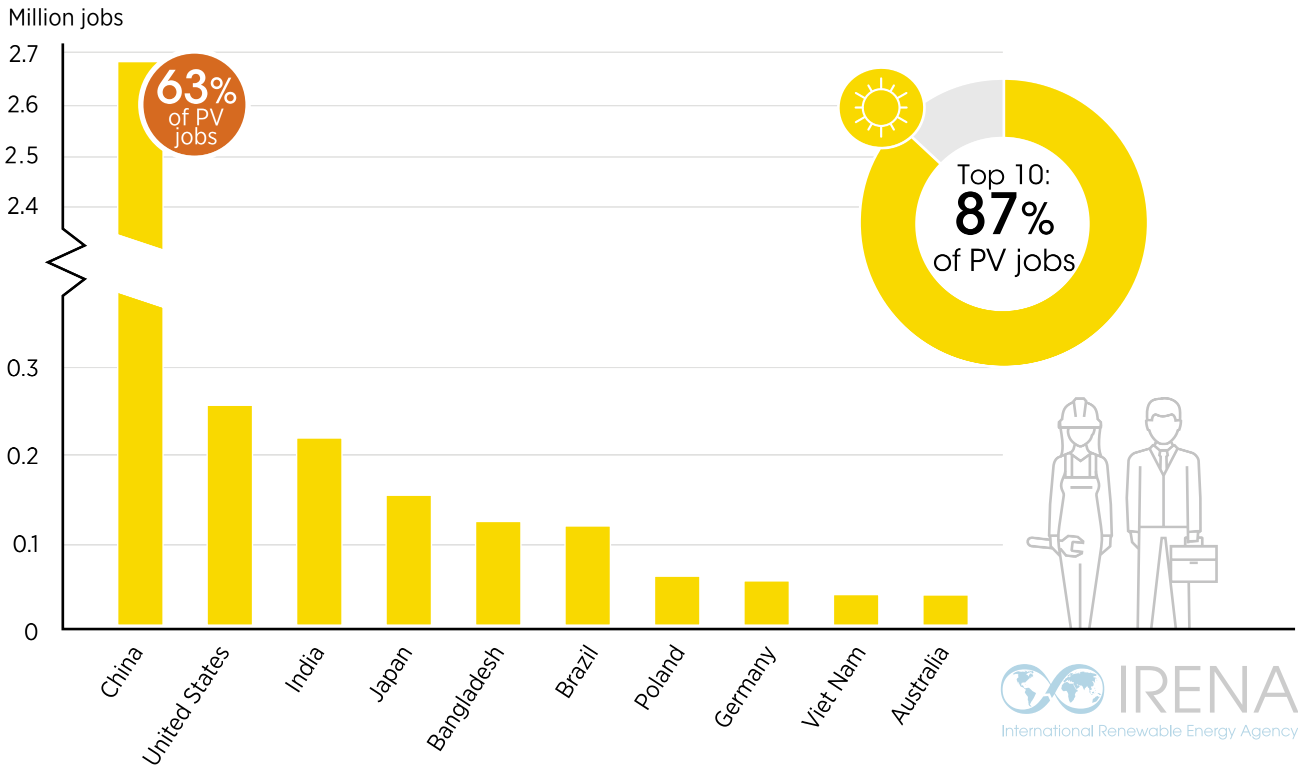
According to the US Department of Energy (US DOE, 2022b), 1 GW of production capacity (for crystalline silicon [c-Si] modules, which account for about 90% of all modules made) could generate anywhere from 1 085 jobs to 2 020 direct jobs across the full value chain, with variations by country and diverging degrees of automation and economies of scale across manufacturing facilities. Thin-film cadmium telluride (CdTe), which accounts for most of the remaining 10% of the global module market, is far less labour intensive and requires an estimated 400-600 direct jobs per gigawatt (US DOE, 2022b). The International Energy Agency (IEA) estimates a similar range of 1 280-2 050 jobs per gigawatt for c-Si,[3] but a lower figure of just 200 jobs for CdTe modules (IEA, 2022b).

IRENA estimates global solar PV employment at 4.3 million in 2021, up from about 4 million in 2020.[4] Of the ten leading countries shown in Figure 5, five are in **Asia**, two are in **the Americas** and two are in **Europe**. Together, the top ten accounted for almost 3.7 million jobs, or 87% of the global total. Asian countries host 79% of the world's PV jobs, reflecting the region's continued dominance of manufacturing and strong presence in installations. The remaining jobs were in **the Americas** (7.7% of all jobs), **Europe** (6.8%) (with members of the European Union accounting for 5.5%) and the rest of the world (4.9%).

[3] For large-scale production in China and Southeast Asian countries, IEA estimates 1 000-1 100 jobs per gigawatt.

[4] This figure is based on an extensive literature review supplemented by IRENA's own calculations.

Figure 5 Solar PV employment in 2021: Top ten countries

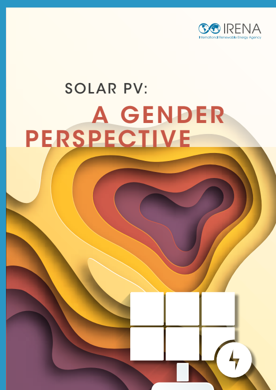


Source: IRENA jobs database.

China, the leading producer of PV equipment and the world's largest installation market, accounted for about 63% of PV employment worldwide, or some 2.7 million jobs. Employment in PV and other solar technologies in the **United States** recovered from a dip in 2020, rising to 255 000 workers. PV employment in **Europe** is estimated at 268 000 in 2020, of which 235 000 are in EU Members States. **India's** on-grid solar employment is estimated at 137 000 jobs, with another 80 600 in off-grid settings, for a total of 217 000 jobs. **Japan** added less capacity in 2021 than the previous year; IRENA estimates its workforce at 151 000.

In terms of gender balance, solar PV fares better than the renewable energy sector as a whole and far better than the global oil and gas industry (Box 1).

Box 1
Solar PV: A gender perspective



IRENA's socio-economic work aims to close the gender-disaggregated data gap in the renewable energy sector by examining the role of women through its gender series. In the forthcoming edition, *Solar PV: A gender perspective*, IRENA assesses the constraints faced by women in the solar PV sector in both modern markets and energy access (IRENA, 2022b). Through a global survey, the study gathers primary data from individuals and organisations within the solar PV sector.

IRENA's previous analyses in the series had indicated that the renewable energy industry in general has a better gender balance than conventional energy industries, but that the share of women nevertheless falls short of the percentage employed in the overall economy. As in the earlier studies, the new report examines this question with attention to occupations in STEM fields (science, technology, engineering and mathematics), other non-technical professional occupations, administrative roles and management.

Much remains to be done to boost women's participation at all levels of the sector. Actions are needed to ease their entry into the industry and improve their career prospects and progression. Initiatives to build awareness of the complexity of the barriers that women face are vital. In addition, national policies are needed to create safer spaces and better workplace practices, policies and regulations. Women need networks and systems to support training and mentorship, and to allow their talents to be fully utilised. Doing so would benefit not only them but the solar PV sector.

1.4
million jobs

1.2 WIND

In 2021, the wind energy sector installed 93 GW of capacity, the second-largest annual addition after 2020. China was in the lead, even though the 47 GW added was considerably less than the previous year. The United States followed, with 14 GW, about the same as in 2020. Other leading installers were Brazil, Viet Nam, the United Kingdom, Sweden, Türkiye, Germany, India and France (IRENA, 2022a).

Record offshore wind additions of 21.3 GW were achieved despite continued COVID-19 impacts and strains on supply chains (Clark et al., 2022). They could not compensate for the lower rate (71.8 GW) of onshore installations, however (IRENA, 2022a). China installed more than 80% of new offshore capacity, driven by an impending phaseout of feed-in tariff subsidies for grid-connected projects (Clark *et al.*, 2022). Just three Chinese companies accounted for 57.5% of global wind installations (Barla and Lico, 2022).

The wind industry's trend towards growing consolidation continued in 2021, when the top ten manufacturers accounted for 85% of the global installation market. Just five companies – Vestas, Goldwind, GE, Envision and Siemens Gamesa Renewable Energy (SGRE) – controlled more than half the market volume.

Chinese firms continued to service primarily their domestic market. GE derived two-thirds of its business from US customers. Vestas and SGRE are present in more than 30 countries and can rely on a mature global supply chain.

Global employment in onshore and offshore wind grew to 1.4 million jobs in 2021, up from 1.25 million in 2020. Most wind employment is concentrated in a relatively small number of countries. **China** alone accounted for 48% of the global total. **Asia** represented 57%, **Europe** 25%, **the Americas** 16%, and **Africa** and **Oceania** 2%. The top ten countries shown in Figure 6 together employed 1.16 million people. Four are in Europe, four in Asia and two in the Americas.


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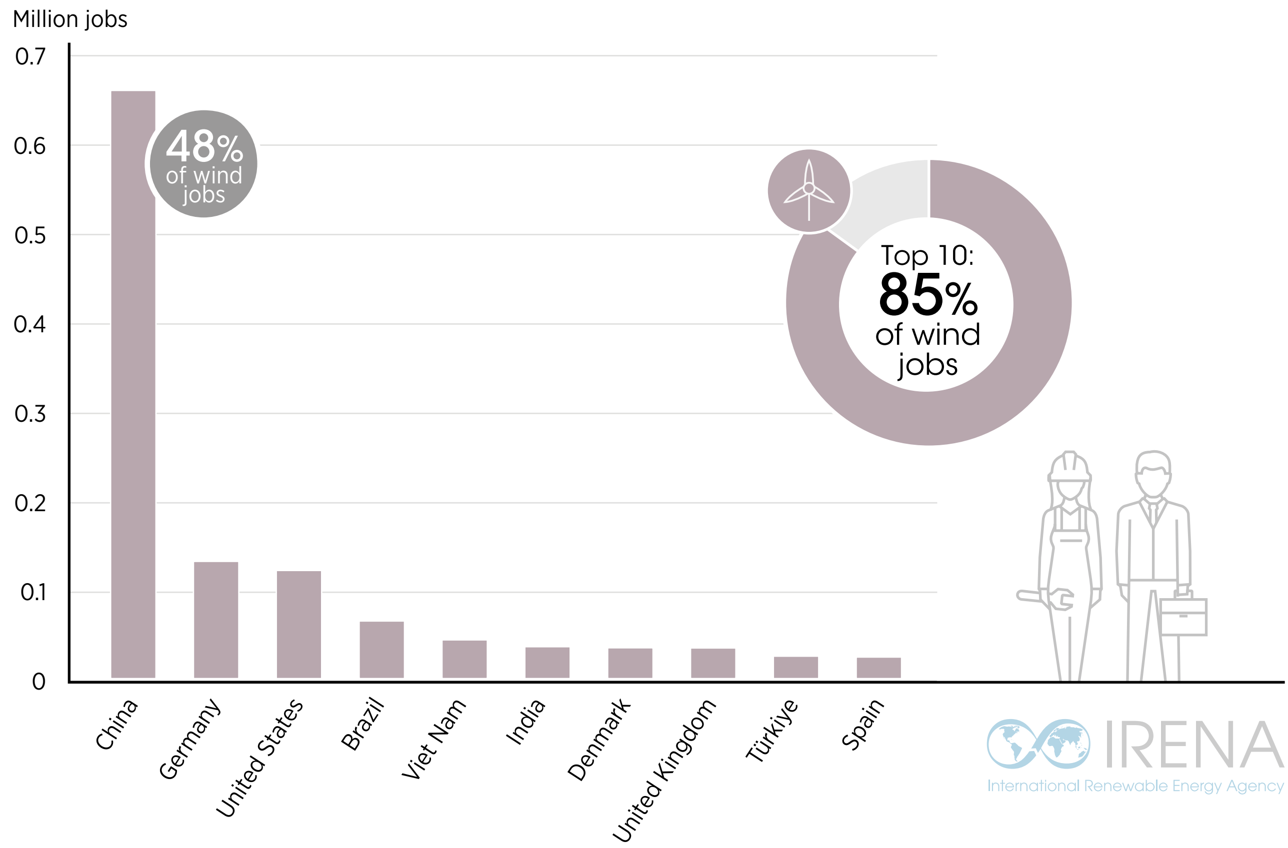
Figure 6 Wind employment in 2021: Top ten countries

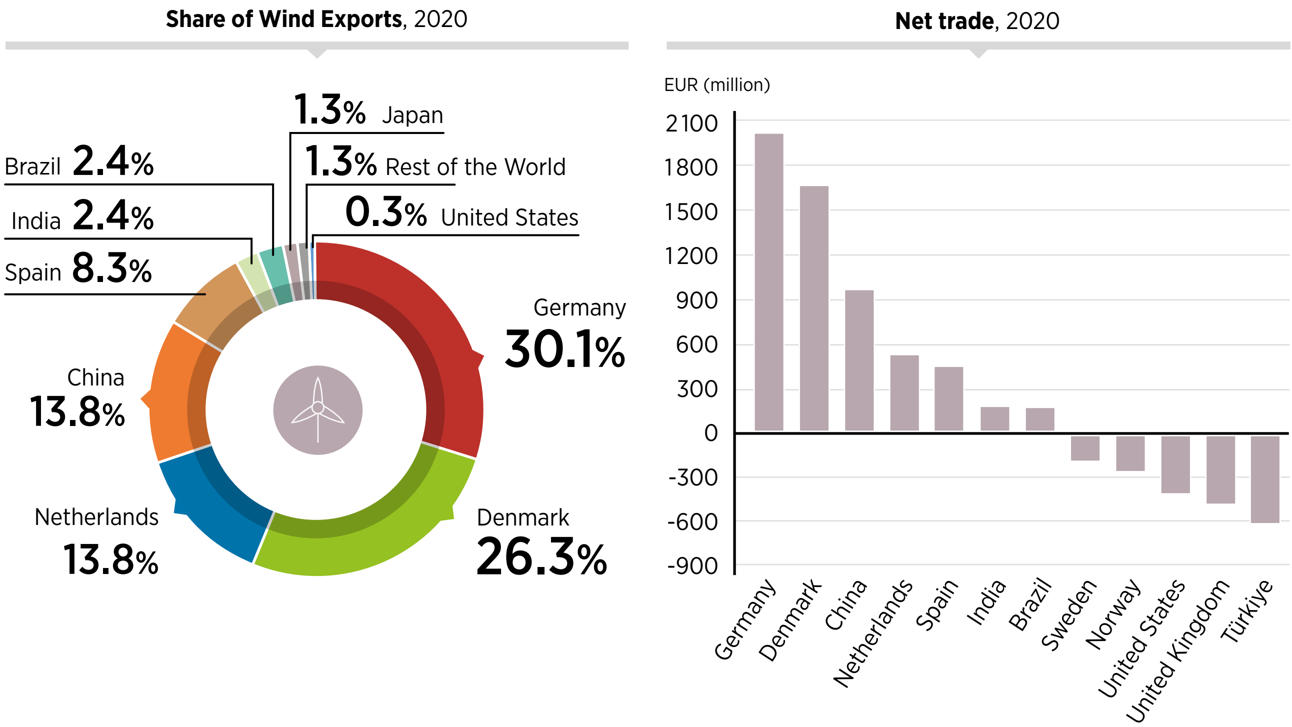


Source: IRENA jobs database.

Based on industry experience, the Global Wind Energy Council (GWEC, 2022) assessed wind deployment pathways under a "green recovery scenario", underlining the job potential in five developing countries. The study estimated that wind power installations between 2022 and 2026 and O&M during project lifetime would create some 230 000 direct and indirect full-time equivalent job years in India, 115 000 in Brazil, 59 000 in the Philippines, 37 000 in South Africa and 29 000 in Mexico.

Wind farms increasingly create construction and installation jobs around the world. The locations of equipment manufacturing jobs are more limited. Denmark and Germany are two leading wind equipment producers and exporters. Together with the Netherlands and Spain, they accounted for more than three-quarters of global exports in 2020 (EurObserv'ER, 2022). Chinese firms still focus primarily on their home market, but the country's share of global exports rose from 7.5% in 2017 to 13.8% in 2020. By contrast, some leading installers such as the United States and the United Kingdom import many turbine components, limiting the extent of domestic manufacturing jobs (Figure 7).

Figure 7 Exports and net trade in the wind sector, 2020: Selected countries



Source: EurObserv'ER, 2022.

Offshore wind farms require more labour than onshore installations, because construction and installation activities are more complex and wind farms require complex foundations, substations, undersea cables and installation vessels that are not needed onshore. Europe is the leader in offshore installations and technology development, but other countries, such as China, are rapidly developing their own capabilities and undertaking improvements in port infrastructure.

1.3 HYDROPOWER

2.4
million jobs

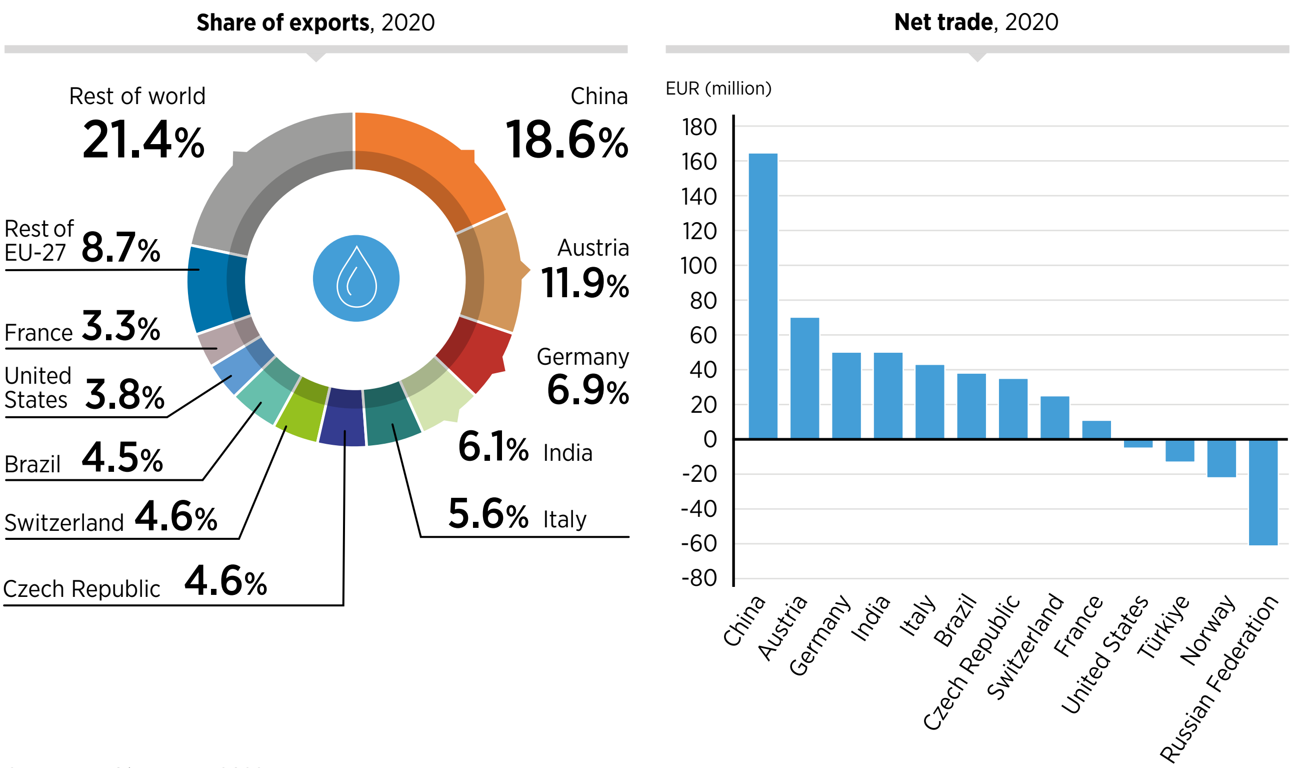
Global hydropower capacity expanded by 25 GW in 2021, with China alone adding almost 21 GW. Canada, India and Viet Nam added about 1 GW each, and European countries added about 1.5 GW.

Nameplate capacity and operational capacity can differ significantly. A number of countries ended 2021 with somewhat less operational capacity than in 2020 (IRENA, 2022a). In the United States, a severe drought in the Pacific Northwest and California resulted in decreased water supplies and diminished hydropower output (US EIA, 2022b).

In addition to serving their domestic markets, companies from a number of countries play prominent roles in selling hydropower equipment in export (Figure 8).

IRENA estimates the number of jobs in the hydropower sector based on an employment-factor approach paired with national-level data for some countries. Taking into account data revisions from the previous edition of the Annual review, this report estimates that approximately 2.36 million people worked directly in the sector in 2021. Globally, two-thirds of these jobs were in manufacturing, 30% were related to construction and installation activities and about 6% were in O&M services.

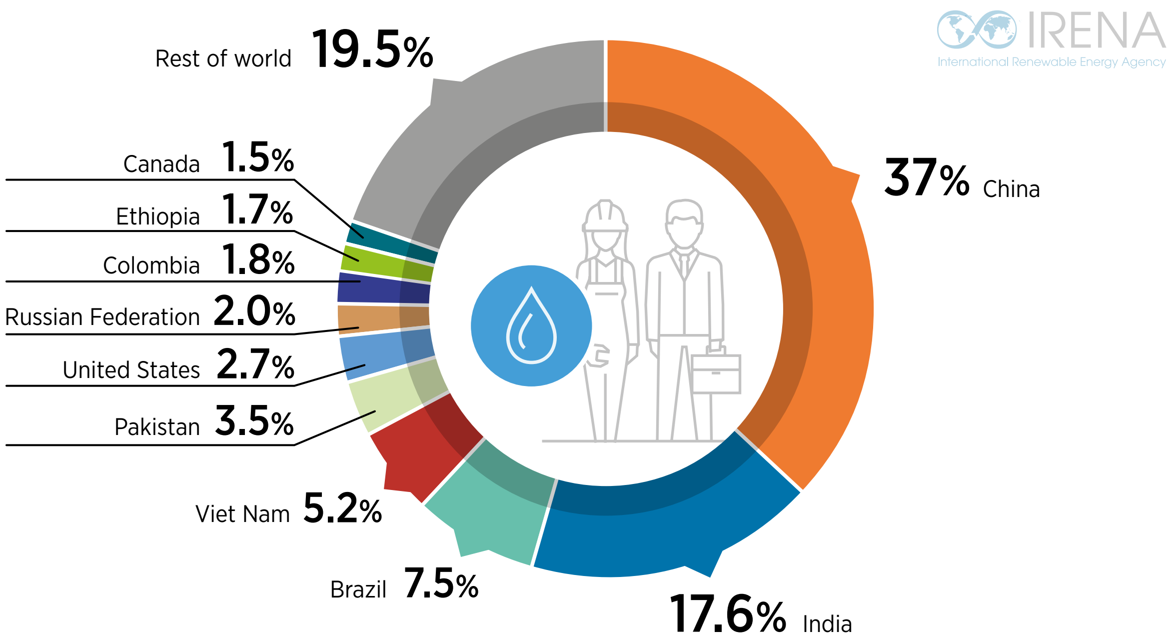
Figure 8 Exports and net trade in the hydropower sector, 2020: Selected countries



Source: EurObserv'ER, 2022.

Once again, China was the largest contributor to hydropower jobs, accounting for 37% of global employment, even though the pandemic caused delays in completing some projects. India accounted for about 18% of global hydropower employment, followed by Brazil, Viet Nam, Pakistan, the United States, the Russian Federation and Colombia. In 2021, Ethiopia climbed to ninth place among hydropower employers, reflecting the construction of large new structures, such as the Grand Ethiopian Renaissance Dam, the largest hydropower project in Africa (Ingram, 2022). Canada rounded out the top ten (see Figure 9).

Figure 9 Hydropower employment (direct jobs), by country, 2021



Source: IRENA jobs database.

1.4 LIQUID BIOFUELS

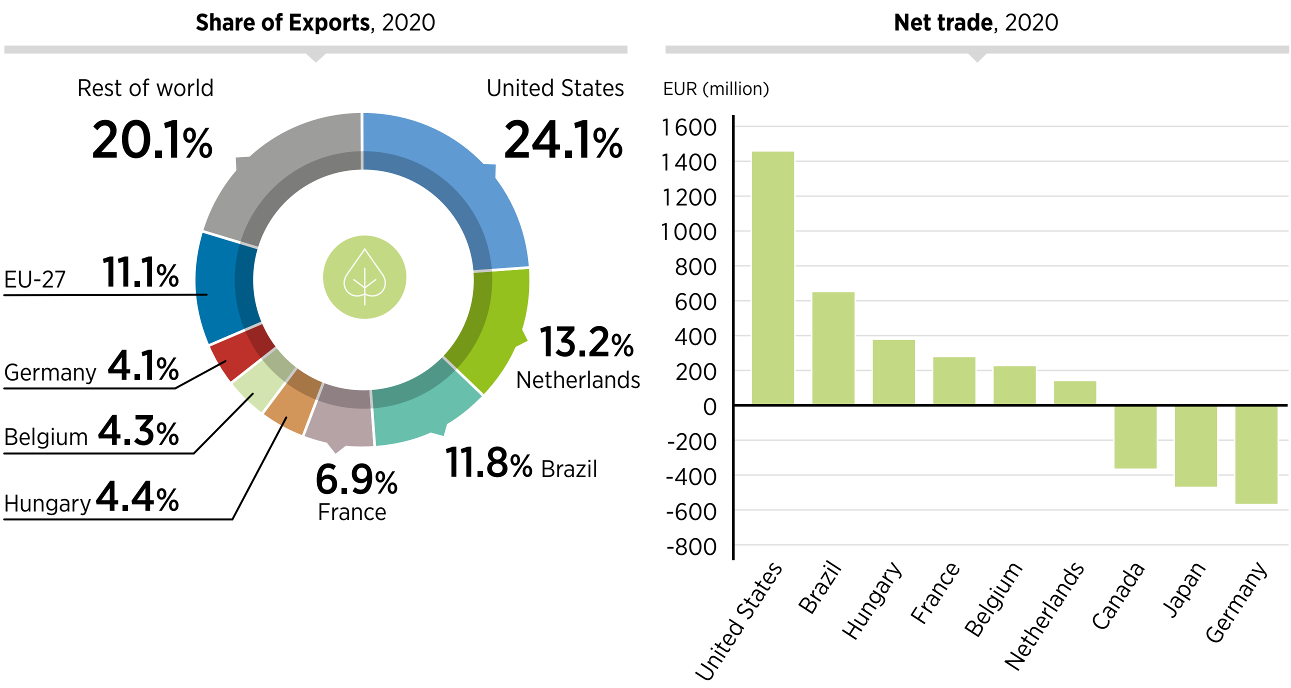
2.4
million jobs

The production of biofuels recovered from the impacts of the COVID-19 crisis, which sharply curtailed energy use for transportation. Production in 2021 rose to levels close to those of 2019. Biodiesel output nearly doubled in the last decade, to 45 billion litres, reaching 37% of total biofuel production; ethanol output reached 105 billion litres and hydrotreated vegetable oil accounted for 9.5 billion litres (REN21, 2022).

According to data published by the US Department of Agriculture's Foreign Agricultural Service (USDA-FAS), most leading biofuel producers hit production records for biodiesel in 2021 (with the notable exceptions of the United States and Canada). For ethanol, however, most countries' output remains substantially below the peaks recorded before the pandemic.

The United States and Brazil were the dominant ethanol producers. For biodiesel, Indonesia was in the lead, followed by Brazil and the United States (REN21, 2022). These countries were also among the largest exporters and net exporters. Germany, Japan and Canada were the leading net importers (Figure 10).

Figure 10 Exports and net trade in the biofuels sector, 2020: Selected countries



Source: EurObserv'ER, 2022.

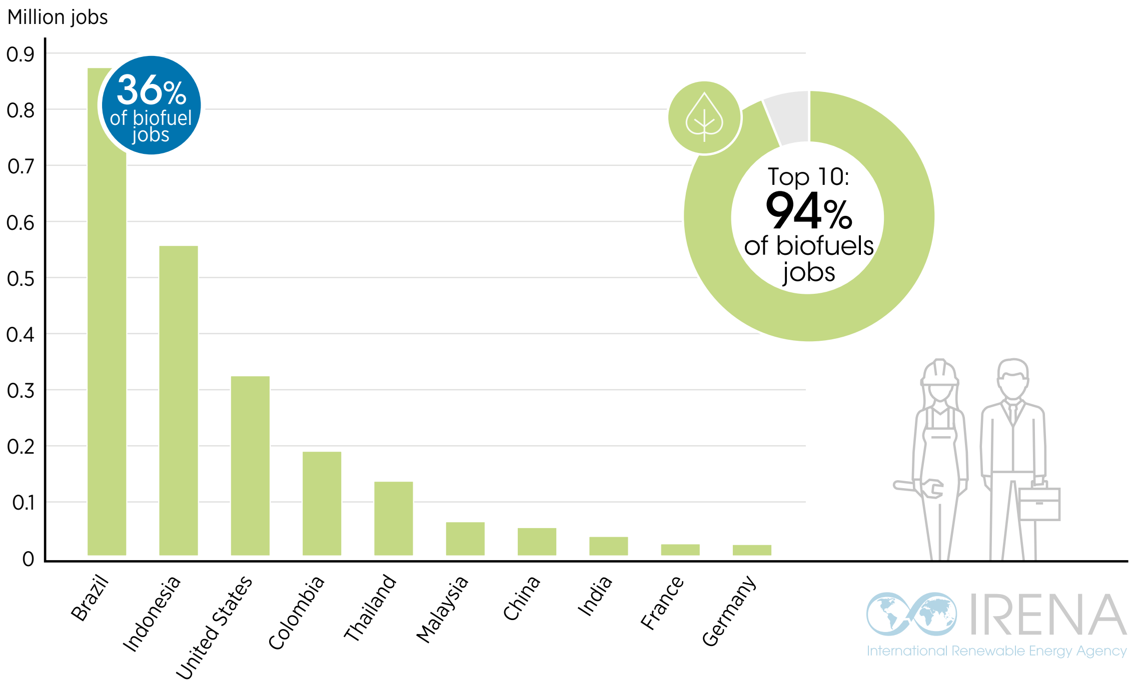
IRENA estimates worldwide biofuel employment in 2021 at 2.4 million. The vast majority of jobs are in planting and harvesting feedstock; fuel processing employs relatively few people, but typically pays higher wages.

Latin America accounts for 44% of all biofuel jobs worldwide and **Asia** (principally Southeast Asia) for 36%. The more mechanised agricultural sectors of **North America** and **Europe** translate into smaller employment shares (14.0% and 6.4%, respectively). The top ten countries together account for about 93.5% of global estimated employment (Figure 11).

Highly mechanised operations in the United States required a direct and indirect labour force of about 322 600 people in 2020. In the 27 member states of the European Union, biofuel employment was estimated at about 141 600 jobs in 2020, the most recent year for which data are available (EurObserv'ER, 2022).

Other producing countries have more labour-intensive feedstock operations. With about 863 000 jobs, Brazil remains the world's biggest liquid biofuel employer, although the balance between ethanol and biodiesel production continues to shift in favour of the latter. Other countries with large numbers of workers in the sector, often employed informally and seasonally, include Indonesia (555 900), Colombia (187 500), Thailand (133 900), Malaysia (61 400) and the Philippines (34 300).

Figure 11 Liquid biofuels employment in 2021: Top ten countries



Source: IRENA jobs database.

1.5 OFF-GRID RENEWABLES

COVID-19 substantially slowed activities in the off-grid sector in 2020 and 2021, with less than 500 megawatts (MW) added each year. The largest share of new additions in 2021 (318 MW) was in off-grid solar PV. Just 114 MW of off-grid hydro was added in 2021 (IRENA, 2022a).

According to GOGLA, an industry association, sales for off-grid solar lighting products in the second half of 2021 recovered to almost 4 million but remained 10% below pre-COVID sales in the second half of 2019. Sales under pay-as-you-go schemes (in which poor households pay in instalments rather than upfront in cash) increased. The sector still struggles with supply chain disruptions, rising prices and a slow recovery from income losses. Recovery has been marked by wide disparities across countries and regions, as well as across product categories (lanterns, multi-light systems and solar home systems) and business models. West Africa recorded a 23% increase in sales and South Asia a 19% gain over the first half of 2021. In contrast, sales in East Africa rose by a meagre 4%. Within regions, individual country experiences diverged widely (GOGLA, 2022).

GOGLA reports that in 2021, some 2.6 million small and micro enterprises relied on off-grid solar products, and 4.9 million people were able to raise their level of economic activity thanks to ownership of an off-grid lighting product. Since 2010, off-grid solar products have enabled an estimated USD 7 billion in additional income generation.

Decentralised renewable energy (DRE) used by households and commercial and industrial enterprises for both electricity and clean cooking applications is a growing contributor to employment creation. New studies are shedding light on the positive impacts and challenges (Box 2). Direct and indirect employment impacts are seen alongside induced benefits from the adoption of DRE solutions, particularly for productive end uses. In Ethiopia, for instance, across three value chains (horticulture, wheat and milk), the adoption of DRE solutions could create over 190 000 jobs (Job Creation Commission Ethiopia, 2021).

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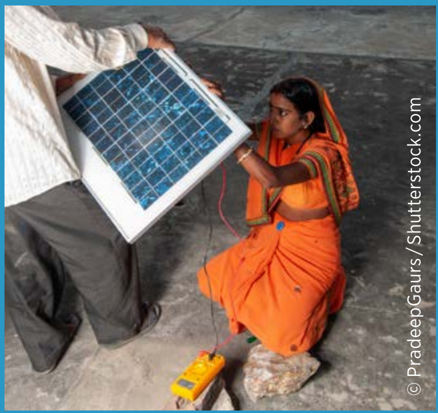
Box 2
Employment in Decentralised Renewable Energy

The number of people directly employed in decentralised renewable energy (DRE) in 2021 reached more than 80 000 in India (mostly in solar PV), 50 000 each in **Kenya** and **Nigeria**, almost 30 000 in **Uganda** and almost 14 000 in **Ethiopia**, according to the *Powering jobs census 2022* (Power for All, 2022). In Kenya, DRE jobs outnumber those of the utility-scale power sector by a ratio of more than three to one. In Nigeria, the number of DRE jobs is closing in on the 65 000 jobs in the oil and gas sector.

As in the energy sector as a whole, the share of women in the DRE workforce is still low, particularly for skilled jobs. Overall, the share of women in DRE was 41% in Kenya, 37% in Ethiopia and Nigeria, 28% in Uganda and 21% in India. Women in the sector tend to work in administrative and support functions; they are under-represented in management and technical positions, reflecting barriers such as cultural and social norms as well as limited access to education compared with men.



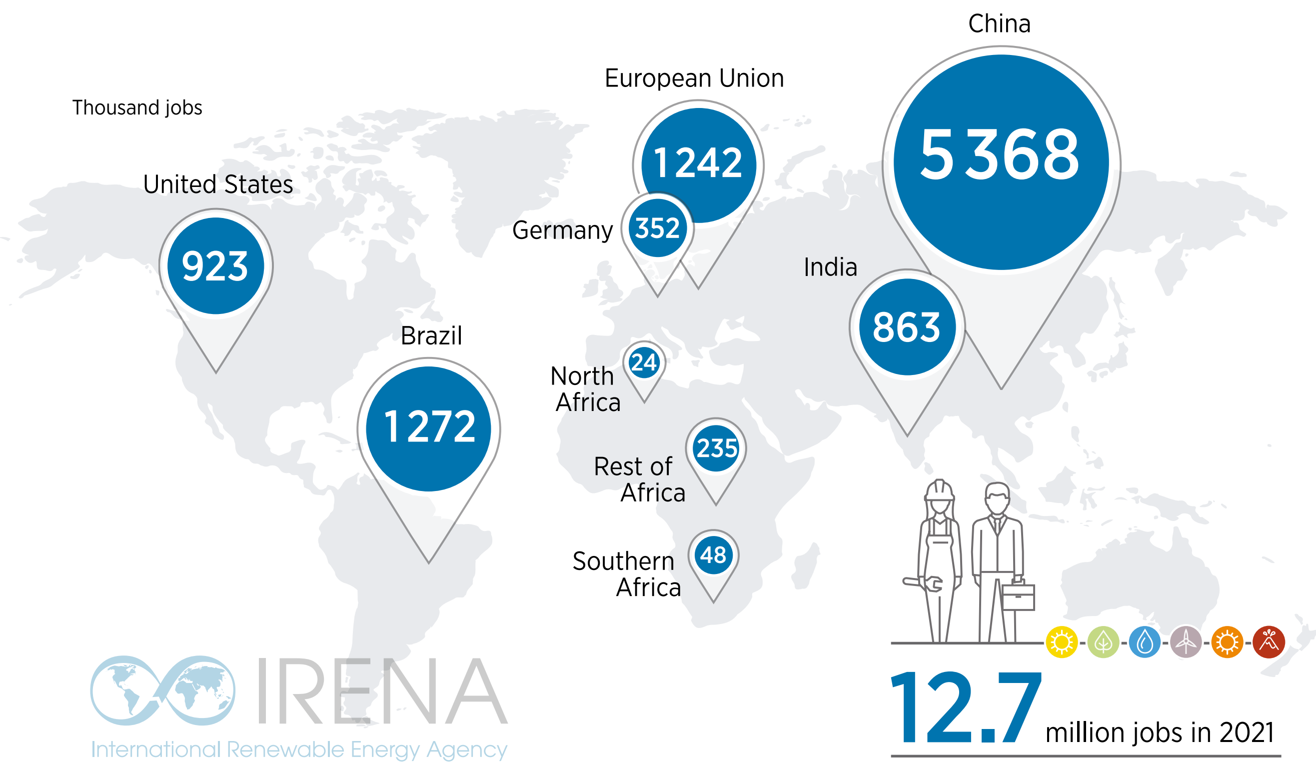
With the exception of Kenya, the majority of DRE sector jobs in these countries are in the formal sector. Considering the very large degree of informality (and associated lack of labour protections) in the overall labour markets in these countries, this finding is encouraging, especially as the shares of informal labour in DRE have declined over the years. However, these findings may have been skewed by the fact that informal workers in developing countries were most adversely affected by COVID-19 policies, implying that this group of workers could now be less represented in employment statistics. In addition, several DRE companies shifted some employees to independent contractor status to gain flexibility.

Chapter 2

RENEWABLE ENERGY EMPLOYMENT **IN SELECTED COUNTRIES**

This chapter presents employment statistics for several leading countries as well as a few other selected countries. The chapter also explores employment in different states or provinces of these countries. As in previous editions, the focus is on China, Brazil, India, the United States and members of the European Union (Figure 12 and Table 1), the countries that lead in equipment manufacturing, project engineering and installations. Overall, the bulk of renewable energy employment is in Asian countries, which accounted for 63.6% of these jobs in 2021.

Figure 12 Renewable energy employment in selected countries



Source: IRENA jobs database.

Disclaimer: This map is provided for illustration purposes only. Any boundaries and names shown do not imply any endorsement or acceptance by IRENA.

Table 1 Estimated number of direct and indirect jobs in renewable energy worldwide, by industry, 2020–2021 (thousand jobs)

	World	China	Brazil	India	United States	European Union (EU27)[o]
Solar PV	4 291[e]	2 682	115.2	217[h]	255[i]	235
Liquid biofuels	2 421	51	874.2[g]	35	322.6[j]	142
Hydropower[a]	2 370	872.3	176.9	414	72.4[k]	89
Wind power	1 371	654	63.8	35	120,2	298
Solar heating and cooling	769	636	42	19		19
Solid biomass[b, c]	716	190		58	46.3[l]	314
Biogas	307	145		85		64
Geothermal energy[b, d]	196	78.9			8[m]	60[d]
CSP	79	59.2				5.2
Total	**12 677[f]**	**5 368**	**1 272**	**863**	**923[n]**	**1 242[f]**

Note: The figures presented here 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. Columns may not add up to totals due to rounding.

a. Direct jobs only.

b. Power and heat applications.

c. Traditional biomass not included.

d. Includes 7 400 jobs for ground-based heat pumps in EU countries.

e. Includes an estimate of 342 000 jobs in off-grid solar PV in South Asia and in East, West and Central Africa.

f. Includes 39 000 jobs in waste-to-energy.

g. Includes about 168 400 jobs in sugarcane cultivation and 167 800 in alcohol/ethanol processing in 2020, the most recent year for which data are available. Figure also includes a rough estimate of 200 000 indirect jobs in equipment manufacturing and 326 900 jobs in biodiesel in 2021.

h. Includes 137 000 jobs in grid-connected and 80 400 in off-grid solar PV. Also see note e.

i. Includes jobs in all solar technologies, principally PV but also solar heating and cooling and concentrated solar power.

j. Includes 258 700 jobs for ethanol and about 63 900 jobs for biodiesel in 2021.

k. US DOE (2022d) estimate, including 53 029 jobs in traditional hydro and 11 485 jobs in low-impact hydro. An estimated 7 901 jobs in pumped hydro (energy storage) are not included in the US total.

l. Includes woody biomass fuels (33 898 jobs) and biomass power (12 388 jobs).

m. Figure is for direct geothermal power employment.

n. Includes 98 932 jobs in technologies not separately broken out in the table, such as solar heating and cooling, geothermal heat, heat pumps and others. Solar heating and cooling are also included (but not reported separately) in the Solar Foundation's estimate for all solar technologies, so there is a small amount of double counting.

o. Solar PV and wind jobs are for 2021; hydropower figures for 2020 and 2021; other technologies are for 2020.

Source: IRENA jobs database.

2.1 LEADING COUNTRIES

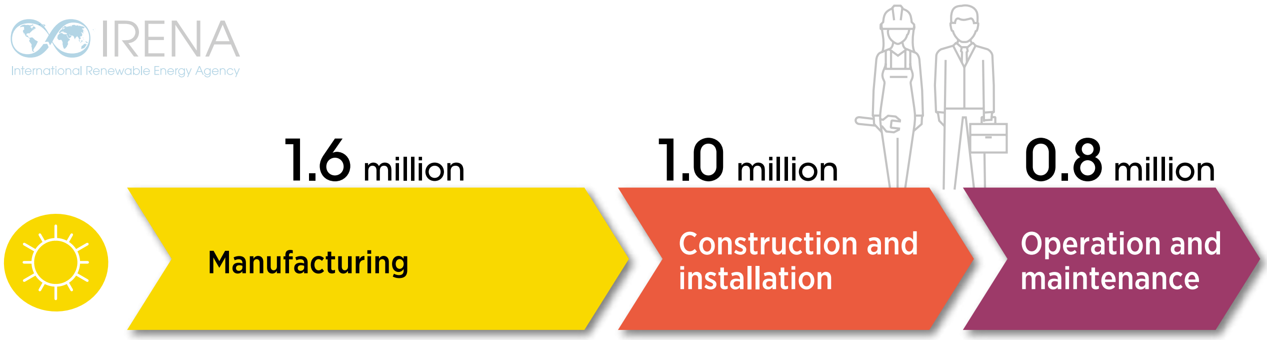
China

5.37 million jobs

The bulk of **CHINA's** renewable energy capacity additions in 2021 were in the solar PV and wind industries. China added 53 GW of solar PV capacity in 2021 (the largest annual addition ever, equivalent to 40% of the amount added worldwide); more than half of the addition was in distributed generation. China also added 49 GW of wind (the second largest amount after 2020, half of the global total) (IRENA, 2022a). Neither the wind nor the solar PV industry suffered any major impacts from the COVID-19 pandemic during 2021, although other renewable energy industries experienced some delays.

China employed 5.4 million people in renewable energy jobs in 2021, up from 4.7 million in 2020, according to calculations by the China Renewable Energy Society supplemented by IRENA estimates. **Solar PV** claims the largest share, with a workforce estimated at almost 2.7 million, up from 2.3 million in 2020 (CRES, 2022). Manufacturing activities accounted for 1.6 million of the PV jobs; construction and installation accounted for almost 1 million, with O&M accounting for the remainder (Figure 13).

Figure 13 Jobs in China's solar PV value chain, 2021



Source: CRES, 2022.

China's dominant role in solar PV employment reflects its strong position as both the dominant manufacturer of equipment and its commanding position in capacity installations. Supported by industrial policy measures, China is home to the bulk of the global PV supply chain. Some 72% of global polysilicon production takes place in China, with massive expansion of capacity under construction or planned (US DOE, 2022b). China commands virtually all (96-98%) of the world's ingot and wafer production, as well as 79% of cell manufacturing and 78% of module production (Wood Mackenzie, 2022a). It is also the leading producer of components such as glass, steel, aluminium frames, encapsulant film, back sheets and inverters (US DOE, 2022b).

The bulk of China's PV supply chain capacity is located in a small number of provinces, with Jiangsu, Zhejiang, Yunnan, Inner Mongolia, Ningxia and Xinjiang the most prominent. Western provinces (with low labour, electricity and land costs) lead in polysilicon and ingot production; eastern provinces (which are closer to key domestic markets and export infrastructure) are more involved in later segments of the value chain (*i.e.* manufacturing of wafers, cells and modules. Some provinces, like Jiangsu, have an integrated presence across various segments (US DOE, 2022b).

China's success largely reflects infrastructure and industrial policies that built an integrated supply chain with large economies of scale. Low labour costs are also key. They represent 8% of the country's total solar PV manufacturing costs, compared with 22% in the United States (US DOE, 2022b).

China added almost 30 GW of onshore **wind** capacity in 2021. It stepped up the pace of offshore installations with more than 17 GW added – more than four times the increase of the previous year. It now has by far the largest cumulative installed offshore capacity in the world (IRENA, 2022a). The country's offshore wind boom is drawing in growing numbers of Chinese and foreign companies, including firms with offshore oil and gas expertise and marine engineering enterprises (Li, 2021).

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China employed an estimated 654 000 people in the wind industry in 2021, up 19% from 550 000 in 2020. Manufacturing accounted for 305 000 of these jobs, construction and installation for 263 000 and O&M for 86 000 (CRES, 2022). The planned decline in subsidies for offshore installations led to a surge in installations during 2021 and thus higher labour requirements.[5] The rise in employment also reflects the fact that offshore installations require more labour input than onshore facilities. Local supply chains for the offshore sector are flourishing, with 24 dedicated industrial parks along China's coastline (Li, 2021).

China accounted for more than 80% of global **hydropower** capacity additions in 2021. IRENA estimates the number of direct hydropower jobs in China at 872 300. **Solar heating and cooling** are thought to employ almost as many people as the wind power industry. The 636 000 jobs in 2021 represent a decline from the 670 000 jobs estimated in 2020, but the number is expected to slowly increase again with economic recovery from COVID-19 (CRES, 2022).

Bioenergy technologies accounted for 386 000 jobs (virtually unchanged from the previous year). **Geothermal heat and power** (79 000) and **concentrated solar power (CSP)** (59 000) saw a notable increase, partly as a result of revised estimates (CRES, 2022). China is the only country that expanded its CSP installations in 2021, amid a generally stagnant global industry landscape (IRENA, 2022a).

China is the world's fourth-largest producer of fuel **ethanol**, after the United States, Brazil and the European Union. Production of 3.4 billion litres in 2021 was 21% below the peak 2019 value, however. Although it reached a record of 1.7 billion litres, biodiesel production was far smaller than output in the leading countries (USDA-FAS, 2021g). China's biofuels sector is estimated to have employed 51 000 people in 2021 (CRES, 2022).

[5] Subsidies were awarded only to offshore wind projects that were approved before 2020 and reached full commission before 31 December 2021 (Li, 2021).

BRAZIL had an estimated 1.27 million renewable energy jobs in 2021, almost as many as in 2020. At 863 100 jobs, **biofuels** remained the single-largest component of the country's renewable energy workforce, but the weights of ethanol and biodiesel keep shifting. Biodiesel production in Brazil continues to expand, reaching an estimated 6.76 billion litres in 2021 (ABIOVE, 2022a). Very little is exported, because of lack of international cost-competitiveness; imports are close to zero, because only domestic biodiesel is eligible for auctions (USDA-FAS, 2021a). Employment climbed to 326 900 jobs in 2021, according to IRENA estimates.[6]

Brazil

1.27

million jobs

Brazil's ethanol output dropped by 23% from its 2019 peak. Most ethanol is made from sugarcane, but corn ethanol production is expanding and now accounts for 11% of Brazil's total ethanol production (an estimated 3.39 billion litres in 2021, eight times as much as in 2017) (USDA-FAS, 2021a). The most recent employment estimate for bioethanol is for 2020, with 536 200 jobs or 11 000 less than in 2019 (MTE/RAIS, 2022).[7]

Record additions of 3.96 GW in 2021 brought Brazil's cumulative **wind power**–generating capacity to 21.2 GW (IRENA, 2022a). IRENA estimates the country's wind workforce at about 63 800 people, primarily in construction, followed by O&M.[8] About 80% of the installed capacity – and thus a considerable part of employment – is in the country's northeast (in the states of Rio Grande do Norte, Bahia, Piauí and Ceará), and another 10% in Rio Grande do Sul in the south (ABEEÓLICA, 2021). The northeast (Bahia and Ceará, together with Pernambuco) also hosts wind equipment manufacturing plants.

The rapid growth of Brazil's **solar PV** installations continued in 2021, with additions of 5.5 GW. Two-thirds of the country's cumulative capacity of 14 GW were in distributed solar PV (defined as systems under 5 MW). Three states in the south and southeast (Minas Gerais, São Paulo and Rio Grande do Sul) plus central-western Mato Grosso account for half of cumulative distributed PV capacity and therefore for many installation jobs. Minas Gerais is the clear leader in large-scale installations, followed by Bahia, in the northeast (ABSOLAR, 2022).

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[6] *The calculation is based on employment factors for different feedstocks (Da Cunha, Guilhoto and Da Silva Walter, 2014). The 2021 shares of feedstock raw materials, principally soybean oil and animal fat (beef tallow), are derived from ABIOVE (2022b).*

[7] *In 2020, about 168 400 workers were engaged in sugarcane cultivation in Brazil (a decline of almost 8 000 from 2019), and 167 800 worked in alcohol and ethanol processing (a slight increase over 2019). IRENA's employment estimate of 536 200 jobs includes 200 000 indirect jobs in equipment manufacturing, although this figure reflects a dated supply chain estimate.*

[8] *This calculation is based on employment factors published by Simas and Pacca (2014).*

IRENA estimates Brazil's solar PV employment at about 115 000 jobs in 2021, up from about 72 600 jobs in 2020.[9] Some 102 500 jobs are in the labour-intensive distributed segment, spread across small installers. Most modules and panels are imported from China; Brazil's manufacturing of components is very limited. A survey of solar firms finds that in 2021, 55% of women employed in the subsector worked in administrative and finance positions, 26% in commercial functions, 7% in project development, 5% in marketing, just under 5% in management and 2% in installations (Greener, 2022).

Brazil added 1.8 million square metres of **solar water heating** capacity in 2021, up 28% over 2020 (ABRASOL, 2022). Employment is estimated at 42 000 jobs, according to an industry survey by ABRASOL that includes manufacturing and installation activities (Johann, 2022).

India

0.73
million jobs

INDIA added 10.3 GW of **solar PV** capacity in 2021, up from 4.2 GW installed in 2020 (IRENA, 2022a). The government imposed import duties of 40% on all modules and 25% on all cells effective April 2022, replacing 15% safeguard duties that had been levied on PV imports from China and Malaysia (US DOE, 2022b). It also introduced a production-linked incentive (PLI) scheme to boost domestic manufacturing of high-efficiency modules.[10] This offers financial support for project developers who commit to setting up production facilities along the value chain (Tyagi *et al.*, 2022). The government hopes that the PLI will lead to the creation of 30 000 direct and 120 000 indirect jobs (Gulia et al., 2022).

Only a small share of India's current solar PV manufacturing capacity is operational, given lower-cost imports from China. In 2021, India used 57% of its cell production capacity (producing 4.1 GW of output from its 7.2 GW of capacity) and just 38% of its module capacity (producing 4.5 GW of output from its capacity of 11.7 GW) (Wood Mackenzie, 2022a).

In 2021, rising costs in China had knock-on effects for Indian module prices. Indian PV imports sank to a low of just USD 500 million, down from almost USD 4 billion in 2018. Dependence on imports for modules could potentially be reduced from 80% to 60-65% within a two- to three-year period (Gulia *et al.*, 2022).

Corporate expansion plans indicate that 29 GW of cell capacity and 33 GW of module capacity could be added by 2025. Creating a vertically integrated domestic value chain, including polysilicon and wafer manufacturing (which India currently does not have), could be key to increasing competitiveness and easing concerns about international price fluctuations, commodity shortages and supply chain disruptions.

[9] Because of different methodologies, this estimate is more conservative than the one issued by ABSOLAR, which put 2021 jobs at 153 000, up 78% over the 2020 figure of 86 000 (Hein, 2022).

[10] A range of other supportive policies were adopted earlier and updated in recent years. They include the Central Public Sector Undertaking scheme, which sets a target of 12 GW by 2022/23, using domestic cells and modules; the PM-KUSUM scheme, which seeks to create total solar capacity of 30.8 GW by 2022, by imposing mandatory domestic content requirements; the Grid-Connected Rooftop Solar Programme, which provides financial incentives for residential, institutional and social segments; and a mandatory Approved List of Models and Manufacturers, intended to enhance domestic manufacturing and establish a product quality benchmark (Gulia et al., 2022).

Based on employment factors, IRENA estimates that India had 137 000 jobs in grid-connected solar PV in 2021, up 47% from 2020. Roughly 80 000 people work in off-grid solar, which recovered from the COVID-19 impacts of the previous years.

In the **wind** industry, India's annual installations continue at a slow pace, although the 1.5 GW added in 2021 represented a slight improvement over 2020 (IRENA, 2022a). IRENA estimates that employment in India's wind sector stood at 35 400 in 2021, with O&M accounting for almost half of these jobs.

According to Tyagi *et al.* (2022), the combined wind and solar workforce stood at 111 400 people in 2021, including 43 000 jobs in rooftop solar, 42 900 in utility-scale solar and 25 500 in wind. This estimate, which is lower than IRENA's, excludes indirect jobs, off-grid solar applications and equipment manufacturing. Tyagi *et al.* (2022) find that 49 900 jobs were in construction and commissioning, 41 100 in O&M and 20 400 in business development and design. Lingering COVID-19 disruptions meant that the number of new renewable energy jobs created fell from 12 400 in fiscal year (FY) 2019 to 5 200 in FY2020 and 6 400 in FY2021.

Tyagi *et al.* (2022) also find that more than 100 000 people were trained between 2015 and 2021, of which 78 000 were certified under the national solar energy Suryamitra training programme. India's Skills Council for Green Jobs plays an important role in this context through the development of Green National Occupation Standards. The success of Suryamitra led to additional similar programmes, including Vayumitra (for wind installers) and Varunmitra (for solar pump installers) (Tyagi *et al.*, 2022).

Reaching India's goal of 500 GW of non-fossil-fuel energy sources by 2030 could create 3.4 million new job opportunities (of short or long duration), or about 1 million direct full-time equivalents. Most would be in the localised deployment of DRE. This goal can be achieved with continuous deployment, sufficient skills development, upgrading and retraining, and enhancement of domestic manufacturing of various components (Tyagi *et al.*, 2022).

United States

0.92
million jobs

The **UNITED STATES** is showing growing interest in pursuing an industrial policy in support of the energy transition. A supply chain strategy for the energy sector's industrial base requested by President Biden in February 2021 laid out challenges and opportunities related to the availability of raw materials; the expansion of domestic manufacturing capabilities; the creation of more diverse, secure and socially responsible foreign supply chains; improvement of end-of-life waste management and the building of a skilled workforce, among other issues (US DOE, 2022a). The USD 1.2 trillion Bipartisan Infrastructure Law passed in November 2021 will provide USD 151 billon in wind, solar and storage tax credits; USD 39 billion in grid enhancement funds and tax credits; USD 18.5 billion for hydrogen hubs, demonstration and tax credits; and USD 15 billion in biofuels incentives (BNEF and BCSE, 2022).

The United States had roughly 923 400 renewable energy jobs in 2021, including more than 369 000 jobs in biofuels, biomass power and woody biomass fuels; about 255 000 in solar PV; almost 99 000 in various renewable heating and cooling technologies;[11] about 72 400 in hydropower[12] and about 8 200 in geothermal power. In addition, there were about 115 200 jobs in various energy transition–related technologies.[13] US DOE (2022d) estimates that energy efficiency employed about 2.2 million people in 2021.[14]

In 2021, a record 23.6 GW of **solar PV** capacity was installed in the United States, a 19% increase over 2020. Residential solar installations reached a new peak of 4.2 GW. Project delays caused by interconnection challenges and supply chain constraints limited new commercial installations to 1.4 GW and community solar additions to 957 MW, however. Although utility-scale solar set a record (17 GW), additions were lower than expected, as a result of problems with logistics, supply chain constraints and trade disputes (Wood Mackenzie and SEIA, 2022).

Although the composition of the leading PV module manufacturers keeps changing and individual company market shares rise and fall, there is nevertheless consolidation of market power at the top. The largest five producers – foreign and domestic – had a residential market share of almost 69% in 2021, up from 56% in 2013. In the commercial market segment, the share rose from 35% to 56% (Wood Mackenzie, 2022b).

The *National solar jobs census 2021* reports that US solar employment reached about 255 000 in 2021, an increase of 9% (IREC, 2022).[15] Significant gains in labour productivity meant that the steady jobs growth in 2010-2016 gave way to a levelling-off in the years

[11] *This figure includes solar thermal, geothermal, biomass, heat pumps and other technologies (US DOE, 2022d).*

[12] *This figure consists of 11 485 jobs in low-impact hydro, 53 029 in traditional hydro and 7 901 in pumped hydro (US DOE, 2022d).*

[13] *This figure includes jobs in battery storage (69 689), smart grids (24 225), micro grids (19 377), other grid modernisation (18 187) and electrical vehicle charging associated with renewable electricity (2 101) (US DOE, 2022d).*

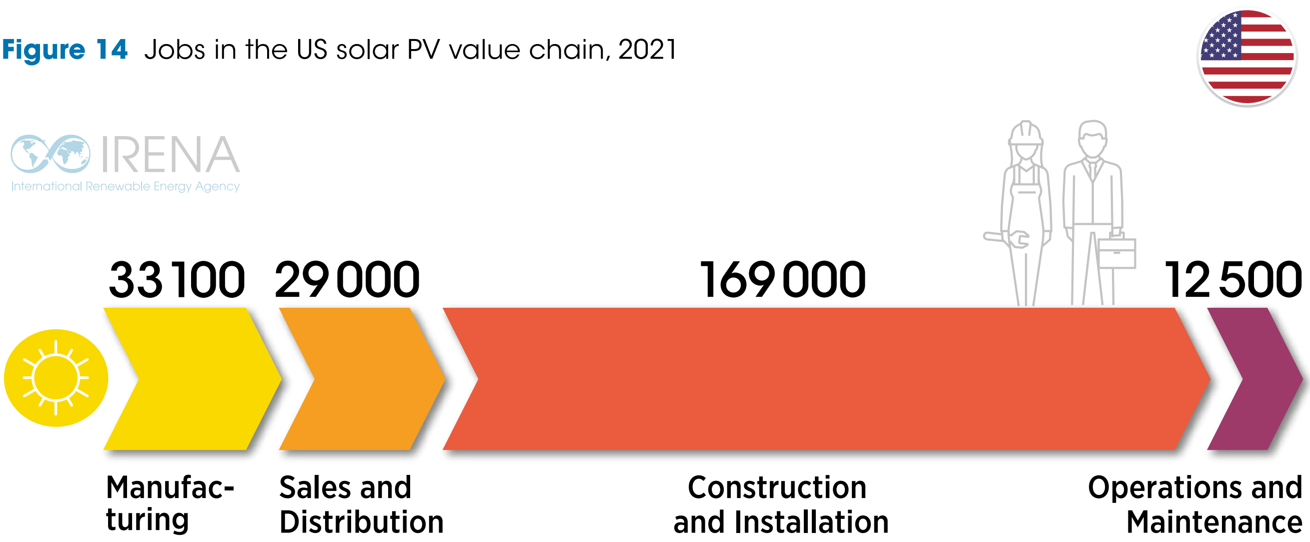
[14] *The energy efficiency category includes appliances; heating, ventilation and air conditioning; water heaters; electronic goods; windows, roofing and insulation; commercial equipment; and lighting.*

[15] *IREC includes only solar workers who spend at least half of their working hours on solar goods and services. In contrast, the US Energy and Employment Report (US DOE, 2022d), which pegs 2021 solar PV employment at 333 887 (up from 316 675 jobs in 2020), includes all employees engaged in solar technologies, regardless of the share of time they spent on solar-related work.*

since. In the first three quarters of 2021, utility-scale solar PV facilities accounted for more than 70% of all US installations; more labour-intensive residential installations represented less than 20% (Feldman *et al.*, 2022).

Two-thirds of all solar jobs in 2021 – almost 169 000 jobs – were in installation and project development. Manufacturing (principally of balance-of-system components, although module production is expanding) accounted for 13%, wholesale trade and distribution 11%, and O&M and "other" activities 5%. Administrative functions accounted for almost 20.0% of all solar jobs, sales for 19.0% and management for 17.5% (IREC, 2022).

Figure 14 Jobs in the US solar PV value chain, 2021



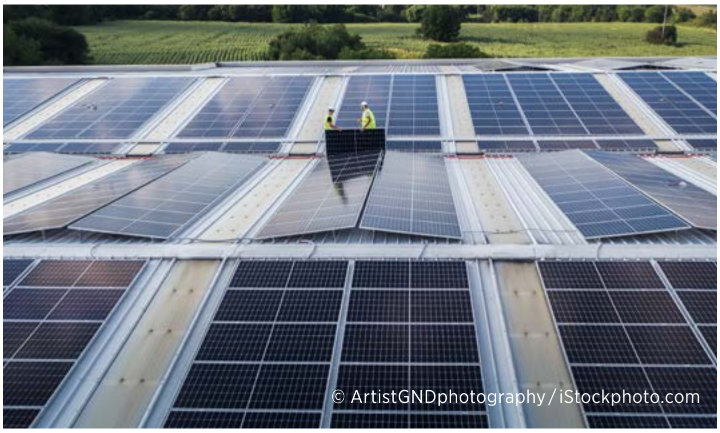
Source: IREC, 2022.

Only about 10% of US solar workers in 2021 belonged to a union. Women accounted for just under 30% of all solar jobs in 2021. Latinos and Latinas held 20% of jobs (above their 18% share in the national workforce), Asians 9% (above their 6.6% national share), and Black employees 8% (below their 12% national share); in management positions, diversity is more limited. When it comes to efforts to heighten workforce diversity, only 26% of solar firms participating in the Interstate Renewable Energy Council's (IREC's) survey had any strategies, policies or programmes in place; 31% reported efforts to hire more women, but just 8% took steps to increase LGBTIQA+[16] hires (IREC, 2022).

The domestic solar PV manufacturing base dwindled over the past decade, before tariffs prompted a minor revival in module production in 2018 and 2019.[17] The tariffs did not spur

[16] *LGBTIQA+ stands for lesbian, gay, bisexual, transgender, intersex, queer/questioning, asexual and many other terms (such as nonbinary and pansexual) (ILO, 2022a).*

[17] *Antidumping and countervailing duties imposed on Chinese PV modules and cells in 2012 and 2014 led Chinese manufacturers to shift manufacturing operations to Southeast Asia. This was followed by a safe-guard tariff in 2018 on most imported cells and modules (with the first 2.5 GW of cells exempt).*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local production of ingots, wafers or crystalline silicon cells, however.[18] The domestically produced share of PV modules available for shipment was 14% in 2021 (US EIA, 2022c). Most US module imports – some 81% of 11.6 GW shipped in the first half of 2021 – come from Chinese-owned factories in Malaysia, Viet Nam and Thailand (Feldman and Margolis, 2021). The bulk of cell imports come from the Republic of Korea, with the remainder from Malaysia, China, Viet Nam and other Asian countries (US DOE, 2022b).

US-based solar manufacturers and installers have long disagreed on the merits and impacts of tariffs. In February 2022, in a bid to help build a domestic solar manufacturing supply chain, the Biden administration renewed tariffs on imported solar panels for four years. The volume of tariff-free imports of solar cells was doubled, from 2.5 GW to 5 GW, however, and bifacial panels will continue to be exempt (Williams, 2022).[19]

The Inflation Reduction Act, passed in August 2022, embraces elements of a broader industrial policy. It includes manufacturing credits for clean energy, in addition to a long-term extension of existing solar and wind tax credits and many other climate and health provisions (Paris *et al.*, 2022). This legislation will likely support the creation of millions of jobs over the next ten years. A clean manufacturing tax credit alone could trigger some 115 000 job-years (direct, indirect and induced jobs), and tax credits for solar, wind and battery manufacturing could create another 561 000 job-years (Pollin, Lala and Chakraborty, 2022).

Some 14 GW of new US **wind** capacity was installed in 2021, nearly as much as the record amount added in 2020 (IRENA, 2022a). The number of wind power jobs in 2021 was estimated at 120 164, up from 116 817 in 2020. About 36%, were in construction, 25% in professional services and about 20% in manufacturing (US DOE, 2022d).

[18] *The United States does have domestic capacity for manufacturing thin-film cadmium telluride (CdTe) modules, which accounted for 16% of US installations through 2020. A new 3.3 GW CdTe module factory will more than double US capacity; it is expected to start operating in 2023 and employ more than 700 people (US DOE, 2022b).*

[19] *In early 2022, the US Department of Commerce considered new tariffs on cells and modules from Cambodia, Malaysia, Thailand and Viet Nam, but the Biden administration ultimately decided to suspend any such action for two years (Swanson, Gelles and Tankersley, 2022). A 2022 survey by the Solar Energy Industries Association (SEIA) indicates that new tariffs could reduce solar installations in 2022 and 2023 by up to 16 GW annually, putting 70 000 jobs at risk.*

The United States imports wind equipment principally from India, Spain, China and Mexico, with smaller shares from Denmark, Brazil, Canada and Germany (US DOE, 2022c). Domestic assembly of nacelles (with components that are both domestic and foreign in origin) accounts for 85% of US demand. Domestic production is able to cover a large share of demand for towers (70%). It covers much smaller shares of blades and hubs (30-50%), generators (36%) and gearboxes (10%) (US DOE, 2022c). By value, about 57% of the components of onshore wind projects are domestically produced (Goldie-Scot, Zindler and Lezcano, 2021).

The closure of three blade manufacturing facilities after 2019 reduced US nameplate capacity by 40%, even as upgrades are needed to be able to produce longer blades for larger and larger turbines. The domestic wind supply chain faces a number of challenges. They include demand volatility, skilled labour shortages, lower labour costs of foreign suppliers and logistical bottlenecks (US DOE, 2022c).

US offshore wind is expected to expand substantially in the coming years. In 2021, the Biden administration announced a target of 30 GW by 2030 (BNEF and BCSE, 2022). The components for US offshore wind will initially come primarily from Europe, as building a domestic supply chain – manufacturing facilities, vessels, port infrastructure and workforce development – will take years. The first US blade factory for offshore use is planned in Virginia, part of an emerging offshore wind hub at the Portsmouth Marine Terminal. Once operational, the factory will employ about 260 people, plus another 50 to provide O&M support for a nearby wind farm (SGRE, 2021b).

A study by the National Renewable Energy Laboratory (Shields *et al.*, 2022) used an input-output model to estimate the component manufacturing workforce required to support the federal 30 GW target. The number of full-time job equivalents would peak in 2028 at 15 500 (if 25% of components are produced domestically) or 62 000 (with a hypothetical 100% domestic share). American Clean Power (ACP, 2021) estimates that the 6 600-11 400 square kilometres of offshore waters that the federal government may lease to developers by 2025 have a potential capacity of 24-41 GW. Projected investments of USD 120 billion could yield 73 000-128 000 construction jobs and 28 000-48 000 jobs in O&M, along the supply chain and in surrounding communities.[20]

State-level policies and requirements (such as local content rules to encourage in-state facilities [Box 3]) are the main drivers of the development of a domestic supply chain, but this competitive approach entails the risk of a fragmented industrial base (US DOE, 2022c; Shields *et al.*, 2022).

US **biofuels** employment is estimated at 322 600 jobs. The bioethanol industry largely recovered from COVID-19 impacts, producing some 57 billion litres in 2021, down from a peak of 61 million litres in 2018. Feedstock and other input costs increased sharply, however, and new investments were limited. An input-output model calculation estimates 2021 employment in US bioethanol at about 258 700 jobs, including 73 200 direct[21] and 185 500 indirect jobs in the agricultural supply chain and ethanol processing. Indirect employment includes 4 500 jobs in R&D and 27 000 export-related positions (exports declined in 2021 because of lingering COVID-19 impacts and trade tariffs in Brazil) (Urbanchuk, 2022). Biodiesel output fell to 6.2 billion litres in 2021, down 11% from 6.9 billion litres in 2020 (US EIA, 2022a). IRENA estimates the number of jobs at about 63 100 in 2021, down 8% from 68 800 in 2020. This employment factor calculation revises IRENA's earlier estimates by factoring in net trade volumes.

20 *Among detailed local content assumptions for offshore wind components, the study posits that 75% of blades and 100% of towers will be manufactured domestically. It will take years to build the domestic supply chain to be able to do so.*

21 *This compares to an estimate of about 55 000 jobs by US DOE, 2022d, due to different methodologies.*

Box 3
State-level efforts to develop local offshore wind supply chains in the United States

Several coastal states in the United States are pursuing industrial and infrastructure policies and workforce development programmes to support offshore wind development.

In **Massachusetts**, Avangrid's 1.2 GW Commonwealth Wind project could create 11 000 jobs during construction and operations. The company is negotiating a Project Labour Agreement with local unions. To support the project, a subsea transmission manufacturing facility is to be built at the site of a former coal plant in Somerset; at Salem harbour, 42 acres are to be redeveloped into an assembly and staging port (Casey, 2021).

In **Rhode Island**, Eversource and Denmark's Ørsted are establishing a regional hub for fabrication and assembly of offshore wind foundation components. A Project Labour Agreement affirms the use of local union labour and offers apprenticeships and career opportunities for women and lower-income, minority and economically disadvantaged people (Ørsted and Eversource, 2021). Vessels supporting construction and maintenance of offshore wind farms will be built at two Rhode Island shipyards, creating about 80 jobs (Lavin, 2022).

New York State will invest up to USD 500 million in ports, manufacturing and supply chain infrastructure for offshore wind. Together with private investment, it is expected to create more than 2 000 jobs (State of New York, 2022).

In **New Jersey**, German manufacturer EEW and Ørsted are constructing a monopile foundation facility at the Paulsboro Marine Terminal (US DOE, 2022c).

Maryland's first offshore wind component factory will produce monopile foundations at Sparrow Point, once the world's largest steel plant, creating 3 500 construction jobs and 500 full-time operations jobs. An agreement between US Wind and the United Steelworkers aims to recruit and train local workers and affirms workers' rights to unionise and engage in collective bargaining (USW, 2021). The company is seeking to build a local supply chain with minority-owned and other small businesses (Toussaint, 2021).

In **Texas**, a Brownsville shipyard that once produced offshore oil and gas rigs has started manufacturing the first US offshore wind installation vessel, a job that will require 800 workers at the peak. The vessel was designed by National Oilwell Varco, one of the growing number of companies that seek to harness their oil and gas engineering and other know-how for renewable energy purposes (Ball, 2021).

EU-27

1.24
million jobs

Countries in **EUROPE** were home to a total of 1.5 million renewable energy jobs, approximately 1.2 million of them in the 27 Member States of the European Union (EU-27). The **bioenergy** sector is the largest renewables employer on the continent. Solid biomass (for heat and electricity) leads, with approximately 360 000 jobs (of which 314 000 are in the EU-27), followed by biofuels with 155 000 jobs (142 000 in the EU-27) and biogas with 67 000 jobs (64 000 jobs in the EU-27).

IRENA estimates European **wind** power employment at 351 500, with 297 600 of those jobs in EU-27. The continent's total wind-generating capacity reached 222 GW in 2021, with about 14.2 GW newly added. The EU-27 added 10.4 GW in 2021, for a total of 187.5 GW (IRENA, 2022a). Europe accounts for roughly 40% of the world's wind manufacturing output (Ferris, 2022). It also remains the most important exporter of wind power equipment, although the production of various components is to some extent shifting to other regions of the world in response to growing local demand and local-content requirements.

In the **solar PV** sector, Europe as a whole added about 23 GW in 2021, more than was installed in previous years (IRENA, 2022a). Members of the EU-27 accounted for 21.4 GW of the total. IRENA estimates solar PV employment in all of Europe at 292 000 jobs in 2021; for the EU-27, the estimate is 235 000.

Based on a different methodology, SolarPower Europe (2021) estimated almost 357 000 solar sector jobs in the EU-27 in 2020.[22] Almost 80% of these jobs were in the deployment segment, about 10% in O&M, 6% in manufacturing and about 4% in decommissioning and recycling. Within the manufacturing segment, inverter production accounted for 46% of jobs, polysilicon for 29% and modules for 23%; the number of jobs in the production of ingots/wafers and cells was negligible.

SolarPower Europe (2021) estimated **Poland's** 2020 solar PV sector employment at more than 90 000 solar jobs in 2020, even though it is not the largest regional market or a large manufacturer. Its installations are made up almost exclusively of labour-intensive residential rooftop systems, far more so than elsewhere in the region. IRENA's estimates for 2021 suggest a lower figure of around 57 600, which still makes Poland home to the largest solar PV workforce on the continent. Other leading countries include **Germany** (51 300 jobs), **Spain** (31 500), the **Netherlands** (20 100), **Ukraine** (17 800), **France** (17 600) and **Italy** (15 000).

Except for inverters, where local manufacturers have a production capacity of 64.9 GW, and other balance-of-system items, such as mounting structures, most solar PV equipment used in Europe is imported from Asia. EU-27 module capacity stands at 8.3 GW; cell production capacity is just 0.8 GW,[23] although Italy and Germany plan to expand capacity. Just one European company produces polysilicon (with 20.7 GW nameplate capacity in Germany) and there is very limited silicon ingot and wafer manufacturing. Most of the continent's small 1.7 GW wafer capacity is in Norway (SolarPower Europe, 2022).

[22] *In its estimate of indirect jobs, SolarPower Europe includes all employment in upstream industries that are involved at some point in the creation or deployment of solar PV. The definition used by EurObserv'ER (2022) – the primary source for IRENA's estimates in the previous edition of the Annual review – is more limited but includes some secondary activities (such as transport or warehousing).*

[23] *Wood Mackenzie (2022a) data indicate a somewhat higher figure of 1.5 GW capacity and 1 GW of actual cell production.*

In support of several consortia of companies planning new manufacturing facilities based on innovative technologies, SolarPower Europe launched the Solar Manufacturing Accelerator to help deploy up to 20 GW worth of manufacturing capacity in Europe by 2025 (SolarPower Europe, 2022). In its medium scenario for 2025, SolarPower Europe expects solar PV manufacturing employment to more than double, to 50 000 jobs; under its high scenario, the number of jobs more than triples, to 74 000. The latter figure would constitute 9% of total 2025 solar employment, which could rise to as many as 768 000 workers (SolarPower Europe, 2021).

EU-27 **ethanol** fuel production initially declined after a peak of 5 billion litres in 2018. In 2021, it climbed to an estimated 5.2 billion litres. Biodiesel output peaked in 2019, at 16.3 billion litres (USDA-FAS, 2022). EU-27 biofuel employment was estimated at about 141 600 jobs in 2020, the most recent year for which data from EurObserv'ER (2022) are available. If the rise in output in 2021 were shadowed by a similar increase in employment, it would translate into 147 500 jobs for that year, according to IRENA estimates. The largest numbers of EU biofuels jobs are in France and Romania (each of which employed more than 20 000 people in 2020), followed by Poland, Hungary, Spain and Germany (with more than 10 000 each).

In **GERMANY**, revised government data indicate that renewable energy employment reversed most of the loss that took place after 2016 (the year German wind employment reached its highest level). But with a preliminary estimate of 344 300 jobs in 2021, employment remains below the all-time peak of 416 000 jobs a decade ago (when the country's solar PV workforce reached its peak) (BMWK, 2022).

German **wind** employment fell from 167 600 jobs in 2016 to 122 100 jobs in 2019 before recovering slightly to about 130 300 in 2021. With 1.6 GW added in 2021, the pace of new domestic installations remained far below the record of 6.1 GW set in 2017; no new offshore capacity was added (IRENA, 2022a). Permitting for new deployments can take years. For now, export sales buffer impacts from a weak domestic market. German wind equipment manufacturers export as much as 60-70% of their production (BWE, 2022).


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Germany does retain Europe's most extensive renewables industrial base, with 82 of 217 wind manufacturing sites (38%) and 53 of 138 solar PV equipment plants (38%) (Ferris, 2022). But a sluggish pace of wind installations may not sustain a vibrant domestic manufacturing industry. In late 2021, Vestas announced it would close a blade factory in the state of Brandenburg, cutting more than 450 jobs in a region that also confronts the phase-out of coal jobs (Wehrmann, 2021). In February 2022, Nordex announced that it would no longer manufacture blades at its Rostock facility in Mecklenburg-Vorpommern, narrowing its German operations to nacelles, hubs and drive trains, endangering 600 jobs (Ferris, 2022).

In sharp contrast with recent wind trends, Germany's **solar** industry has added 19 000 jobs since reaching a low point in 2017. Employment rose to 51 300 in 2021 (BMWK, 2022) on the strength of new PV installations of 4.8 GW in 2020 and 4.7 GW in 2021 (IRENA, 2022a).

Bioenergy – biofuels, biomass power and biogas – remains the largest renewable energy employer in Germany, with 113 700 jobs in 2021. The number has stagnated over the last 15 years or so, however. Geothermal energy (36 000 jobs) and hydropower (5 700 jobs) are much smaller employers (BMWK, 2022).


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In **SPAIN**, 2.8 GW of renewable capacity was installed in 2020, and 4 GW in 2021 (IRENA, 2022a). This increase was driven directly by the market or by self-consumption; it took place even without auctions or support mechanisms in place. However, the sector was not immune to the health and economic crises caused by the pandemic, which had consequences in the labour market. In 2020, the last year for which industry association data are available, total employment in the sector contracted 2.3%. The technologies that suffered the most were wind and biomass; solar PV capacity and jobs expanded (APPA, 2021).

The reduction in jobs reflected a 6% drop in indirect jobs, as construction of new projects was halted or postponed. Direct jobs experienced very slight growth. In total, the Spanish renewable energy sector ended 2020 with 92 930 jobs, of which 58 724 (63%) were direct jobs. The wind industry employed about 27 000 people in 2020 (APPA, 2021). A quarter worked in manufacturing or related activities, almost two-thirds were in installation and the remaining portion (11%) in O&M (Montes Muñoz de Verger, 2022).

IRENA estimates **solar PV** and **wind** employment in Spain at 31 500 and 23 900 jobs, respectively, in 2021. The number of jobs will likely continue to pick up. According to some projections, the renewable energy market could generate a cumulative 468 000 jobs over the next decade. Almost half of the jobs could be created in just three of Spain's 17 autonomous communities – Andalusia, Castilla y León and Aragon (Montes Muñoz de Verger, 2022).

According to a survey and modelling exercise by the Offshore Wind Industry Council (OWIC, 2022), the **UNITED KINGDOM**'s offshore **wind** industry had a workforce of 31 082 at the end of 2021, up 16% from the previous year. This figure included 19 591 direct jobs and 11 491 indirect jobs. Women represented 19% of the total, up only marginally from 18% in 2020. OWIC forecasts that with average annual investments of GBP 17.2 billion and a pipeline of projects amounting to 47 GW, the industry could employ more than 97 000 people by 2030, including about 61 000 direct and 36 000 indirect workers.

The United Kingdom has the world's second-largest installed offshore wind capacity, requiring many people to install and operate wind farms. But the country's industrial base supplies only a small share of the needed equipment, limiting the number of jobs created domestically in manufacturing. Between 2017 and 2021, for example, 83% of wind towers were imported from producers based in Denmark, Spain and Viet Nam (Wood Mackenzie, 2022c). A similar share of foundations and substations came from abroad, with Germany, China, the Netherlands, the United Arab Emirates, Spain and Denmark the leading suppliers (Wood Mackenzie, 2022d).

FRANCE employed about 24 300 people in solid biomass, 21 900 in biofuels, 15 800 in wind power and 3 600 in solar PV in 2020, according to EurObserv'ER (2022). At least for wind, these estimates may be too conservative. France has Europe's fourth-largest wind capacity after Germany, Spain and the United Kingdom. Additions in both 2020 and 2021 were slightly above 1 GW, a slower pace than in previous years (IRENA, 2022a).

According to an extensive analysis by FEE and Capgemini Invent (2021), direct and indirect **wind** employment ran to about 22 600 jobs at the end of 2020, a gain of 12% over 2019. Planning and design claimed the largest share of jobs (33%), followed by engineering and construction (29%), O&M (19%) and component manufacturing (18%). In geographic terms, the Île-de-France region (the area surrounding Paris) commands the largest slice of employment (28%), based on its leading role in planning and design. Five other regions together account for another 47% of jobs. Two of them, Hauts-de-France and Grand Est, together account for half of France's grid-connected wind capacity (FEE and Capgemini Invent, 2021).

Offshore wind – the Saint-Nazaire, Fécamp and Saint-Brieuc farms – accounted for about 5 200 jobs in 2020 (including 1 300 in manufacturing). This number could grow to 15 000 by 2030, even though France currently has less ambitious plans than its neighbours. The development of offshore wind terminals in the ports of Brest, Cherbourg, Le Havre and Saint-Nazaire on the Atlantic coast and Marseille-Fos and Port-La Nouvelle on the Mediterranean coast will create thousands of jobs in construction, installation and O&M in coming years (FEE and Capgemini Invent, 2021). IRENA estimates that jobs in the French wind industry (onshore and offshore) remained steady at around 22 000 in 2021.

2.2 OTHER COUNTRIES

This section describes the renewable energy employment landscape in selected countries in Asia and the Pacific, the Western Hemisphere and Africa.

In **West Asia**, installations of solar PV plants and wind farms continued in **TÜRKIYE**. An increase in domestic production of renewable energy equipment has been a central objective of policy makers, reflected through domestic content requirements in auctions and industry support mechanisms. Wind energy projects are reportedly sourcing up to 72% of their wind turbines from domestic sources (Todorović, 2022). IRENA estimates that employment in the wind energy sector could be as high as 25 000 jobs. The country's solar PV industry workforce is estimated to reach 21 000 jobs. An industrial survey of 16 solar panel production companies in Türkiye by Stantec (2020) reveals that these companies employed more than 3 300 people, 31% of which were women.

In **East Asia**, **JAPAN's** cumulative solar PV capacity reached 74.2 GW in 2021, the third-largest in the world. The pace of growth continued to slow, however, to about 4.4 GW, down from 7 GW added in 2019 (IRENA, 2022a). IRENA estimates 2021 employment at some 150 500 jobs.[24] In the first three quarters of 2021, foreign-produced modules accounted for 88% of total shipments (JPEA, 2022). Domestic manufacturing likely employs only about 10% of the total solar workforce, with the remaining workforce split evenly between construction and installation and O&M segments.

Among **Southeast Asian** countries, **INDONESIA's** biodiesel employment rose to about 555 900 in 2021, reflecting production levels that were about 9% higher than in 2020. The increase in production was driven by growing domestic consumption (in the wake of relaxed travel restrictions); export volumes remained at about the same low level as in 2020 after countervailing duties were imposed by the European Union. Logistical challenges and supply chain bottlenecks constrained domestic consumption somewhat (USDA-FAS, 2021c).


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[24] *In the absence of direct employment data, this calculation is based on employment factors for direct employment and multipliers for indirect employment.*

COVID-19 impacts continued to affect **MALAYSIA's** biodiesel consumption, leading to a delay in the implementation of a B20 blend mandate (that is, a 20% mix of biodiesel in vehicle fuels). Biodiesel production in 2021 was expected to drop to 1.05 billion litres, 41% below the 2019 peak of 1.8 billion litres. Domestic consumption keeps growing. In contrast, exports were projected at less than half the 2019 volume, as a result of an all-time high in crude palm oil prices (USDA-FAS, 2021d). IRENA estimates that the biodiesel sector accounted for about 61 400 jobs in 2021, down from 106 200 in 2019.

Estimates for renewable energy jobs in the **PHILIPPINES** in 2021 run to some 189 000 (REMB DOE, 2022), including about 69 423 in hydropower (of which almost 60% were in large facilities), 61 926 jobs in solar PV, 26 718 in wind power, about 14 047 in biomass and 11 628 in geothermal power. With the exception of the geothermal sector, these numbers include direct jobs only. In the agricultural supply chain for liquid biofuels (not included in the above total), IRENA estimates about 34 300 jobs. Ethanol production recovered from the 2020 COVID-19 impacts, reaching 330 million litres in 2021, close to the 2019 peak. At 180 million litres, biodiesel production remained considerably below peak levels and lower than in 2020 (USDA-FAS, 2021e). The number of direct jobs in biofuels processing was reported at 3 324 in 2021 (REMB DOE, 2022). The number of overall renewable energy jobs grew, despite some COVID-19–related mobility restrictions that delayed some construction and other activities. For example, the number of geothermal jobs increased by about 30%.

THAILAND's ethanol production increased to 1.9 billion litres in 2021, a new peak. The government had increased the blend rate for biodiesel to B10 in 2020, with some exemptions granted, and provided higher consumer subsidies. Ethanol production remained at the 2020 level of about 1.5 billion litres, about 8% below the 2019 peak (USDA-FAS, 2021f). IRENA estimates the number of biofuel jobs in Thailand at 133 900 in 2021, almost 5 000 more than in 2020.

VIET NAM is a major manufacturer, exporter and installer of PV cells and modules. Cell production rose from just 37 MW in 2014 to 3.75 GW in 2021; module output increased from 1.2 GW to 8.5 GW over the same period (Wood Mackenzie, 2022a). The breakneck expansion of domestic solar installations, triggered by high feed-in tariffs, saw total capacity swell from just 105 MW in 2018 to about 17 GW in 2020 (of which 8.5 GW was utility-scale and 8.9 GW distributed solar). As a result, the country's electricity grid became severely overloaded, leading to curtailments. Despite some grid improvements, the domestic solar PV expansion came to an abrupt halt in 2021, and emphasis shifted to off-grid rooftop deployment.

The unprecedented installations in 2020 resulted in significant economic activity and job creation. More than a hundred new installation companies were set up in south-central Ninh Thuan province, which was home to around 2.5 GW of installations in 2021 (Le, 2022). As installations shot up, Viet Nam's solar PV workforce rose to 126 300 jobs in 2020, according to IRENA estimates. In 2021, the lack of installations apart from limited rooftop additions likely led to a sizable reduction in the workforce. IRENA estimates that employment in the solar PV industry declined to 31 700 jobs, 23 000 of which were in O&M, with the remaining jobs primarily in the manufacturing of modules, cells, inverters and wafers.

In contrast, Viet Nam's wind capacity grew strongly in 2021, from just 500 MW to 4.1 GW, driven by the end-of-October expiration of advantageous feed-in tariffs. The domestic supply chain is still in its infancy, so foreign suppliers continue to play a central role (Liew, 2021). European and US firms installed 70% of Viet Nam's new capacity in 2021, with the remainder provided by Chinese firms (Barla and Lico, 2022). The country's draft power development plan envisages 21 GW of wind by 2030, but the government announced that no new wind or solar projects would be connected to the grid in 2022 (Cao, 2022). Curtailments and uncertainties about auction dynamics could affect the 2022 market in a major way (Liew, 2021). For 2021, IRENA estimates that Viet Nam may have 43 000 wind jobs, including 19 000 in offshore wind, which accounted for around 0.9 GW of new installations in 2021.


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In the **Pacific**, **AUSTRALIA** completed some of it largest wind and solar projects in 2021, according to the Clean Energy Council (2022). New capacity additions included 3.3 GW of small-scale solar, 1.2 GW of large-scale solar and 1.75 GW of wind industry. The Clean Energy Council reports another 9.3 GW worth of renewable energy projects under construction or financially committed at the end of 2021, representing over 35 000 jobs, including almost 21 000 in New South Wales. Meanwhile, the federal government's bioenergy roadmap created some 26 200 full-time jobs. The government committed about AUD 464 million to the construction of seven regional hydrogen hubs, which might create 130 000 jobs by 2030 (Clean Energy Council, 2022). Overall, however, there is lack of systematic reporting on renewable energy employment data.

A 2021 survey indicates that women accounted for 39% of the Australian clean energy workforce, compared with 23% in the oil and gas sector and 16% in the coal industry. Salaries in renewables tend to be lower than for conventional energy. The starting salary for a coal power station operator could be about AUD 164 500, compared with AUD 100 000 - AUD 120 000 for a wind turbine technician (McKay, 2022). In 2021, the Clean Energy Council established the Skills and Training Directorate, which brings together representatives of industry and higher education institutions to identify the skills required and improve alignment between the supply of, and demand for, skills.

In the **Western Hemisphere**, hydropower is the largest employer in **CANADA's** renewable sector, with 33 260 direct and 15 530 indirect jobs in 2020. For other renewables, only direct jobs estimates are available; they strongly reflect the ebb and flow of annual installations. Solar PV accounted for 14 630 jobs in 2021 and liquid biofuels for about 13 000 jobs. Other forms of bioenergy, wind power, solar heating and cooling, geothermal energy and energy storage together added about 5 000 jobs (Natural Resources Canada, 2022).

In **MEXICO**, following an expansion of capacity to more than 7 GW, the number of direct wind jobs declined to 6 933 in 2021, down from 11 590 the previous year, according to the Mexican Wind Energy Association (AMDEE). This decline mainly affected the number of construction jobs, which plummeted from 5 100 to 1 183; the effect on the number of manufacturing jobs, which fell from 5 140 to 4 319, was more moderate. The number of jobs in O&M increased slightly, from 1 350 to 1 413 (AMDEE, 2022). In coming years, wind employment will be less dependent on the domestic market, giving that Mexico has become the leading supplier of blades in the Western Hemisphere (Lico, 2022). In the solar PV sector, capacity expanded from 5.1 GW to 7 GW. PV module manufacturer Solarever plans to increase its production capacity from 500 MW to 1 GW (Zarco, 2022).

PANAMA's renewable energy employment is centred on hydropower, which directly employs 776 people, more than three-quarters of whom work in large hydro facilities. Solar PV and wind employed just 54 people in 2021 (ANSP, 2022).

COLOMBIA's solar PV jobs, while still small in number, rose to 2 381 in 2021, up from just 360 in the previous year (MME, 2022), as installed capacity expanded from 86 MW to 184 MW. In 2021, the government decided to relax the ethanol blending mandate from E10 to E4 in response to reduced local supplies in the wake of adverse La Niña weather conditions in sugarcane producing areas and political protests. Ethanol production fell for a third consecutive year, to an estimated 370 million litres in 2021, 21% below the 2018 peak. For biodiesel, the blend mandate was raised from B10 to B12. Production in 2021 is estimated to have risen to a new high of 690 million litres (USDA-FAS, 2021b). A rough employment factor calculation suggests that the number of people deriving livelihoods from biofuels (not necessarily full-time equivalents) was about 84 300 in ethanol and 103 200 in biodiesel. The combined total of 187 500 jobs is up by about 12 000 from 2020.

In **ARGENTINA**, the outbreak of the pandemic led to mandatory social distancing from mid-March 2020 until the second four-month period, with varying degrees of gradual openings for different activities. The requirement led to delays in construction, logistics and transport activities, slowing work at wind farms under construction. Conditions gradually normalised in 2021, permitting 26 wind farms to be put into operation, adding 1 GW of capacity. The period of January-April 2022 saw the commissioning of another three farms, adding 6.2 MW. The lingering effects of the pandemic, however, resulted in a decrease in employment in the renewable energy sector of over 25% in technologies such as solar PV, wind energy and biomass. The decrease in jobs in the wind sector largely reflected the reduction in construction activity as newly completed wind farms entered commercial operation but required relatively little operation and maintenance labour (Government of Argentina, 2022).

In the overall region of **Africa**, the formal energy sector employed about 3 million people in 2019, mostly in conventional energy.[25] This figure does not include millions of informal jobs in traditional biomass, including a vast charcoal economy. Given that the continent's share of renewable energy investments is very low, its installed capacities are equivalent to only about 1% of the world's solar PV and wind power capacities (IRENA, 2022a). As a result, renewable energy employment is still limited. That could change if an ambitious energy transition unfolds that promotes access to both centralised and decentralised renewable electricity (enabling additional employment in agriculture, health services, commerce and other productive uses) and to clean cooking. An African Green Deal could help countries in the region that produce metals critical to renewable energy and electric vehicles create higher-value jobs in the domestic processing of such materials, instead of remaining limited to raw materials extraction (IRENA and AfDB, 2022).

Employment generated through the deployment of decentralised renewable energy is not well documented, except for a small number of country reports, such as those conducted by Power for All (see Box 2). Among the companies operating under the pay-as-you-go model, **M-KOPA** has crossed the threshold of more than 1 million customers for solar lighting and related products. It employs more than 1 000 people (up from 855 in 2018, half of whom were women). The number of direct sales agents working on commission rose from 2 100 in 2018 to more than 7 000 at present. Most of the company's workers are in Kenya, with most of the rest in Uganda (M-KOPA, n.d.; M-KOPA, 2019) .

BBOXX operates in more than two dozen African countries. It has sold more than 500 000 solar home systems. The company has a staff of more than 1 000 in the Democratic Republic of Congo, Kenya, Rwanda and Togo. A major market for the firm is Kenya, where it has 350 employees, 40% of whom are women (Bboxx, 2022). The company's headquarters is in the United Kingdom and its solar equipment is manufactured in China. Employment in Africa is therefore concentrated in sales, installations and related services.

In **NIGERIA**, more than 90 million people lack energy access. Of the estimated 49 600 people working in the country's DRE sector, 31% are in informal working situations (Power for All, 2022). With experience in India, where it operates more than 100 solar and biomass minigrids (employing 125 people from local communities full time and 80 part time),

[25] This figure includes oil and gas production, coal mining, the power sector, transmission and distribution, bioenergy and mineral extraction. Oil and gas jobs are principally in northern Africa; most coal mining jobs are in Sub-Saharan Africa (see IEA, 2022a).

Husk Power Systems (n.d.) launched a Sunshot initiative in Nigeria to build at least 500 solar minigrids. The aim is to add some 400 000 new grid connections for households and small- to medium-sized enterprises by 2026, electrifying 900 health clinics and 100 schools; enabling productive activities, including agri-processing and cold storage; and providing energy for 8 000 female-led businesses (Energy Monitor, 2022).

Cumulative direct employment through **SOUTH AFRICA's** Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) doubled from 31 207 job-years in 2016-2017 to 63 291 by the third quarter of 2021. But three-quarters of the total (48 110 job-years) were in construction, which typically provides employment for only a limited time, leading to a roller coaster of job creation and loss. Construction also has limited cross-linkages to other sectors of the economy. The remaining quarter, some 15 182 job-years, was in more permanent occupations in O&M. Women's share of these jobs is just 10% (IPPPP, 2022).

Increasing the local production of solar system components has been a key objective of the South African government. REIPPPP rules focus on relatively low-value solar PV components, such as module frames, mounting structures and inverters. Local manufacturing capacities were leveraged for solar in the steel, electrical equipment and fiberglass industries and among specialised services, including legal and financial services, engineering design and others. South Africa does not have any manufacturing capacity for ingots, wafers or cells. Also, a long lull between auction bidding windows led to a stop-and-go cycle that slowed domestic manufacturing progress (USAID and Power Africa, 2022).

One study estimates that with an investment of about USD 4 billion by 2030 and greater localisation, more than 30 000 local solar jobs could be created under the country's 2019 Integrated Resource Plan, with its goal of 6.4 GW of solar PV capacity (SAREM, n.d.). Another study (RES4Africa, 2020) finds that some 35 000 jobs could be created by 2030. Creating these jobs will require addressing barriers, including insufficient and unpredictable local demand and lack of price competitiveness with low-cost foreign producers; stronger local content requirements; and strategic cooperation between the government and industry in finance, infrastructure and trade policy (USAID and Power Africa, 2022).

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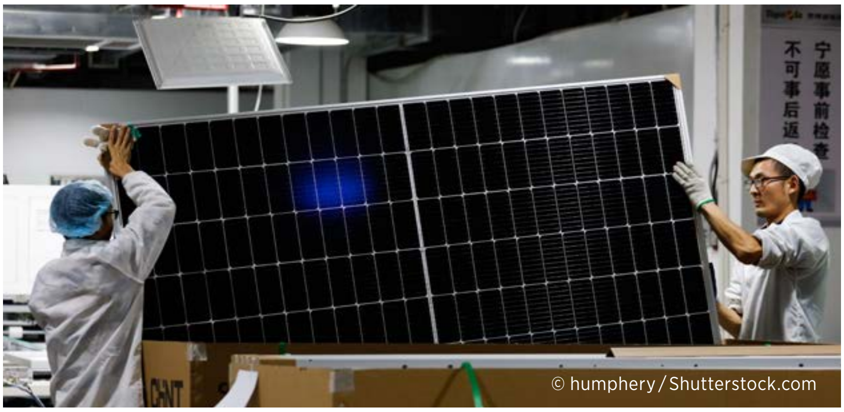
UPSTREAM AND DOWNSTREAM ASPECTS

Chapter 3



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3.1 A CHANGING SUPPLY CHAIN LANDSCAPE

The global supply chain landscape for renewable energy keeps shifting. A handful of countries established themselves as leading manufacturing hubs for projects worldwide. The COVID-19 crisis has put a spotlight on the wisdom and viability of maintaining far-flung supply chains. Security of supply – of finished products, key components such as semiconductors or raw materials critical to renewable energy – has become a concern in the context of ongoing supply chain disruptions, trade disputes and geopolitical rivalries.

Supply chain worries in the emerging energy system differ from those in conventional energy. Fossil fuel–based economies are vulnerable to disruptions in the flow of the fuels themselves (oil, gas and coal). For renewable energy and other energy transition–related technologies, the concerns centre on access to raw materials (such as silicon, copper, cobalt, lithium and rare earths) and processed materials (such as steel and aluminium), together with the ability to produce or reliably procure manufactured components (such as semiconductors, solar PV cells and inverters, and wind turbine blades and towers).

The use of such commodities and components is expected to soar as the energy transition gains momentum. Timely investments will be needed to expand the underlying industrial base. Measures are also needed to harmonise demand and supply, in order to avoid either shortages or large overcapacities. But these commodities are also in demand in other sectors of the economy, affecting their pricing and availability.

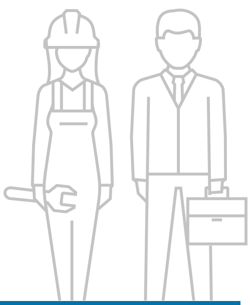
The rising interest among many countries in localising a larger portion of supply chains is driven by a newly found need to make them more resilient to external shocks but also by an ongoing desire to create jobs and strengthen domestic value creation. In the solar PV sector, governments have imposed duties in recent years that apply to about 15% of global demand outside of China (IEA, 2022b).

But countries are also adopting sophisticated industrial policy strategies to build and expand their supply chains. India, the United States and the European Union have announced initiatives for integrated solar PV manufacturing in order to become more competitive with Chinese suppliers. Policies adopted by a range of countries in the solar and wind industries include local content requirements; manufacturing tax credits; manufacturing-linked auctions; free or low-cost land; subsidies, grants, preferential loans and loan guarantees; public R&D funds; regional innovation clusters and infrastructure upgrading. But in this race, there is also a danger that countries with more limited industrial capacities will be left behind.

Building up more localised capabilities will not happen overnight. The availability of skilled labour is one potential bottleneck. Addressing it requires educational and skill-building strategies. Much also depends on creating domestic markets of a sufficient size and demand stability from year to year to warrant building production facilities. One way in which small countries, particularly small developing countries, can overcome market-size obstacles is by pursuing regional or subregional supply chains.

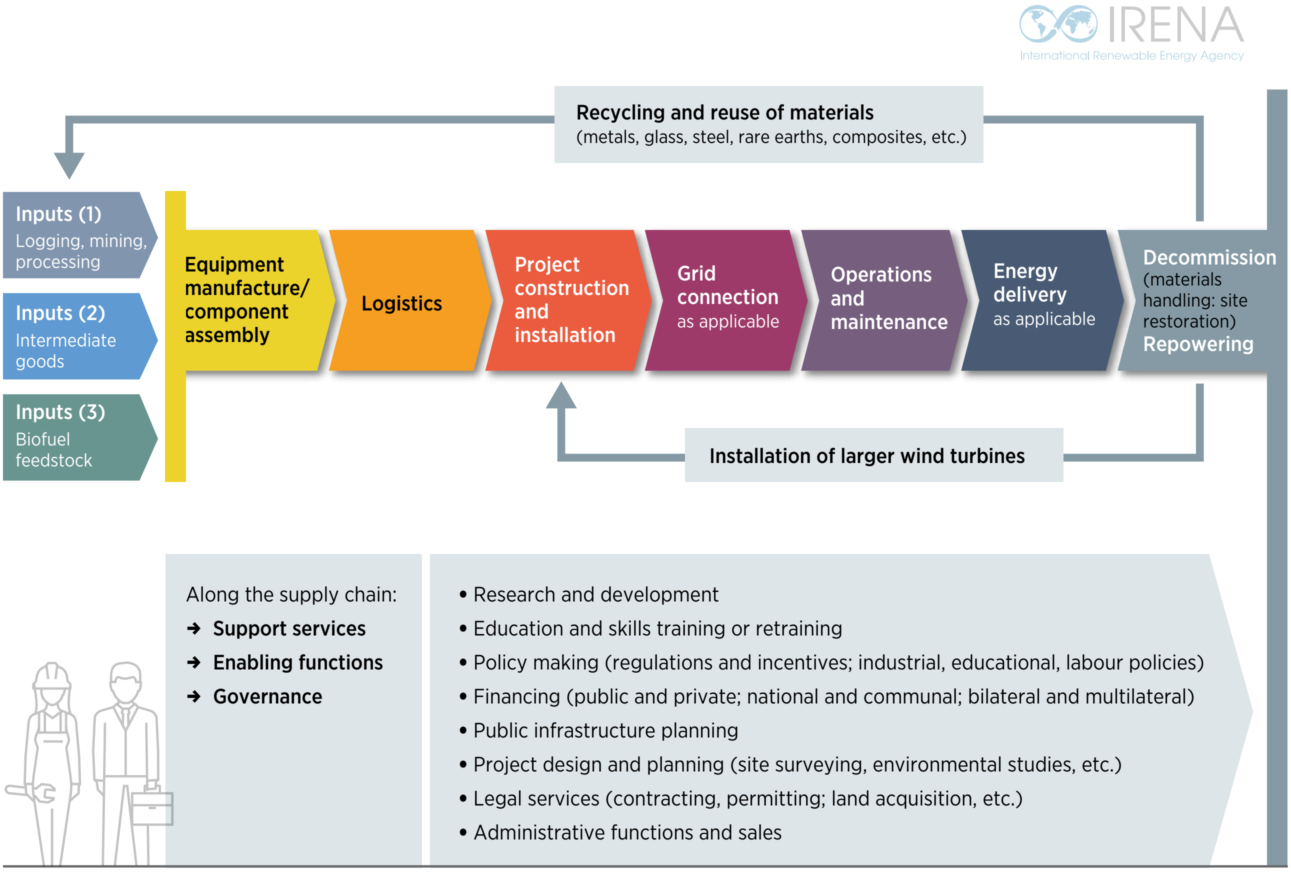
Rising costs from supply chain disruptions stemming from the COVID-19 crisis are complicating the picture, at least in the short run. In the wind industry, costs grew sixfold for freight and 50-60% for steel and copper between 2020 and early 2022,[26] raising wind turbine prices to 2015 levels (Hook, 2022).

IRENA's *Renewable energy and jobs: Annual review* series focuses on core segments of the renewable energy value chain, which extends from the manufacturing of equipment to construction and installation activities to O&M. Segments that lie further upstream (particularly raw materials) and downstream (the handling of materials after equipment reaches the end of its useful life) are now receiving greater scrutiny. Figure 15 shows the elements of this extended supply chain.



[26] China is a major exception. Turbine prices there fell in 2021, driven by lower domestic steel costs and a price war among domestic turbine manufacturers (Hook, 2022).

Figure 15 Extended renewable energy supply chain



Note:

Logistics: Transport of equipment to project sites (centralised generation); distribution of equipment for distributed, stand-alone applications.

Energy delivery from centralised generation: Grid feed-in, transmission and distribution; district heating and cooling network; biofuels wholesale and retail sales.

Source: IRENA.

3.2 LOGGING AND MINING FOR THE ENERGY TRANSITION: JOBS AND OTHER IMPACTS

Governments, civil society groups and academics are increasingly scrutinising industry practices in the commodity sector with regard to environmental and labour standards, consequences for local communities and impacts on jobs and job quality. Concerns include the logging of balsa wood used in wind turbine blades, which sometimes adversely affects indigenous communities (Box 4), and the mining and processing of various minerals and metals for different types of renewable energy equipment and other energy transition–related technologies, such as batteries.[27]

China is the dominant producer of several metals and minerals critical for manufacturing renewable energy equipment. But several countries in Africa, Asia and Latin America also play critical roles. Peru, for example, is an important source of copper, silver, tin and zinc; Indonesia figures prominently among nickel and tin producers; and the Republic of Congo produces copper (Ladislaw *et al.*, 2021). Increased demand for these countries' minerals could increase income and employment. However, the full extent of benefits can be reaped only if these countries develop the capacity to process raw materials, rising above the role of mere commodity producers with limited value-added generation. Such efforts are part of a larger challenge of overcoming deep historical dependencies within the world economic order.

The mining and processing of raw materials impose substantial **environmental costs**. Forging a more sustainable future energy system requires that these impacts be reduced. Aluminium is an essential material for solar PV cells, module frames, mounting structures and inverters. Because its primary production from bauxite requires large amounts of energy (and causes substantial greenhouse gas emissions), it is critical that the world rely more on secondary, recycled aluminium (which currently represents a third of total supplies) and reduce the energy and emissions intensity of primary production processes. Secondary production requires only about 5% of the energy used in primary production (Maisch, 2022).

Nickel production provides another example of the deleterious effects of mining on the environment. In Indonesia, the world's top supplier, mining operations have been linked to deforestation and flooding (Hidayat and Hermawan, 2022), and researchers have expressed concerns about biodiversity and livelihood impacts, waste disposal and declining labour standards (Morse, 2021; Rushdi *et al.*, n.d.). In Russia, the world's third-largest nickel producer, mining and refining operations by Nornickel are major contributors to air and water pollution, affecting the livelihoods of indigenous communities in the Arctic (Stone, 2022).

Industry practices also affect **job quality, occupational health and safety, and the rights of workers**. National laws and regulations do not always exist or are not necessarily enforced. Growing awareness of abusive situations – such as child labour under harsh work conditions in cobalt mining[28] – could force change. A challenge is formalising current informal work arrangements. Enforcement of applicable labour standards may affect where supply chain investments are made and therefore where job creation takes place. For example, allegations of forced labour in polysilicon production have led to a scramble for greater supply chain transparency and efforts among some firms to reorient the sourcing of this critical material (Wagman, 2022).

Commodities needed for the energy transition are extracted by large-scale, capital-intensive mining corporations but also, on a much smaller scale, by artisanal miners. The two types of mining have different impacts not only in terms of the numbers of jobs they create but also with regard to occupational safety and health for workers and social and environmental consequences in surrounding areas and communities (Box 5).

[27] *In addition, the production of feedstock for biofuels and other forms of bioenergy on large-scale plantations has potential negative impacts on local farmers, an issue that is not addressed in this report.*

[28] *For example, of an estimated 255 000 people engaged in small-scale artisanal cobalt mining in the Democratic Republic of Congo, 40 000 are believed to be children (Lawson, 2021).*

Box 4
Balsa logging and community livelihoods

Balsa wood is considered one of the best materials for lightweight construction of wind turbine blades. Escalating demand for it by the wind industry is putting increasing pressure on Amazon rainforest areas, where balsa trees grow. Balsa suppliers (Swiss- and Swedish-owned firms dominate the market) either own plantations directly or contract with independent growers in Ecuador (*The Economist*, 2021), which produces over 90% of the world's balsa (Traffic, n.d.).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With already weak forestry regulations in remote areas undermined by the pandemic, illegal loggers and timber traffickers who traditionally focused on hardwoods like mahogany and cedar have carved out a slice of the balsa market, cutting down trees in protected areas inhabited by indigenous people such as the Achuar, Kichwa, Shuar, Wampis and Waorani on the Ecuador-Peru border. Illegal balsa logging and cutting down of protected wood species to grow balsa is also taking place in Colombia's Putumayo Department (Jones and Ramírez, 2021).

Deforestation from balsa logging enables extraction of other resources, raises the risk of flooding along rivers and undermines local livelihoods. Incursions of loggers have led to prostitution, drug and alcohol abuse, and sometimes human trafficking (Tapia, Garcés and Montahuano, 2021). Indigenous communities have sought to impose a logging ban, and some are trying to make logging more sustainable by incorporating biodiversity conservation principles (Baquero, 2021; Pérez, 2021). The Waorani have formed a co-operative to sell their balsa at fair prices (*The Economist*, 2021).

Volatile demand for balsa has led to boom-bust swings. Meanwhile, supply shortages in 2020, driven by the COVID-19 pandemic, triggered a partial shift from balsa to a synthetic foam, polyethylene terephthalate (PET), with European manufacturers the early adopters. Balsa made up 38% of wind blade core materials in 2019, followed by polyvinyl chloride (PVC) at 31% and PET at 25%. PET's share of materials used for blade construction could increase to 50% in 2022 and 65% by 2025 (Lico, 2022).

Box 5
Mineral mining for the renewable energy transition: Job and community impacts

Mineral commodities like cobalt, copper, lithium, nickel and zinc are vital to building solar panels, wind turbines and batteries. The World Bank (2020) estimates that the production of critical minerals could increase nearly fivefold by 2050 to meet the growing demand for clean energy technologies and equipment.

As most of these minerals are typically found in low concentrations and are difficult to extract, they are usually produced by large-scale mining companies headquartered in Canada, China, the European Union or the United States. Being highly capital intensive, large-scale mining accounts for a relatively small share of employment in the countries and communities endowed with the critical energy transition minerals. Although the increase in demand for these minerals will no doubt create many new jobs, particularly in the construction of new mine sites and infrastructure, the rapid uptake of automated mining technologies will likely have a dampening effect on mining employment.

Large-scale mining companies have a significant economic, environmental and social footprint. In places that are poor and politically unstable, the capacity to enforce labour and environmental laws is limited. But mining companies are increasingly putting in place systems to ensure that their operations are aligned with environmental, social and governance (ESG) standards and best practices. Most also have due diligence processes in place to ensure that their suppliers comply with national laws as well as with international labour and environmental standards and human rights.

In its 2022 *Responsible Mining Index Report*, the Responsible Mining Foundation (2022) notes that ESG commitments have become the norm among the 40 companies and 250 mine sites it assessed. In many mining countries and communities, occupational safety and

health performance, working conditions and wages of large-scale mining operations are better than in other sectors.

Efforts to track and improve performance on ESG issues is still inadequate, however, especially at the mine site level. Notwithstanding some improvements, most corporate practices still score low on issues ranging from economic development and community well-being to working conditions and environmental responsibility.

Two issues that have lagged in improvement are assessing and addressing gender impacts in affected communities and mining-related impacts on health in affected communities. Globally, women constitute less than 20% of the workforce and face multiple challenges, from gender bias to violence and harassment (ILO, 2021).

Artisanal and small-scale mining (ASM) is more labour intensive than large-scale mining and often takes place in the informal sector. According to the DELVE (2022) database, ASM employs over 44 million people, 30% of whom are women. According to the OECD (2019), ASM supplies 20-30% of the world's cobalt, which is key to the production of batteries and energy storage solutions.

Despite their contribution to global mineral supply chains, workers in ASM are among the world's most marginalised and vulnerable. In many developing countries, these workers operate in the informal economy, where they are exposed to hazardous and exploitative working conditions and where they are unable to enjoy their rights at work. Their plight calls for urgent action to ensure that the workers that produce critical energy transition metals in this sector can do so in conditions of freedom, equity, security and human dignity.

The 187 Member States of the International Labour Organization (ILO) have developed a rich body of international labour standards (ILO, 2022) that should guide the development of sound legal and regulatory frameworks to improve the constraints that micro and small enterprises and workers in ASM face. They include the formalisation of ASM, in accordance with the ILO Transition from the Informal to the Formal Economy Recommendation, 2015 (No. 204); improvement of occupational safety and health, in accordance with relevant international labour standards; and the promotion, respect and realisation of the ILO Declaration on Fundamental Principles and Rights at Work.

To advance decent work in the ASM sector, the ILO is implementing several development co-operation projects. One is the COTECCO project in the Democratic Republic of Congo, which aims to improve and strengthen the legal and policy framework to eliminate child labour in the cobalt ASM sector. The project seeks to improve the mechanisms for the monitoring and remediation of child labour in cobalt supply chains while also promoting international standards of due diligence through tripartite working groups and social dialogue (US DOL, n.d.).

3.3 A CIRCULAR ECONOMY APPROACH TO RENEWABLE ENERGY MATERIALS

At the other end of the value chain, end-of-life (EOL) issues require much closer attention. As the world commits to sustainable economies and societies, reducing the reliance on fossil fuels has become critical. Although the shift towards renewable energy is a big step towards climate neutrality, it also brings about new challenges – a complex waste stream when wind turbines, solar panels and other equipment are decommissioned. EOL waste flows related to wind, solar PV and energy storage technologies in Europe are expected to grow by a factor of 30 in the next decade (European Environment Agency, 2021).

Repair, recycling and reuse of equipment and embedded materials are alternatives to the conventional approach of produce-use-dispose. They can limit waste volumes and reduce the extraction of virgin raw materials such as copper, cobalt, nickel, bauxite, silver and many others. Doing so eases supply concerns and reduces the environmental impact of additional mining activities. Recycling and reusing materials also offer greater employment opportunities than simply consigning them to landfills or incineration.

The circular economy is a concept that "promotes the design of durable goods that can be easily repaired, with components that can be reused, remanufactured and recycled" (Weibe, *et al.*, 2019). The three core pillars of circularity, driven by design choices, are (1) eliminating waste and pollution; (2) circulating products and materials; and (3) regenerating nature (Widmer, 2021; Ellen MacArthur Foundation, n.d.). In the context of renewable energy, the circular economy could mean designing infrastructure that allows for longer life, better repair and maintenance, and recycling of the large quantities of valuable and critical raw materials used in building this equipment.

Studies conducted on the recyclability of some renewable energy infrastructure show immense potential for the adoption of circular economy approaches. About 95% of the materials used in the solar PV industry and up to 100% of the materials used in lithium-ion batteries can be recovered (Graulich *et al.*, 2021). However, much of the renewables infrastructure currently in place was not designed with circularity in mind, risking the loss of rare materials such as lithium, cobalt, indium and germanium. A lot of equipment contains highly hazardous substances that are cumbersome to deal with. And many countries, both developed and developing, lack the infrastructure to manage the huge volumes of waste expected in the future.

Circular approaches in this sector can present an opportunity for the world of work. The ILO estimates that an increase in circular economy approaches could lead to a net increase of 6 million jobs worldwide in activities such as recycling, repair and remanufacture (ILO, 2018). Although many jobs may be lost in extraction of virgin materials and manufacturing many other jobs could be created in reuse, repair, refurbishment, recycling and waste management.

Many of the people currently engaging in circular economy activities are working informally in unsafe conditions, with limited opportunities to improve their livelihoods. These are not the kinds of jobs that should be created on a large scale. Decent work is a key concept to embed in circular policies, so that a circular system does not perpetuate and exacerbate existing decent work deficits.

Key policy areas for a just transition strategy include social protections, skill training, creation of an enabling environment for sustainable micro and small enterprises, gender inclusion and social dialogue. Improved coordination across ministries (labour, finance, trade, etc.) as well as global solidarity, co-operation and innovative partnerships will be necessary to realise a just circular transition.

Can experience with managing e-waste help in managing renewables waste?

The world generated a record 53.6 million metric tonnes of e-waste in 2019, according to the Global e-Waste Monitor. The amount of e-waste generated grew by 21% in only five years. The volume was projected to double between 2020 and 2030. Only 17.4% of the e-waste generated in 2019 was properly collected and recycled (UNU, ITU and ISWA, 2020).

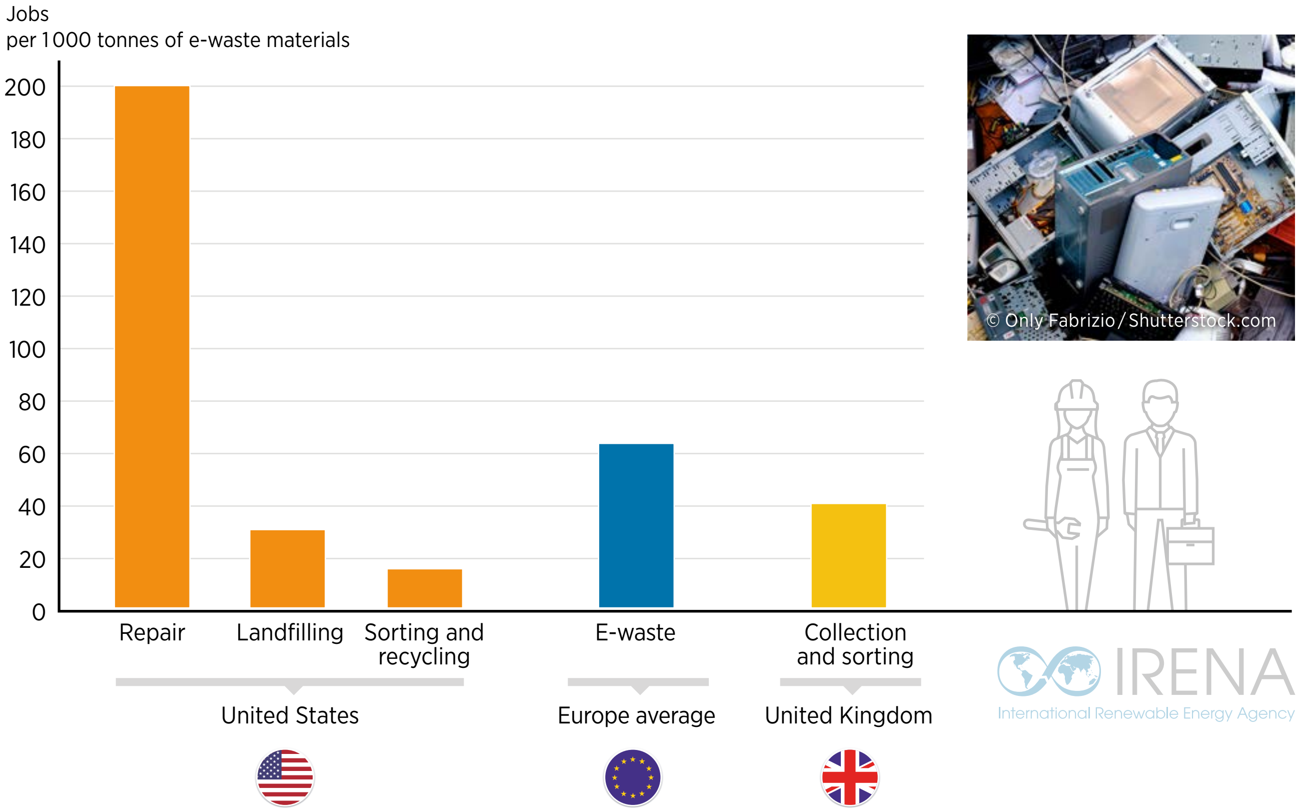
ILO studies of the management of e-waste in Argentina, India and Nigeria have shown how complex the e-waste value chain is – and how urgent the need is to protect workers from occupational safety and health hazards and to improve work conditions, particularly for migrant workers, women and children in the informal segments of the chain (ILO, 2019a, 2019c, 2019d).

Like waste from renewable energy infrastructure, e-waste contains valuable materials. In both cases, proper management of this waste has the potential to support livelihoods and the creation of innovative sustainable enterprises. Some types of renewable energy equipment, such as solar panels, are categorised as e-waste under European law. A large body of information on the challenges of and opportunities for advancing decent work in e-waste management could potentially inform the approach to managing waste from renewable energy infrastructure (ILO, 2019a, 2019e).

Regarding the creation of jobs, it is estimated that 63 jobs are created per 1 000 tonnes of collected waste electrical and electronic equipment (Figure 16). National-level studies in the United States estimate that electronics recycling supports 10 times more jobs than landfilling and that repair and remanufacturing generate over 100 times more jobs than recycling. For every 1 000 tonnes of e-waste processed, 15 jobs are created in sorting and recycling and 200 jobs are created in repair (30 in landfilling) (Rreuse, 2015). In the United Kingdom an estimated 40 jobs are created in collection and sorting for every 1 000 tonnes of e-waste (ILO, 2019a).

The impact of adopting circular approaches on job creation is promising, but the quality of those jobs must be considered. As with e-waste management, the occupational safety and health risks associated with hazardous chemicals as well as risks associated with the way waste is collected and recycled must be prioritised. Investments must be made in developing the right skills for handling this waste stream.

Figure 16 Employment in e-waste reuse in the United States, Europe and the United Kingdom



Source: Based on Rreuse (2015) and ILO (2019a).

In April 2019, the ILO convened a global meeting to adopt far-reaching consensus on ways to advance decent work in the management of e-waste (ILO, 2019a). The Global Dialogue Forum was an important platform for fostering dialogue and collaboration among governments and organisations of employers and workers and ensuring that efforts to advance circularity promote decent work across the e-waste value chain. These points of consensus can provide valuable guidance for managing the renewables waste stream while creating decent jobs and ensuring that the transition is just and inclusive. The ILO has since worked with the World Economic Forum, the UN e-Waste Coalition, the World Circular Economy Forum and the Platform for Accelerating the Circular Economy to advance decent work in e-waste management.

Supporting the human aspect of the circular transition must be approached with the same urgency and enthusiasm as technical and logistical aspects. A circular economy transition in the renewable energy sector will inevitably need to be realised through co-operation by workers and enterprises. Just transition policies, including social protections, skills training, an enabling environment for sustainable enterprises, gender inclusion and social dialogue, will ensure that no one is left behind and that both industry and society can benefit from a circular, energy-efficient, low-carbon economy. Box 6 offers a list of measures to move forward.

Box 6
Measures to promote a circular economy approach in renewable energy

Twelve actions could accelerate circularity in the design, production and management of renewable energy infrastructure:

1. Generate better and gender-disaggregated data and statistics, analysis and research.
2. Help raise awareness of circularity as critical to reducing the footprint of the industry.
3. Generate commitment at the highest levels of decision making to make circularity a shared industry goal.
4. Adopt coherent laws, regulations, policies and plans that enable a just transition to circularity.
5. Put in place supportive macroeconomic, trade, fiscal and active labour market policies.
6. Design renewable energy infrastructure for durability, reuse and safe recycling.
7. Rethink current renewable energy business models and supply chains for a thriving circular economy.
8. Incentivise the uptake and innovation of circular renewable infrastructure and business models.
9. Decrease dependence on virgin materials and reintegrate recycled materials.
10. Reduce waste and pollution and improve working conditions in the production of renewable energy infrastructure.
11. Keep infrastructure and equipment in use for longer periods of time.
12. Scale up investments in advanced maintenance, reuse, repair, closed- and open-loop recycling and waste management systems.

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Recycling opportunities in wind and solar

WIND

Some 85-90% (by weight) of the foundations, towers and wiring used in the wind industry can in principle be recycled. Fewer solutions are available for generators, which contain rare earths and other critical materials, and the materials used in blades (polymers, glass fibre and carbon fibre) represent a challenge (Graulich *et al.*, 2021). Blades already represent 10% of Europe's fibre-reinforced composite material waste. Future volumes of blades and materials will surge as installed capacities grow and new, larger blades replace older ones. Wood Mackenzie projects that onshore wind farms alone will add more than 181 000 turbines globally by 2030 (Liu and Garcia da Fonseca, 2022).

Various consortia of companies, universities and research centres are searching for ways to extract fibreglass from blades for direct reuse, downcycle turbine blades into other products, use them for civil engineering purposes or turn them into raw material for use in cement manufacturing (Laurence, 2021; Broom, 2021). In late 2021, SGRE pioneered what it calls the world's first recyclable wind turbine blade (allowing the separation of resins, fibres, wood and other materials). Developed in Aalborg, Denmark, and produced at a facility in Hull, in the United Kingdom, the first such blades were installed in July 2022 at the Kaskasi wind farm, off the coast of Germany (SGRE, 2021a; Largue, 2022). In France, a consortium of companies working with the research centre IRT Jules Verne developed a 100% recyclable blade prototype (Engie, 2021).

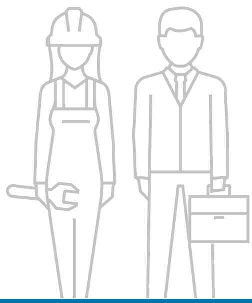
SOLAR

Solar PV deployments are expected to multiply rapidly as the energy transition gains momentum, generating growing volumes of PV panel waste in the coming decades unless action is taken to recycle or repurpose panels at the end of their lifetime. Currently, 1 MW of solar PV modules contain on average 37 tonnes of glass; 5.9 tonnes of aluminium; 1.6 tonnes of silicon and 15 kilogrammes of silver for the cells; and 0.4 tonnes of copper for cables, busbars and cross connectors. Based on IRENA's projections under its 1.5°C Scenario, global cumulative solar PV waste will amount to 4 million tonnes in 2030, almost 50 million tonnes in 2040 and more than 200 million tonnes by 2050 (IRENA, forthcoming).

A circular economy approach can create new and expanded markets and job opportunities in disassembly, repair, recycling and reuse, research, governmental regulation and other functions.[29] The value of the global solar panel recycling market is estimated at around USD 100 million in 2020. Under IRENA's 1.5°C Scenario, the volume of materials available for recycling from solar PV panel waste could be worth USD 8.8 billion by 2050, up from less than USD 500 million in 2030. Aluminium and silver would contribute close to three-quarters of the total value (IRENA, forthcoming).

Given Europe's pioneering role in solar PV deployment, countries in the region will be the first ones to confront this issue. In 2020, Europe generated some 50 000 tonnes of waste PV panels, an amount that is likely to grow to more than 350 000 tonnes in 2025 and more than 1.5 million tonnes in 2030. Glass accounts for two-thirds of the total waste stream in terms of weight and copper and aluminium for about 15%. The rest – including critical raw materials such as indium or germanium or hazardous substances such as cadmium, arsenic, lead and antimony – is currently usually incinerated (Graulich *et al.*, 2021).

Better design could reduce the quantity of materials needed and increase recyclability. Technical solutions will need to be accompanied by policy action to make recycling and reuse the standard rather than the exception and to create a skilled workforce for handling the waste. Doing so requires imposing progressively more exacting standards on manufacturers and developers of renewable energy equipment, by linking financing and other support policies to such requirements and applying the principles of extended producer responsibility, as the European Union has done in some areas. The lessons from the e-waste crisis should also spur more governments to adopt binding standards and protections to ensure that workers are not exposed to hazardous materials when equipment is disassembled, as often happens in informal settings in poor countries. Such steps can ensure that the jobs created in this final stage of the renewable energy value chain adhere to occupational safety and health standards.



29 Technology development may allow a reduction in the amount of materials needed for solar PV panels and/or reduce the share of hazardous items such as silver, tin, lead, indium, gallium, selenium, cadmium and tellurium. R&D and design could also increase the durability and recyclability of panels (IRENA and IEA-PVPS, 2016).

Chapter 4 DECENT JOBS AND SOCIAL PROTECTION FOR **A JUST TRANSITION**

4.1 CHALLENGES AND OPPORTUNITIES

Keeping average global temperatures to 1.5°C will require a swift and massive transformation of the world's energy system, including a vast scaling-up of renewable energy installations, upgrading of power grids and other energy delivery systems, creation of large energy storage systems and many related measures – with enormous implications for industrial capacities along the supply chain and broad structural underpinnings of economies around the world. Demand for needed commodities and intermediate and finished goods will soar, competing with demand from other sectors.

Workforce development is essential to making the energy transition successful. It needs to be addressed in the context of a broad policy framework that includes industrial policies, education and skills training, labour market policies, diversity and inclusion strategies, and regional revitalisation and social protection measures.

The 2021 edition of *Renewable energy and jobs: Annual review* highlighted the need for such a holistic approach to make the just transition a reality. It cited the need to address structural barriers (including fossil fuel dependence, supply chain strengths and weaknesses, and commodity and technology trade patterns); overcome potential job misalignments as the energy transition unfolds; and support workforce diversity in ways that offer equal opportunities to men and women, youth, minorities and marginalised groups. A key requirement is that renewable energy jobs are decent jobs, in terms of wages, occupational health and safety and other workplace conditions, job security and rights at work.

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Job quality in the renewable energy sector varies widely. These differences partly reflect the degree to which labour legislation exists and standards are enforced across countries. They also reveal fundamental differences in practices across the renewable energy industry landscape. Labour standards are much stronger in industries with formalised structures than in the informal sector, where there are few social protections. Jobs in the utility sector tend to offer better pay and benefits than jobs in construction or in the agricultural supply chain. Unionisation rates vary widely across industries and countries.

Some positive developments have recently occurred. In early 2022, Denmark's Ørsted (one of the world's largest offshore wind developers) struck a National Offshore Wind Agreement with North America's Building Trades Unions. Built around a Project Labour Agreement and covering all of Ørsted's contractors and subcontractors, the pact establishes an industry standard for wages, local training programmes, and occupational health and safety. For each project, it establishes Workforce Equity Committees to prioritise the recruitment and retention of people of colour, women and other disadvantaged groups, including gender non-conforming people. Ørsted has a track record of working with local building trade unions, including the South Jersey Building and Construction Trades Council, the Rhode Island Building and Construction Trades Council, and the New York Greater Capital Region Council (Ørsted, 2022).

4.2 A JUST TRANSITION FOR HOUSEHOLDS AND WORKERS

A transition that can be considered just needs not only to create decent jobs but also to offer social protection for affected workers, communities and regions during the transition and ensure that poor households are not priced out of the energy market by measures intended to reflect the full environmental costs of fossil fuels in their price. A successful and just energy transition requires strong public policy interventions and capable institutions for policy implementation, but it also rides on a productive process of bottom-up social dialogue among governments, workers, employers and other stakeholders. Not only the ultimate outcome of the energy transition but also the process of a decades-long transformation of all economies must be just.

What does the energy transition entail for jobs, workers, economies and regions?

Past energy crises offer some insights into the potential social repercussions of the energy transition. The volatility and sudden increase of energy and food prices have repeatedly triggered social unrest and had profound impacts on the labour market.

Energy is a major input for most economic activities. Through its impact on fertiliser production, food processing, transport, cooking and heating, the cost of energy has a major effect on the price of food and other basic needs. As food, transport and housing account for a large share of household expenditures, a sudden increase in energy prices is felt across the world.

The impacts are not evenly distributed. Although rich households consume more energy than poor households, energy expenditures represent a much smaller share of their income. Across all countries, energy price changes have the greatest effects on poorer households, which often spend more than half their income on food and energy. Sudden or extreme price hikes can lead to widespread social unrest and even contribute to the fall of governments.

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Globally, over 80% of total primary energy supply is still based on fossil fuels. Adding a carbon price would make the continued use of fossil fuels less attractive and thus help drive the shift to clean energy. But the higher cost of fossil fuel consumption could have social consequences similar to those caused by an energy crisis. Indeed, across the developed and developing world, social unrest has been observed, and can be expected to continue, when fossil fuel subsidies for consumers are reformed or carbon is taxed.

Carbon prices increase the costs of energy and hence of basic necessities, hurting poor households the most. Although poor and low-middle-income households would benefit the most from climate action, given their vulnerability to climate change impacts, they may oppose policies that render energy supplies more expensive if no mitigating measures are offered. Fearful of social unrest and worsening inequality, governments often shy away from carbon pricing and energy subsidy reforms. Paradoxically, global energy and income inequality is a key factor hindering climate action and slowing the energy transition.

For the energy transition to be just from a social and income distribution perspective, it must acknowledge and address the income and energy inequality paradox. Among the most successful policies are social protection programmes that offer climate action cash transfers to the poor, enacted before the implementation of energy/carbon policies. Such measures can protect the poor against an increase in the cost of basic needs while avoiding energy subsidies, which tend to benefit rich households the most. Providing protection gives governments room to take urgently needed strong climate action.

Assessing the impacts of the energy transition on jobs in different places

The energy transition will cause job creation, destruction, relocation and transformation. The scale and importance of the labour market transitions depend on each country's economic structure, industrial sectors, skills availability and policy choices.

Studies that assess the likely employment impacts of the energy transition differ on the numbers, but they all point to a global net gain of jobs (*e.g.* ILO, 2018; IRENA, 2022c). However, as each country has a unique economic and labour market structure, impacts differ from one country and region to another. In some industries, regions and labour market segments, the net impact may even be negative, if accompanying structural changes are not implemented. *Ex ante* national employment assessments are required to understand and quantify the social and employment implications and allow governments to design context-specific social and labour market responses.

Based on the findings in each setting, national just transition policy frameworks should be developed to accompany climate action, enabling economic and labour market restructuring and ensuring a just energy transition. Core objectives would be to maximise employment and income opportunities while minimising social and economic disruptions.

Just transition policies to guide countries' responses

The ILO tripartite Guidelines for a Just Transition (ILO, 2015), negotiated by representatives of governments, the private sector and labour unions, offers the building blocks of a comprehensive and globally accepted policy package:

1. Macroeconomic and fiscal policies to price pollution, incentivise employment in green goods and services, and channel funds from carbon-rich consumers to the energy poor through a Just Transition Fund.
2. Skills training, which is critical because skilled workers install, maintain and operate energy transition investments.
3. Enterprise development and well-functioning markets, which play a crucial role in rapidly increasing energy transition investments.
4. Social protection, including of informal work, which is needed to ease labour market disruptions and frictions, improve matching and prevent social unrest.
5. Social dialogue to forge a broad consensus to make the necessary transitions possible and acceptable.
6. Attention to the energy transition's implications for gender equality.

A focus on human capital is warranted, as the right skills are required to manufacture, install and maintain energy transition technologies. Providing workers with the right skills and helping them transition to the renewable energy sector requires investments in education, training and human resource development. Such spending is often misunderstood as a cost to be minimised; in fact, it is an investment that offers high economic returns, as a better-skilled labour force reduces unemployment and increases productivity and wages.

As job creation in the energy transition is concentrated among medium-skill occupations, the transition creates an enormous opportunity to create middle-class jobs. Of the nearly 25 million jobs that could be created under the ILO energy transition scenario up to 2030, almost 16 million fall into the medium-skill category (ILO, 2019b).

Key enablers for massive upskilling include investment by employers and workers in skills development. Work and skills councils, industrywide collaboration and enterprise-level agreements are conducive in that regard.

Financing just transition policies

In terms of financing a just transition, the most significant policy areas are climate targeted social protection and skills development programmes. Within and across countries, the richest 10% of households are responsible for 34-45% of global greenhouse gas emissions, the middle 40% contribute 40-53% and the bottom half contributes just 13-15% (IPCC, 2022), mirroring the inequality in final demand and income in the world. At the same time, the rich spend a smaller share of their income on energy and hence are less affected by higher energy prices. A just transition and distributive perspective implies that rich households shoulder the burden of a carbon price, with revenues used to finance climate-targeted social protection programmes, green skills development systems and labour transitioning efforts.

TAKE-AWAYS AND **THE WAY FORWARD**

Chapter 5

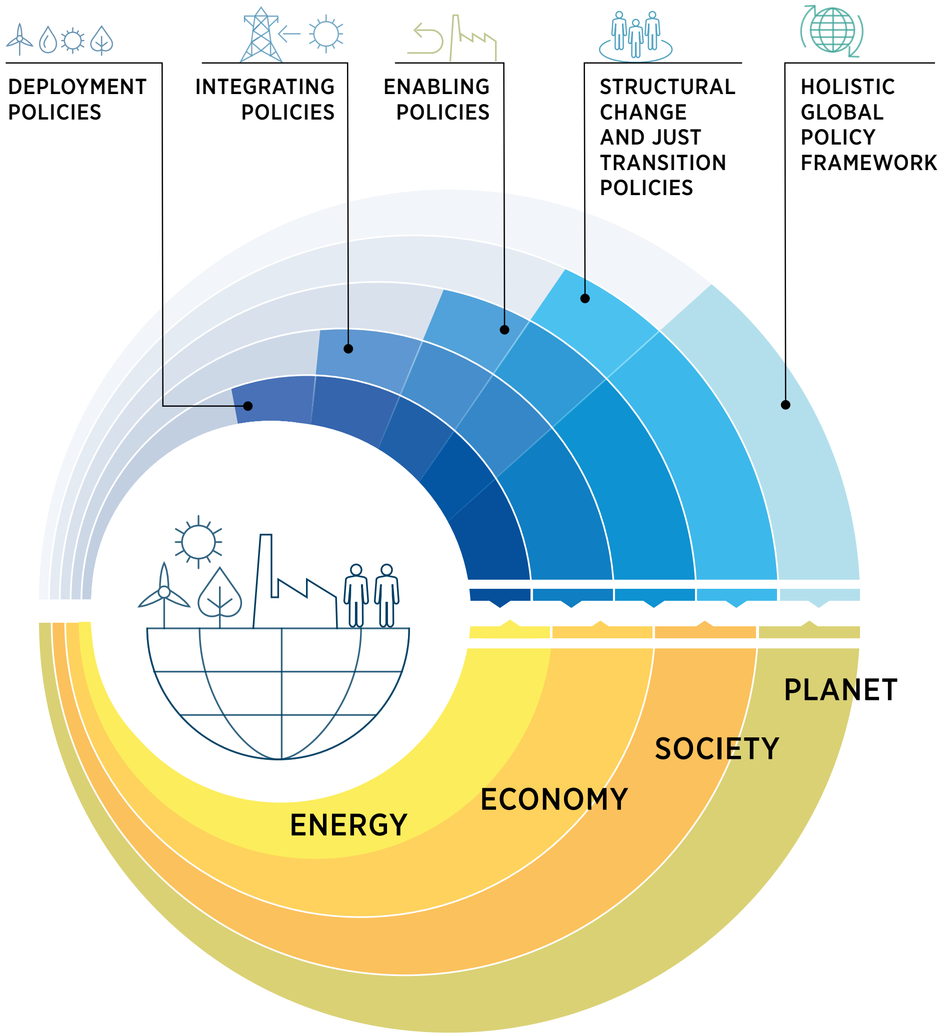
5.1 AN ALL-ENCOMPASSING APPROACH TO POLICY MAKING

The energy transition can bring many benefits. Employment in the renewable energy sector continues to expand, especially in the solar PV and wind industries. There are also growing employment opportunities (along with challenges to ensure that jobs are decent) in the upstream portions of the renewable energy value chain and in a circular economy approach after projects reach the end of their lives and are decommissioned.

Growing numbers of countries are participating in the renewable energy market. But most of the jobs created to date have been in a relatively small number of countries, led by China and including Brazil, India, the United States and EU member states. These countries lead in installations. Reflecting their strengths in equipment manufacturing, engineering and a range of services along the value chain, some of these countries also dominate exports of renewable energy equipment.

Their experience affirms the importance of adopting ambitious energy transition policies. IRENA's work points to the need for a comprehensive policy framework driven by holistic analysis (Figure 17). Such an approach starts with deployment, integrating and enabling policies in the renewable energy sector itself, but it also incorporates dedicated policies and programmes to leverage and strengthen industrial capabilities, upgrade infrastructure, build skilled workforces and reduce structural dependencies in the economy that may obstruct a successful transition.

Figure 17 A comprehensive policy framework for a just energy transition



Source: IRENA, 2022c.

The renewable energy sector navigated the challenges posed by the COVID-19 crisis reasonably well. Supply chain disruptions triggered by the pandemic linger, however, and new challenges – such as the energy sector impacts of the war in Ukraine and rising trade barriers – have pushed up shipping costs, altered global trade patterns and led to commodity price volatility.[30] Concerns about the security of supply of key semi-finished components and a range of raw materials needed for the energy transition is becoming a growing issue, though the needs and perspectives of different regions of the world vary. The upshot is greater scrutiny of supply chains and raising the appetite for localisation. At the same time, there is tension between the desire for greater local production (and local value added) and the need to ensure that solar panels and wind turbines are affordable to encourage their growing use.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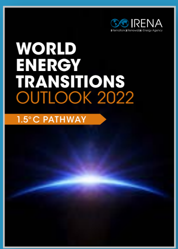
5.2 FUTURE JOB ESTIMATES AND SOCIO-ECONOMIC FOOTPRINTS

Evidence of ever more serious climate disruptions reinforces the need for momentous changes to the world's energy system in a short timeframe. The *World energy transitions outlook 2022* (IRENA, 2022c) recognised the need for urgent action during the current decade, followed by sustained efforts to 2050. It models the likely impacts, including job creation, of an ambitious 1.5°C roadmap, with upfront cumulative investments totalling USD 57 trillion by 2030. More ambitious and equity-oriented policies are likely to generate much greater socio-economic benefits than more conservative approaches (Box 7).

The need to quickly supercharge the transition puts pressure not only on continued technology development and scaling up of investments but also on workforce development (skilling and [re-]training programmes). Gender equity is also critical, so that the renewable energy sector taps more fully into the large pool of talent and ideas among women. Bringing in youth, minorities and disadvantaged groups is also important.

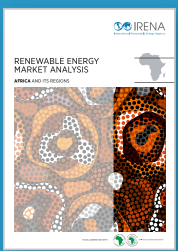
30 The cost of new onshore wind projects rose 7% between 2021 and 2022 and that of new fixed-axis solar farms by 14%, reflecting increases in the cost of materials, freight, fuel and labour. However, fossil fuel power generation costs rose even more (BNEF, 2022).

Box 7
Energy transition jobs potential to 2030 and 2050



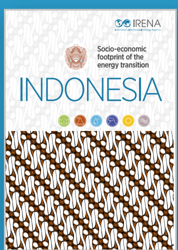
The 2022 edition of the Outlook assesses impacts of two transition scenarios, a Planned Energy Scenario (PES), based on current policies and plans, and a much more ambitious 1.5°C Scenario. The global economy creates more jobs under the 1.5°C Scenario than under the PES.

Globally, the number of workers employed in the energy sector by 2030 could rise to 139 million under the 1.5°C Scenario, 31% more than the 106 million under the PES. Losses in fossil fuel industries would be more than offset by gains in renewables and other energy transition technologies. The number of renewable energy jobs would rise from today's 12.7 million to 38.2 million in 2030 (more than double the 17.4 million under the PES). Energy efficiency, electric vehicles, power systems/flexibility and hydrogen could employ another 74.2 million people by 2030 (62 percent more than the 45.8 million under the PES). The number of jobs created by 2050 is also substantially greater under the 1.5°C Scenario than under the PES.



A report on Africa (IRENA and AfDB, 2022) indicates that the energy transition holds enormous potential there. On average, the number of jobs created between 2022 and 2050 under the 1.5°C pathway is 3.5% greater than under the PES, underscoring the importance of more diversified economies, industrial development and innovation. The energy transition could boost employment in renewables substantially from around 350 000 in 2020 to over 4 million by 2030 and over 8 million by 2050 under the 1.5C Scenario. Most of these jobs would be in solar, bioenergy, and wind.

IRENA is continuing its work on regional and national-level energy transition assessments, with reports on Japan, Indonesia, the Association of Southeast Asian Nations (ASEAN), Egypt and South Africa, as well as a planned series of regional energy transitions outlooks in Africa, Latin America and the Caribbean, and Europe. Frontloaded investments are key, given the need to kick the energy transition into high gear as quickly as possible.



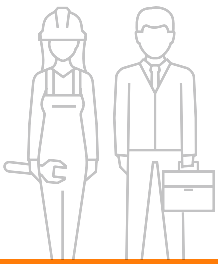
The **Japan** analysis projects a rise of renewable energy employment under the 1.5°C pathway from 330 000 jobs in 2019 to 957 000 in 2030 and 792 000 in 2050 (IRENA, forthcoming, 2022a). In **Indonesia**, an ambitious transition could raise renewable energy jobs to 2 million in 2030 and 2.5 million in 2050, principally in bioenergy and solar (IRENA, forthcoming, 2022b).

The *Renewable energy and jobs: Annual review* series is part of a broad portfolio of ongoing work by IRENA that examines the socio-economics of the global energy transition (Figure 18). This work includes analysis of opportunities for local value creation (the *Renewable energy benefits* series); modelling of the GDP, employment and human welfare impacts of the transition in coming decades (the *World energy transitions outlook* and related reports); assessments of the gender aspect of renewable energy (the A gender perspective series) and studies of energy access.

Figure 18 IRENA reports on employment in the renewable energy sector and the socio-economics of the energy transition, 2011-2022

IRENA is also working with a broad range of partners to ensure that the socio-economic impacts of the energy transition are understood. A working group on Sustainable Energy Jobs under the umbrella of IRENA's Coalition for Action brings together stakeholders from intergovernmental organisations, the private sector, organised labour and civil society, chaired by the ILO. The objectives of the working group include improving knowledge and understanding of key challenges and opportunities; sharing best practices, experiences and quality data; and strengthening capacity building with regard to the policies, regulations and approaches needed to effectively manage energy-employment interlinkages. IRENA has also established a collaborative framework on just and inclusive energy transitions – co-facilitated by the United States and South Africa – that seeks to facilitate both peer-to-peer engagement among countries on lessons learned from just transition efforts and multistakeholder exchanges.

Expanding renewable energy employment – fulfilling the potential for job creation and increasing other socio-economic benefits of an ambitious energy transition pathway – requires a comprehensive and holistic package of policies in all countries. Rather than go it alone, countries can reap substantial advantages from a far-sighted collaboration that seeks to share technological advances, financial resources and policy insights while keeping equitable outcomes as a core objective.



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