IRENA
International Renewable Energy Agency

Renewable Energy and Jobs

Annual Review **2018**

IRENA
International Renewable Energy Agency

Key Numbers

10.3 million jobs in 2017

5.3 % growth

43 % of all RE jobs are in China

3.4 million jobs are in the solar industry

1.5 x job growth from 2012 (excl. large hydro)

KEY FACTS

Annual Review 2018

- Global renewable energy employment reached 10.3 million jobs in 2017, an increase of 5.3% compared with the number reported in the previous year.
- An increasing number of countries derive socio-economic benefits from renewable energy, but employment remains highly concentrated in a handful of countries, with China, Brazil, the United States, India, Germany and Japan in the lead.
- China alone accounts for 43% of all renewable energy jobs. Its share is particularly high in solar heating and cooling (83%) and in the solar photovoltaic (PV) sector (66%), and less so in wind power (44%).
- The PV industry was the largest employer (almost 3.4 million jobs, up 9% from 2016). Expansion took place in China and India, while the United States, Japan and the European Union lost jobs.
- Biofuels employment (at close to 2 million jobs) expanded by 12%, as production of ethanol and biodiesel expanded in most of the major producers. Brazil, the United States, the European Union and Southeast Asian countries were among the largest employers.
- Employment in wind power (1.1 million jobs) and in solar heating and cooling (807 000 jobs) declined as the pace of new capacity additions slowed.
- Large hydropower employed 1.5 million people directly, of whom 63% worked in operation and maintenance. Key job markets were China, India and Brazil, followed by the Russian Federation, Pakistan, Indonesia, Iran and Viet Nam.
- Employment remains limited in Africa, but the potential for off-grid jobs is high, particularly as energy access improves and domestic supply chain capacities are developed.

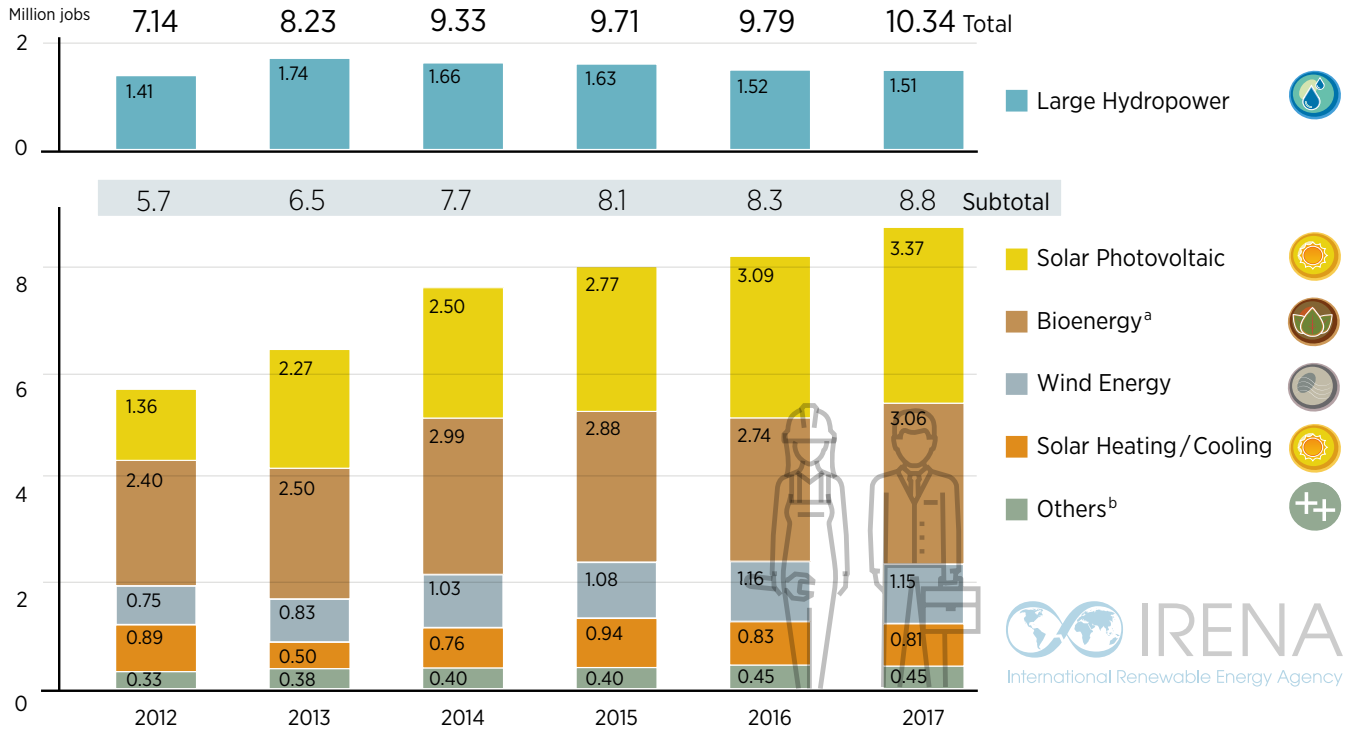
RENEWABLE ENERGY AND JOBS Annual Review 2018

The renewable energy sector, including large hydropower, employed 10.3 million people, directly and indirectly, in 2017[1]. This represents an increase of 5.3% over the number reported the previous year.

Renewable energy employment worldwide has continued to grow since IRENA's first annual assessment in 2012. During 2017, the strongest expansion took place in the solar photovoltaic (PV) and bioenergy industries. In contrast, jobs in wind energy and in solar heating and cooling declined, while those in the remaining technologies were relatively stable (Figure 1).

1 Data are principally for 2016-17, with dates varying by country and technology, including some instances where only earlier information is available. The data for large hydropower include direct employment only.

FIGURE 1: **GLOBAL RENEWABLE ENERGY EMPLOYMENT BY TECHNOLOGY, 2012-17**



Source: IRENA jobs database.

Note: The numbers shown in this Figure reflect those reported in past editions of the Annual Review.

a Includes liquid biofuels, solid biomass and biogas

b Other technologies include geothermal energy, hydropower (small), concentrated solar power (CSP), heat pumps (ground-based), municipal and industrial waste, and ocean energy.

Employment trends and patterns are shaped by a wide range of technical, economic and policy-driven factors. The falling costs of renewable energy technologies continue to spur the deployment of renewables, and during 2017, total investments edged up over 2016. Job creation dynamics are subject to geographic shifts in the production and installation of renewable energy equipment. Corporate strategies and industry realignments are important factors in this context, as portions of the supply chain become more globalised and geographically differentiated.

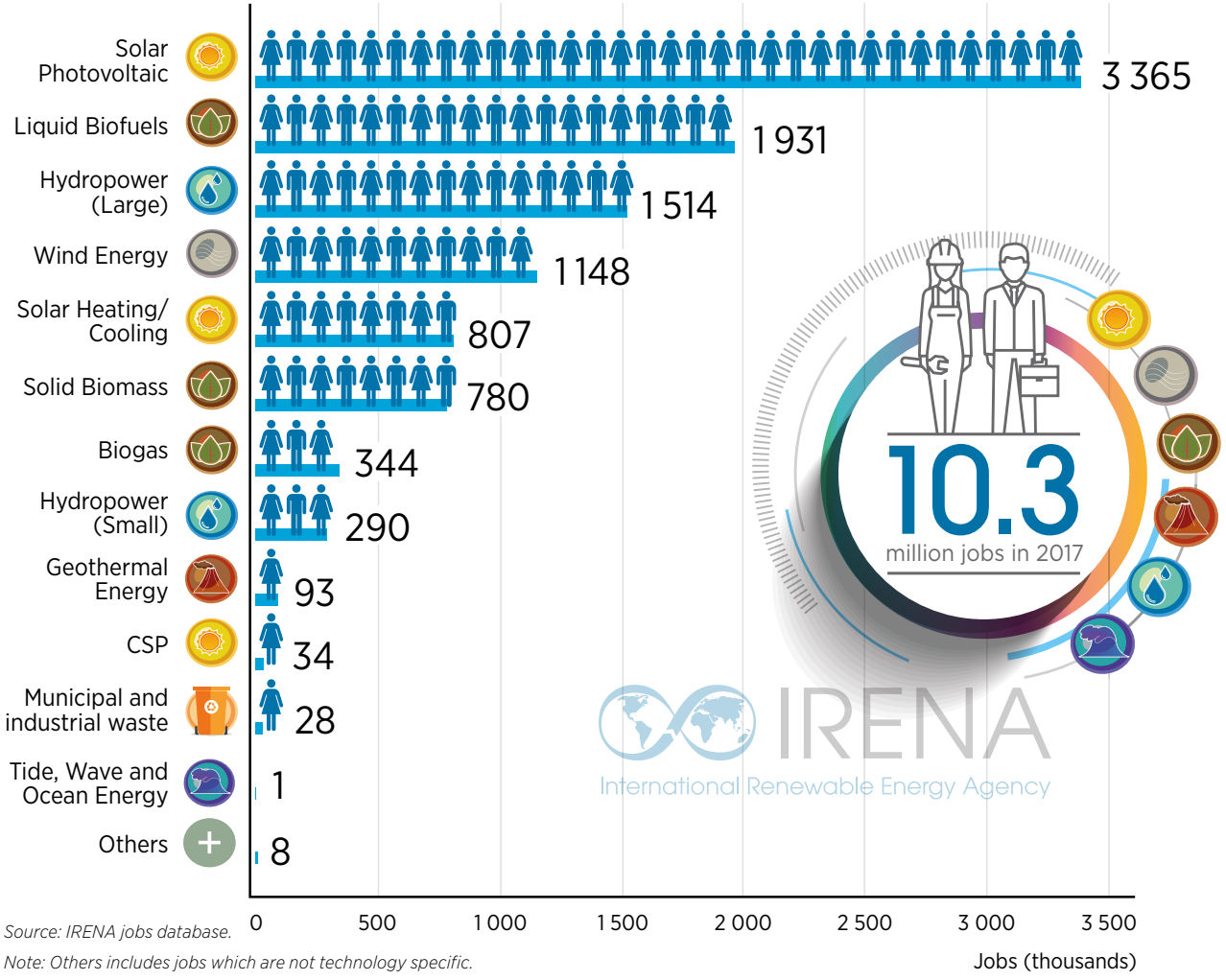
Governmental policy, including the degree of commitment to transforming the energy sector, is also a key factor (IRENA, IEA and REN21, 2018). Policy encompasses mandates, regulations and market design in support of deployment, as well as industrial policies to create and strengthen domestic value creation. Where policies become less favourable to renewable energy, change abruptly or invite uncertainty, the result can be job losses or lack of new job creation. On the other hand, expectations of adverse policy changes can lead project developers to push forward a portfolio of projects that would otherwise be initiated later, in order to beat a certain cut-off date. The result in such cases is a temporary surge of activity and employment creation, followed by a drop. In the United States, for instance, the expected imposition of tariffs on solar PV panel imports led to larger deployments in 2016 but a slower pace during 2017.

Labour productivity has grown in importance as renewable energy technologies have matured, processes have been automated, and economies of scale and learning effects have risen. As previous editions of this Review have pointed out, bioenergy feedstock harvesting is subject to growing mechanisation in some countries. Automation of solar PV panel manufacturing is already well advanced.

This fifth edition of *Renewable Energy and Jobs – Annual Review* provides the latest available estimates and calculations on renewable employment. It represents an ongoing effort to refine the data, including IRENA's own methodology. Global numbers are based on a wide range of studies with varying methodologies and uneven detail and quality[2].

The first section highlights employment trends by technology (Figure 2). It discusses employment in solar PV, liquid biofuels, wind, solar heating and cooling, and large hydropower (Box 1). For other technologies which employ far fewer people, less information is available. The second section offers insights for selected countries. In addition, gender aspects (Box 2) and off-grid developments (Box 3) are discussed.

FIGURE 2: **RENEWABLE ENERGY EMPLOYMENT BY TECHNOLOGY**



Source: IRENA jobs database.

Note: Others includes jobs which are not technology specific.

2 Prominent methodologies include input-output modelling, industry surveys and employment-factor calculations, with varying degrees of detail and sophistication. For the most part, the employment numbers in this report cover direct and indirect (supply chain) jobs. The data for large hydropower include direct employment only.

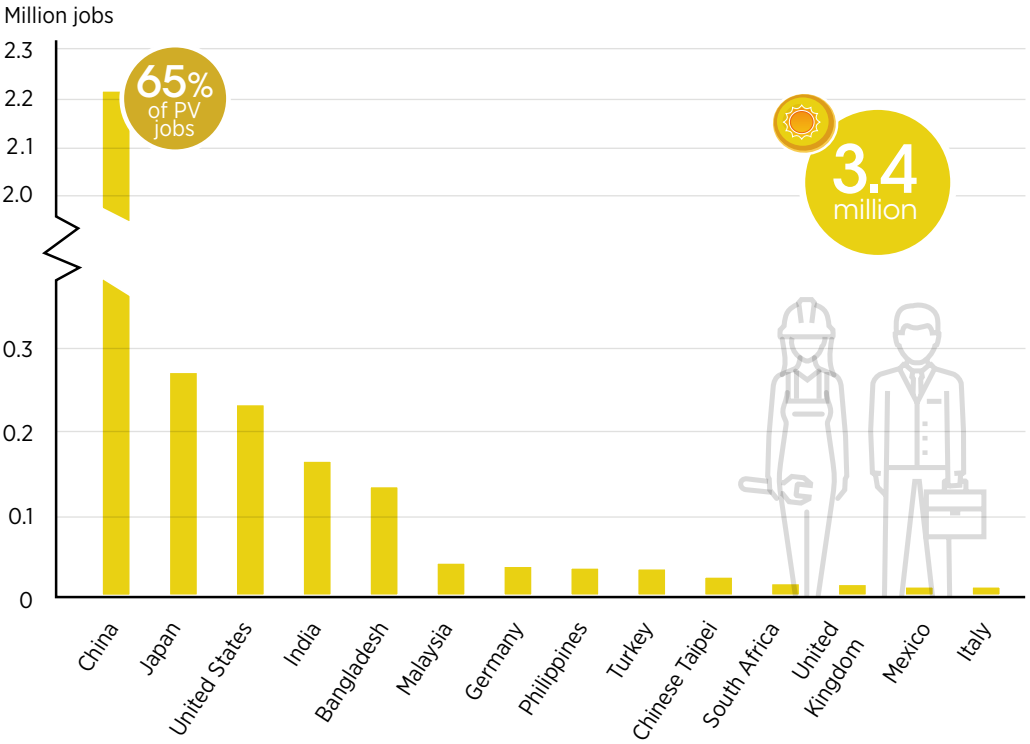
RENEWABLE ENERGY EMPLOYMENT BY TECHNOLOGY

SOLAR PHOTOVOLTAICS

Globally, the solar PV industry had another banner year, with record installations of 94 gigawatts (GW) during 2017, up from 73 GW in 2016, and significant new job creation. China, India, the United States and Japan were the most important markets, followed by Turkey, Germany, Australia and the Republic of Korea (IRENA, 2018b). Employment increased by 8.7% to approach 3.37 million jobs in 2017[3].

A key feature of the solar PV landscape is that jobs remain highly concentrated in a small number of countries. This can be attributed to the fact that the bulk of manufacturing takes place in relatively few countries and domestic markets vary enormously in size. The top five countries, led by China, account for 90% of solar PV jobs worldwide. Of the leaders shown in Figure 3, eight are Asian. Overall, Asia is home to almost 3 million solar PV jobs. This represents 88% of the global total, followed by North America's 7% share and Europe's 3%.

FIGURE 3: **LEADERS IN SOLAR PV EMPLOYMENT**



Source: IRENA jobs database.

Note: The threshold for inclusion in the figure is 10 000 jobs.

3 The countries for which IRENA's database has solar PV employment estimates represent 387 GW of cumulative installations, or 99% of the global total. They also represent the same share of the 94 GW of new installations in 2017.

Reflecting its unchallenged status as the leading producer of PV equipment and the world's largest installation market, China accounted for about two-thirds of PV employment worldwide, or some 2.2 million jobs. Job gains were once again strongest in the installations segment, which now accounts for 36% of China's PV jobs (CNREC, 2018). Likewise, strong growth in new capacity additions boosted employment in India to an estimated 164 000 jobs.

By contrast, European PV employment continued its downward slide, reflecting limited domestic installation markets and a lack of competitiveness among European module manufacturers. Revised estimates indicate an 8% decrease to 99 600 jobs across the European Union in 2016[4] (EurObserv'ER, 2018). More surprisingly, US employment fell as well, for the first time, to about 233 000 jobs[5] (Solar Foundation, 2018). Japan's slowing pace caused employment to fall from 302 000 in 2016 to an estimated 272 000 jobs in 2017.

As deployment of solar PV continues to expand, more and more countries will benefit from job creation along the supply chain, primarily in installations and operations and maintenance (O&M) (IRENA, 2017b).

LIQUID BIOFUELS

With the exception of Brazil, all major bioethanol producers were estimated to have reached new output peaks in 2017. Biodiesel production also rose in many of these countries, but remained somewhat below previous levels in Argentina, Indonesia and the Philippines, and at much lower levels in China[6]. Worldwide employment in biofuels is estimated at 1.93 million, a change of 12%. Most of these jobs are generated in the agricultural value chain (in planting and harvesting of feedstock).

The construction of fuel-processing facilities and O&M of existing plants employ fewer people, but typically require higher skills and offer better pay.

It should be noted that changes in biofuels employment do not necessarily equate to net job gains or losses. Oil palm, soybean and similar types of feedstock are used for a range of agricultural and commercial purposes in addition to the energy sector, and the composition of end-use demand is relatively fluid.

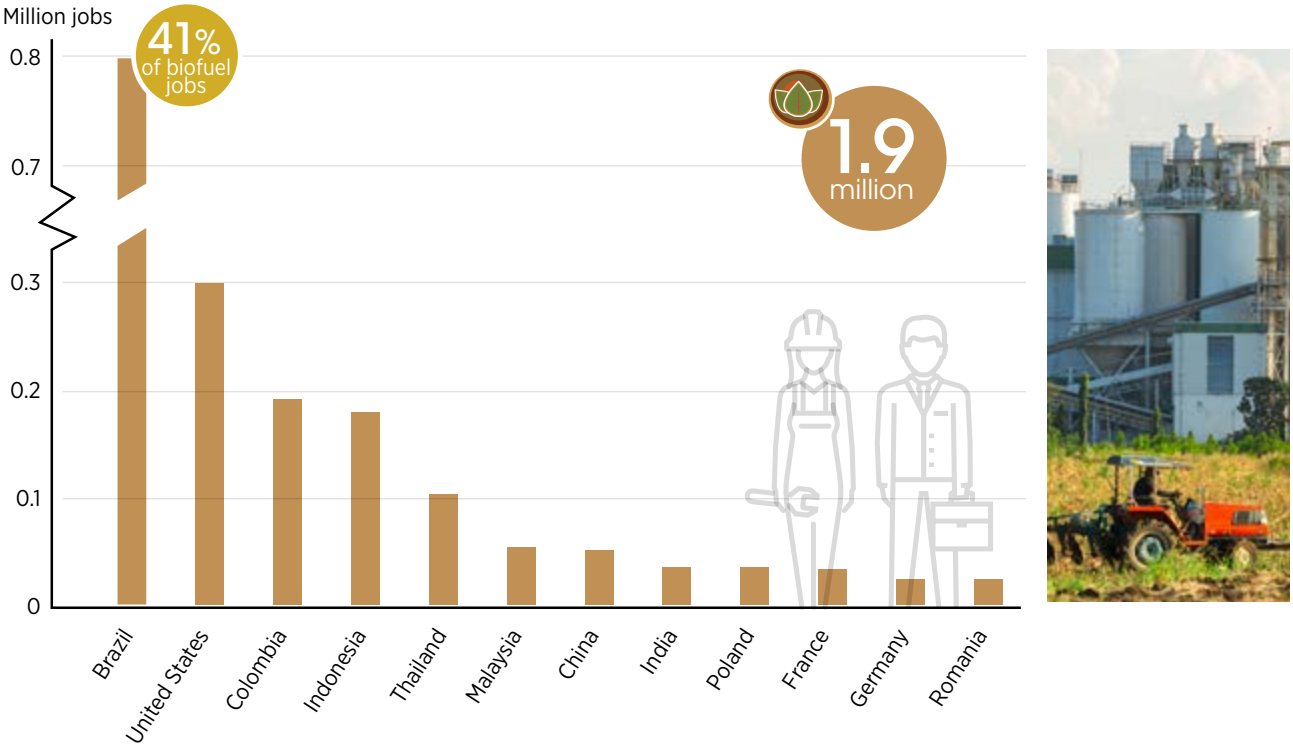
The regional profile of biofuels employment differs considerably from that of the solar PV sector. Latin America accounts for half the jobs worldwide, whereas Asia (principally labour-intensive Southeast Asian feedstock supply activities) accounts for 21%, North America for 16% and Europe for 10%. Figure 4 includes the dozen countries with at least 10 000 jobs and shows that the top 5 alone account for about 80% of global estimated employment.

4 The jobs data for the European Union and its member states throughout this report are for 2016, the most recent year for which such information is available. Details are at the EurObserv'ER website, https://www.eurobserv-er.org/17th-annual-overview-barometer/.

5 The Solar Foundation carries out an annual survey of employment across all solar technologies, but does not offer a breakout for solar PV jobs. The figure reported here is an IRENA estimate.

6 The 2017 production estimates are derived from the national biofuels reports published by the US Department of Agriculture's Foreign Agriculture Service, available at https://www.fas.usda.gov/commodities/biofuels.

FIGURE 4: **LEADERS IN LIQUID BIOFUELS EMPLOYMENT**



Source: IRENA jobs database.

Note: The threshold for inclusion in the figure is 20 000 jobs.

Brazil continued to have the largest liquid biofuel workforce. The estimated 795 000 jobs indicate a small increase from the previous year. Employment also rose in the United States, buoyed by record production of ethanol and biodiesel (Urbanchuk, 2018). Biofuel output and employment also expanded in the European Union, which had an estimated 200 000 jobs in 2016 (EurObserv'ER, 2018).

Indonesia's biofuels production has experienced a roller-coaster in recent years, impacted by changing export demand. Production in 2017 fell again, though not as dramatically as in 2015 (USDA-FAS, 2017a). Based on its employment-factor approach, IRENA estimates that close to 180 000 people worked in Indonesia's biodiesel sector in 2017, a 22% decline from the previous year[7]. Biofuel output reached new peaks during 2017 in Malaysia and Thailand. IRENA estimates that these two countries together employed some 133 000 people, with most of the jobs in feedstock supply[8].

Colombia is another important and labour-intensive Latin American biofuel producer. Its output in 2017 rose to a high of about 1 billion litres in 2017 (USDA-FAS, 2017b). Estimates based on data published by Federación Nacional de Biocombustibles de Colombia (FNBC, n.d.) suggest the number could have been as high as 190 800 jobs in 2017, but it is unclear whether these represent full-time equivalents.

7 The calculation relies on revisions of an employment factor initially developed by APEC (2010). This factor is applied as a constant each year for smallholder production, which accounts for 45% of volume (WWF, 2012) and is more labour intensive than large-scale plantations. For plantations, IRENA applies an assumed "decline" factor of 3% per year as a proxy for rising labour productivity.

8 In Thailand, IRENA estimates 102 600 jobs. Smallholders have a 73% production share, an average of values reported by Termmahawong (2014) and by RSPO (2015). In Malaysia, smallholders account for 35% of production (WWF, 2012). IRENA estimates 29 700 jobs in Malaysia. In addition, IRENA estimates 35 400 jobs in the Philippines.

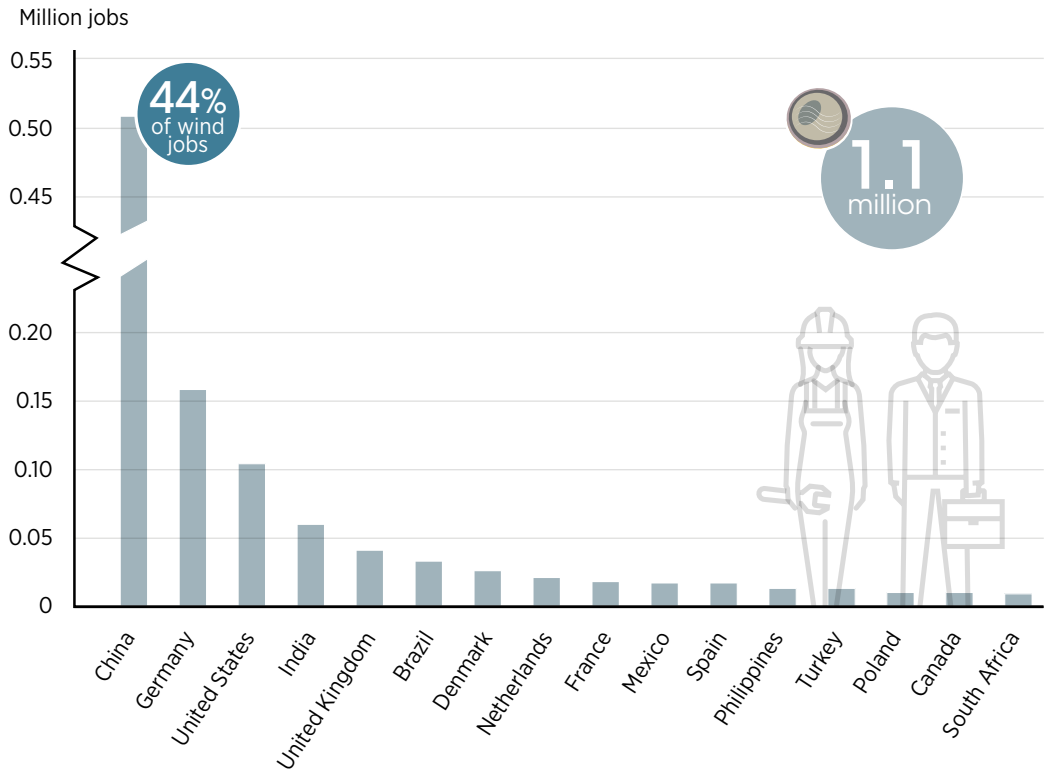
WIND

Including its onshore and offshore segments, the wind industry employs 1.15 million people worldwide, a 0.6% decrease from 2016[9]. Most wind jobs are found in a small number of countries, although the degree of concentration is lower than in the solar PV sector. China alone accounts for 44% of global wind employment. The top five countries represent 76% of the total. The regional picture is also somewhat more balanced than in the solar PV industry. Asia's 610 000 wind jobs make up about half the total, while Europe accounts for 30% and North America 10%. Of the top 16 countries shown in Figure 5, seven are European, four are Asian[10], three are from North America and one each is from Africa and South America.

China retained its undisputed lead in both new and cumulative installations during 2017. While new wind installations decreased 15%, those in the job-intensive offshore sector increased by 26%. The country's total wind employment remained steady at 510 000 jobs (CNREC, 2018). Following China, five countries – Germany, the United States, India, the United Kingdom, and Brazil – together accounted for another 50% of global installations.

Wind employment in the United States edged up by 3% to a new high of 105 500 jobs in 2017 (AWEA, 2018). Brazil's pace of installations remained roughly at the level of 2015, with employment estimated at 33 700 jobs.

FIGURE 5: **LEADERS IN WIND EMPLOYMENT**



Source: IRENA jobs database.

Note: The threshold for inclusion in the figure is 10 000 jobs.

9 *The countries for which IRENA's database has wind power employment estimates represent 511 GW of cumulative installations, or 99% of the global total. They also cover the same share of the 46 GW of new installations in 2017.*

10 *For the purposes of this report, Turkey is counted as part of Asia.*

Employment in Europe's wind sector reached 344 000 jobs in 2016 (the year with the latest available data), representing a 10% increase over 2015. New wind installations amounted to 15.6 GW during 2017, up 25% from 2016. Some 12.5 GW added onshore and 3.2 GW offshore brought the continent's cumulative total to 168.7 GW (Wind Europe, 2018b). Europe's wind industry is a global technology leader, especially in the offshore segment, where it accounts for 88% of installed capacity worldwide.

Export markets hold considerable importance for sales and jobs; some European sites produce exclusively for export (Deloitte and Wind Europe, 2017).[11]

Competition among manufacturers and service providers is intensifying internationally; requirements in some countries to source a certain share of equipment, components and services locally are reshaping the industry; and the supply chain is becoming more globalised. More than 80% of European wind firms have either a manufacturing or commercial presence in other parts of the world (Deloitte and Wind Europe, 2017). As a recent example, Danish turbine manufacturer Vestas announced in early 2018 plans to build a hub and nacelle assembly facility in Argentina, where it has sold its products since 1991 (Weston, 2018).

With a diversifying global supply chain, employment will be created in growing numbers of countries. IRENA's work has documented the opportunity to create jobs along the supply chain (IRENA, 2017c, 2018c).

SOLAR HEATING AND COOLING

The available information for 2017 shows a decline in major solar heating and cooling markets including China, Brazil and India (Epp, 2018). IRENA estimates that global employment in the sector stood at 807 000 jobs in 2017, a 2.6% decrease from the previous estimate.

Estimates for China suggest that employment declined from the previous year (CNREC, 2018). The country has long been the clear leader in deployment of solar heating and cooling, and still accounts for 83% of total jobs in the sector. The top five countries account for 94% of all jobs. Of the top 10, four countries each are from Asia and Europe.

Employment in the European Union is thought to have declined slightly in 2016 (the most recent year with available data), to 34 300 jobs[12]. The Brazilian market declined for a second year in a row, by 3% in 2017 (ABRASOL, 2018). IRENA's employment-factor-based estimates[13] suggest that the country's employment in this sector fell slightly, to about 42 400 jobs. Turkey has an estimated 16 600 people working in this sector (Akata, 2018). In the United States, employment was estimated by IRENA at 12 500 jobs in 2017. For India, where annual installations have fluctuated in recent years, the employment-factor calculation suggests that the country may have had some 17 240 jobs in 2017, when 1.5 million square metres of collector area was added (Epp, 2018).

11 This is the case, for instance, at Enercon's Viana do Costelo manufacturing cluster in Portugal (tower, blades and generators), and at Vestas' Daimiel blade factory in Spain. In Portugal, the site provides employment for 2 500 people directly and indirectly; the Spanish factory employs 1 000 people directly (Deloitte and Wind Europe, 2017).

12 Eurobserv'ER (2018) reports a combined 29 000 jobs for solar heating and cooling and concentrating solar power but national-level reports suggest a higher figure of 39 900. Of these, there are some 5 600 CSP jobs in Spain and Germany. On the basis of these numbers, the solar heating and cooling employment is estimated at 34 300 jobs.

13 IRENA uses an employment factor of one full-time job per 87 square metres installed, as suggested by IEA SHCP (2016).

HYDROPOWER

As described in previous editions of this publication, estimating employment in hydropower is quite challenging, as data remain surprisingly scarce and it is difficult to clearly distinguish small from large hydropower jobs. Small hydropower is estimated to have employed 290 000 people in 2017. Large hydropower employed about 1.5 million people directly in 2017, with the majority in the O&M segment of the value chain (Box 1). The global estimates for 2013-17 have been updated following a major revision of employment factors, statistics and available data from countries. Temporal and geographic variations in labour productivity were also reviewed.

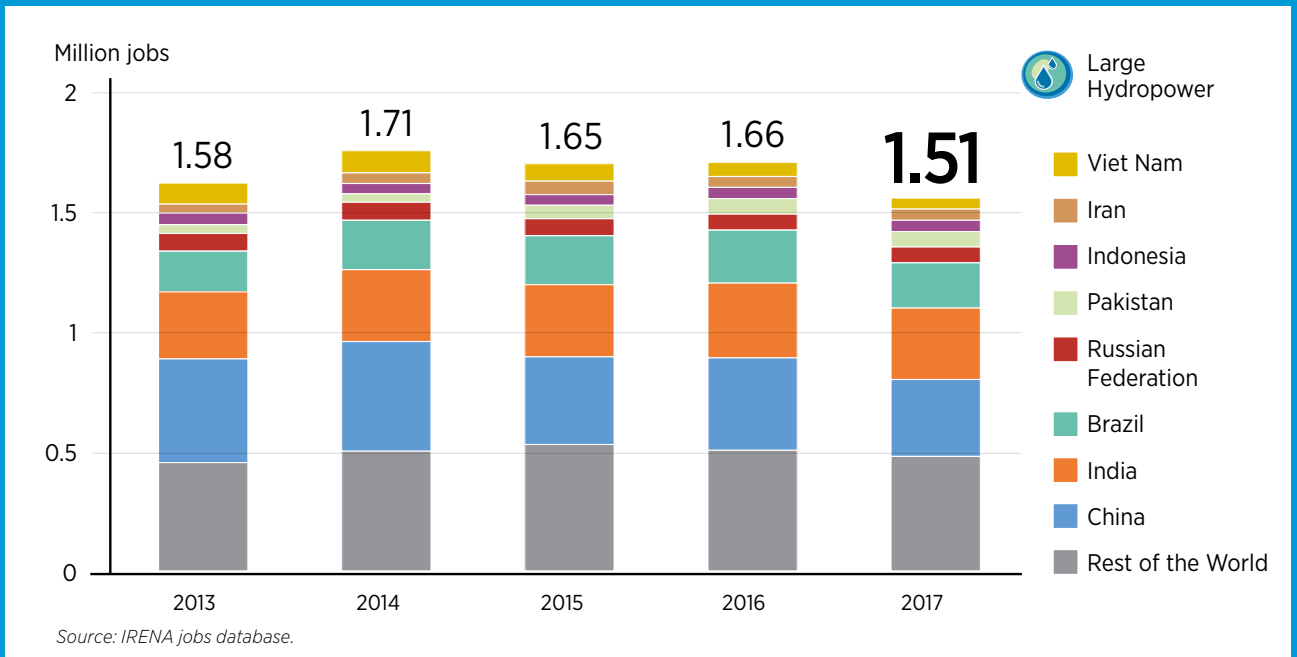
BOX 1. EMPLOYMENT IN LARGE HYDROPOWER

Information on employment in the hydropower sector remains sparse. For the fourth year in a row, IRENA estimates the number of jobs in large hydropower through an employment-factor approach that allows an examination of direct jobs in the different segments of the value chain (manufacturing; construction and installation; and O&M).

This year's calculations indicate approximately 1.5 million direct jobs in 2017, a decline of 10% from the previous year. The drop was primarily driven by developments in China and Brazil, where new installations in 2017 levelled off from the earlier rapid pace of capacity additions. The key job markets in the sector are China, India and Brazil, which together account for 52% of total direct employment (Figure 6).

China's share of large-hydropower employment declined by 20% in 2017 because of rising labour productivity and a drop in new installations. India's

FIGURE 6: EVOLUTION OF LARGE HYDROPOWER EMPLOYMENT BY COUNTRY

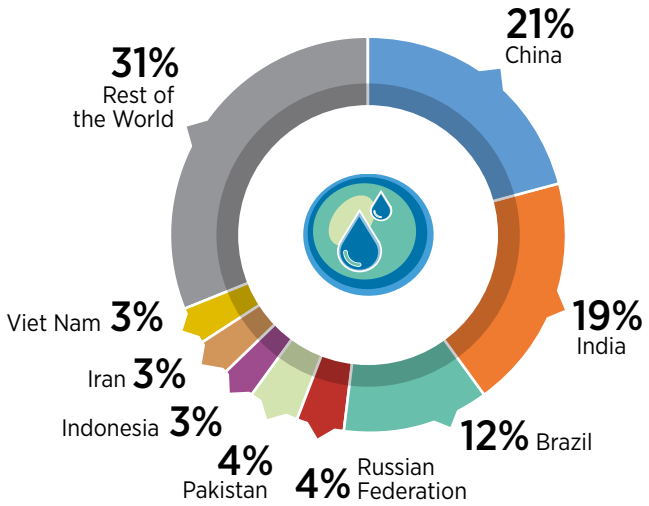


Source: IRENA jobs database.

labour-intensive hydropower sector accounted for 19% of the jobs, followed by Brazil (12%), the Russian Federation (4%) and Pakistan (4%). Other relevant employers include Indonesia, Iran and Viet Nam (3% each) (Figure 7).

The results provide interesting insights into segments of the renewable energy value chain. Given the large cumulative capacities installed, 63% of the direct jobs in the global large hydropower sector are found in O&M. In fact, O&M employs more than 932 000 people to service the 1 terawatt of installed capacity worldwide. The share of jobs in construction and installation decreased from 38% in 2016 to 30% in 2017, owing to a leaner project pipeline. The manufacturing segment, because of its lower labour intensity, remains a distant third.

FIGURE 7: **EMPLOYMENT IN LARGE HYDROPOWER BY COUNTRY IN 2017**



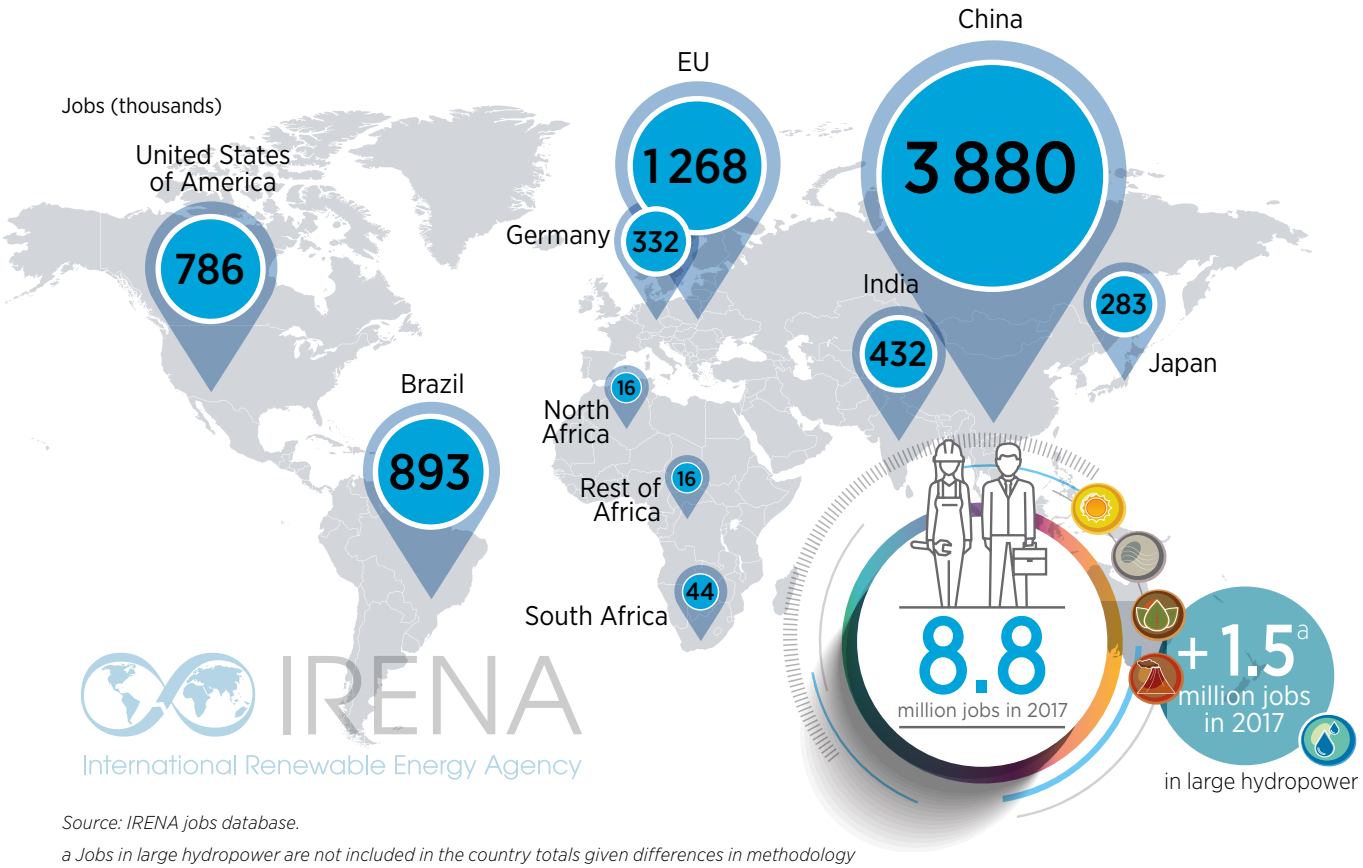
Source: IRENA jobs database.

RENEWABLE ENERGY EMPLOYMENT IN SELECTED COUNTRIES

The renewable energy sector employed 10.3 million people, directly and indirectly, in 2017. Excluding large hydropower, employment increased by 6.3% to reach 8.8 million in 2017. As in previous years, the leading renewable energy job markets were China, Brazil, the United States, India, Japan and Germany (Figure 8). This section presents key country-level trends. Jobs in the hydropower sector have not been included in this analysis because job estimates for large facilities include only direct jobs (based on the IRENA employment-factor approach), whereas data for most other renewables include both direct and indirect jobs (primarily based on data collection from primary and secondary sources).

Overall, renewable energy employment continued to shift towards Asian countries, which accounted for 60% of jobs in 2017, compared with 51% in 2013. Most of Asia's dynamism is based on growing domestic deployment and strong manufacturing capabilities, supported by policies such as feed-in tariffs, auctions, preferential credit and land policies, and local content rules.

FIGURE 8: **RENEWABLE ENERGY EMPLOYMENT IN SELECTED COUNTRIES**



Source: IRENA jobs database.

a Jobs in large hydropower are not included in the country totals given differences in methodology and uncertainties in underlying data. However, data for the EU and Germany include large hydropower jobs.

As in past years, **China** continued to have the largest number of people employed, accounting for 43% of the world's total. The number climbed from 3.6 million jobs in 2016 to 3.8 million in 2017, a growth of 5% (CNREC, 2018). This was entirely due to the continued expansion of the solar PV sector. Employment in solar water heating declined, and remained essentially unchanged in other renewable energy sectors. Solar PV employment was estimated at 2.2 million jobs, an expansion of 13% over the previous year. Of these jobs, almost 1.4 million were in manufacturing. Following the record solar PV installations in 2017, some 792 000 people were working in the construction and installation segment, 25% more than in 2016.

Wind employment was estimated at 510 000 jobs in 2017. The pace of new installations, at 15 GW, was somewhat slower than in 2016. However, installations in the job-intensive offshore wind energy sector rose by 26%. Increased localisation of the value chain and growth in exports ensured that employment in the sector remained steady.

Employment in the Chinese solar water heating industry continued its downward trend. After a 2.8% drop in 2017, employment in the sector stood at 670 000 jobs. The other renewable energy technologies weigh less heavily: solid biomass at 180 000 jobs, biogas at 145 000, small hydropower at 95 000, biofuels at 51 000 and concentrated solar power at 11 000. This year's estimates also include, for the first time, a figure of 2 000 jobs in geothermal heat.

In **Brazil**, most renewables employment is still in liquid biofuels and large hydropower. Total biofuel employment rose by 1% in 2017 to 593 400 jobs. Ethanol jobs declined due to the steady automation of feedstock supply and a decline of ethanol production (USDA-FAS, 2017c)[14].

While ethanol-related employment fell, it was more than offset by gains in biodiesel jobs (ABIOVE, 2018). IRENA estimates that Brazil employed 202 000 people in biodiesel in 2017, up more than 30 000 from the previous year[15].

Brazil's wind industry added about 2 GW in 2017, about the same as during the preceding year (GWEC, 2018), to reach a cumulative 12.8 GW. Correspondingly, IRENA's employment-factor-based calculation yields a wind power workforce of about 33 700 people in nacelle and blade manufacturing; tower construction and installation; and O&M[16].

New installations in Brazil's solar heating market declined by 3% in 2017 (ABRASOL, 2018). Total employment in 2017 was estimated at about 42 000 jobs, with about 27 500 in manufacturing and 14 500 in installation[17].

14 In 2016, Brazil had around 225 400 workers in sugarcane cultivation and 164 900 workers in ethanol processing (MTE/RAIS, 2018). A rough and dated estimate suggests that there may be another 200 000 indirect jobs in equipment manufacturing.

15 Calculation based on employment factors for different feedstocks (Da Cunha et al., 2014). The shares of different feedstock raw materials are derived from USDA-FAS (2017c). Soybean oil accounts for the bulk (about 71%), followed by beef tallow (16%) and cotton seed and vegetable oils (13%).

16 This calculation is based on employment factors published by Simas and Pacca (2014).

17 This IRENA calculation of installation jobs is based on Brazilian market data and a solar heating and cooling employment factor. The estimate for manufacturing jobs is derived from an original 2013 estimate by Alencar (2013).

The **United States** experienced its first job loss in the solar sector since 2010 when the Solar Jobs Census (Solar Foundation, 2018) first began tracking employment. The number of solar jobs fell by 9 800 or 3.8%, to about 250 000[18]. Most of the loss took place in the installation segment, affected by a 22% reduction in new capacity additions, particularly of utility-scale plants. The contrast between 2016 and 2017 is skewed by the fact that installations in 2016 were driven higher by expectations that a 30% federal investment tax credit might expire. Policy uncertainties in states such as California, Massachusetts and Nevada also had an impact (Solar Foundation, 2018).

The installation segment of the value chain generates more than half of all US solar jobs – 129 400 in 2017. Manufacturing accounts for a fairly small 15% of employment; more than 95% of solar panels are imported (Swanson and Plumer, 2018). Project development represents another 14% of jobs; sales and distribution 12%; and the rest is in research and development, government, and other activities.

The US solar industry is more gender diverse than its fossil fuel industry. Women represented 27% of the solar workforce. In general, women seem to hold a higher share in total renewable energy jobs than in the overall energy industry, about 20 to 25% (Box 2).

In January 2018, in response to a trade petition filed by two manufacturers (Suniva and SolarWorld), the US government imposed import tariffs for modules and cells at a rate of 30%, set to decline to 15% over four years. An initial analysis suggested that the tariffs may reduce installations by 11% over the next five years (Pyper, 2018). The Solar Energy Industries Association (SEIA, 2018) forecasts a loss of up to 23 000 jobs in 2018, but the impact could be softened because the first 2.5 GW of solar cells imported annually will be exempted from tariffs (Eckhouse, 2018).

Previous trade duties imposed on Chinese solar products in 2012 and 2014 failed to raise US solar manufacturing (Roselund, 2016). In 2013, China imposed retaliatory tariffs of 57% on imports of US polysilicon. As the US share of world polysilicon production plummeted from 29% to 11% between 2010 and 2017 (while China's share rose to 70%), one-third of the US polysilicon workforce was laid off (Foehringer Merchant, 2018; Roselund, 2018).

Employment in the US wind industry rose to about 105 500 jobs in 2017 (AWEA, 2018). The wind sector continues to enjoy a period of stability made possible by steady policies (notably the multiyear extension of the production tax credit) and employment is now double the level of 2013[19]. The number of manufacturing jobs in 2017 is estimated at more than 23 000. This is down slightly from 2016, but is offset by higher numbers in the development, transportation and construction segment of the supply chain. This reflects the fact that by year-end, more than 13 GW of capacity were under construction and 15 GW in advanced stages of development.

More than 80% of all US wind capacity is located in low-income rural counties. Land lease payments totalling USD 267 million in 2017 are helping to stimulate these rural economies, in addition to tax revenues and income earned from segments of the value chain (AWEA, 2018).

US ethanol production rose to a new record of about 60 billion litres in 2017, lifted by higher domestic and export sales. Direct and indirect employment is estimated at 237 000 jobs in 2017, a 6.5% increase over 2016 (Urbanchuk, 2018). In the biodiesel sector, production edged up slightly to about 6 billion litres in 2017 (EIA, 2018). IRENA's employment-factor calculation suggests a level of 62 200 jobs in 2017.

In 2016, the United States had a biomass power capacity of about 16 GW in 2016 (EIA, 2017). An employment-factor-based calculation suggests that direct and indirect employment in biomass power might be close to 80 000 jobs, roughly the same level of employment as the previous year[20].

18 This figure includes jobs in solar PV, solar heating and cooling, and concentrated solar power.

19 The production tax credit expired in 2013, leading to a drop in new investment to nearly zero and causing a temporary, but sharp, downturn in installations and jobs before this support measure was renewed and extended by the US Congress.

20 This figure is based on an employment factor of 4 jobs per MW, applied to 16 GW of biomass power capacity, for some 64 400 jobs, and to 3.8 GW of biomass-fired combined heat and power plants, for an additional 15 300 jobs.

BOX 2. IRENA'S WORK ON GENDER

IRENA has strived to address the gender dimension in its work on renewable energy employment. The 2013 report, *Renewable Energy and Jobs* (IRENA, 2013) examined the role of women in renewable energy development in both modern markets and energy access contexts, and assessed the various constraints faced by women in the sector.

Recognising a gap in gender-disaggregated data for the renewable energy sector, IRENA has integrated surveys as part of the Annual Reviews. The 2016 edition of the *Annual Review* (IRENA, 2016a) reported that women represented an average of 35% of the workforce of nearly 90 companies responding to the online survey. The 2017 edition (IRENA, 2017a) presented findings of a survey conducted jointly by IRENA, the Clean Energy Business Council and Bloomberg New Energy Finance in the Middle East and North Africa region. It found that gender discrimination in renewable energy is less pronounced than in the energy sector at large. Challenges to employment and promotion remain. A variety of actions are needed, including flexibility in workplace, mentorship and training, support for parenting, fair and transparent processes, equal pay and targets for diversity.

In 2018, IRENA will present new analysis of the gender dimension of employment impacts among local rural communities affected by large-scale renewable energy project development. The study gathers primary data from solar and wind projects being developed across sub-Saharan Africa.

In the access context, IRENA has emphasised the importance of integrating a gender perspective in policy and programme design as a means to accelerate adoption, enhance sustainability and maximise benefits. The 2017 edition of the Annual Review highlighted the benefits of cleaner cooking fuels, such as biogas and improved cookstoves, for women. As social entrepreneurs, women are also catalysts for deployment as seen from several cases analysed by IRENA such as the Wonder Women Initiative in Indonesia (IRENA, 2016b, 2018d).

Globally, various initiatives have been launched to focus attention on gender and energy. **ENERGIA**, an international network focused on gender and sustainable energy, has been playing a key role in mainstreaming gender in energy policy making. The challenge of expanding access to energy has elicited women-centric efforts such as **Barefoot College** in India and **Solar Sister**. In the United States, **WRISE** (Women of Renewable Industries and Sustainable Energy) has provided support to women in the wind sector for more than a decade; it expanded its focus in 2017 to include solar energy and a variety of related issues such as energy storage, efficiency and smart grids. The **GWNET** (Global Women's Network for the Energy Transition) has been recently established with the aim of empowering women in energy through interdisciplinary networking, advocacy, training, coaching and mentoring, and services related to projects and financing.

IRENA is committed to continue its work on the issue. The agency has started work on a stand-alone report on gender that will integrate up-to-date information from around the world and present cutting-edge thinking and insights on this topic.

In **India** new solar installations reached a record 9.6 GW in 2017, effectively doubling the total installed base of the technology in the country. Employment in solar PV increased by 36% to reach 164 400 jobs, of which 92 400 were in on-grid applications. IRENA estimates that the construction and installation segment of the value chain accounts for 46% of these jobs, with O&M and manufacturing representing 35% and 19%, respectively.

Manufacturing of solar PV modules is limited, given the availability of inexpensive imports, mostly from China. The market share of domestic firms decreased from 13% in 2014-15 to 7% in 2017-18. As of September 2017, the average price for imported modules was USD 0.39 per Watt compared with USD 1.44/W for domestic products and a large share of the existing manufacturing capacity stands idle (Sraisth, 2018).

India had the world's fifth-largest additions to wind capacity in 2017 at 4.1 GW and the fourth-largest cumulative capacity (GWEC, 2018). IRENA estimates that employment in the sector stood at 60 500.

In 2016, the most recent year for which estimates are available, the number of jobs in the **European Union** reached 1.19 million, up from 1.16 million in 2015. The numbers for both years reflect a significant revision of estimates following adoption of a new methodology (EurObserv'ER, 2018), and cannot be directly compared with the results reported in previous years[21].

The European solid biomass and wind power industries are providing the most jobs, at about 389 000 and 344 000, respectively. Both added jobs during 2016. Biomass use is receiving growing policy support, but half of Europe's jobs in this sector are in just six countries: Germany, France, Spain, Italy, Poland and Finland.

The wind industry remains one of the bright spots of the European renewable energy sector. Half of the top ten countries with the largest installed capacity in the world are European. Germany, the United Kingdom, France and Belgium were among the ten countries worldwide that added the most new capacity in 2017 (GWEC, 2018).

21 EurObserv'ER (2018) switched its methodology from a survey of industries to an input-output analysis, which allows for more consistent results for individual EU member countries. The EU total, along with the other EU figures presented here, was adjusted by IRENA with national data in the cases of Austria (BNT, 2017), Germany (O'Sullivan et al., 2018), Spain (APPA, 2017) and the United Kingdom (REA, 2017).

IRENA estimates the European Union's wind power employment in 2016 at close to 344 000.[22] Germany's 160 000 jobs represented 47% of this total, followed by the United Kingdom (41 800 jobs) whose onshore market almost tripled in 2016. Denmark (26 600), the Netherlands (21 500) and France (18 800) were next, followed by Spain (18 000) (EurObserv'ER, 2018; APPA, 2017; REA, 2017).

Offshore, European countries added a record 3.1 GW of new wind capacity during 2017, double the pace of 2016. The United Kingdom and Germany are the global leaders in offshore wind, followed by Denmark and the Netherlands (Wind Europe, 2017 and 2018a). The Netherlands' offshore capacity quadrupled in 2016 with close to 700 megawatts (MW) of capacity added, doubling the country's total wind jobs to an estimated 21 500 (EurObserv'ER, 2018).

The European Union's biofuels sector employed about 200 000 people, up from 172 000 in 2015. The solar PV industry continued to shrink in 2016, from 108 500 jobs in 2015 to 99 600 in 2016. The solar thermal market[23] contracted by 4.6% in 2016, a reflection of low gas prices and the lack of steady support policies. Poland's solar thermal market dropped by half, as did the number of jobs. IRENA estimates employment in the European Union's geothermal sector at 25 000 jobs, of which heat pumps accounted for 16 000 jobs[24].

Renewable energy employment estimates have also been revised for **Germany**. In 2016, the downward trend in evidence since 2011 came to an end. At 325 000 jobs, the figure was slightly higher than during the preceding year. The wind industry was the largest renewables employer in 2016, up 10 000 jobs. In fact, the 160 100 people working in Germany's wind sector equal the number of workers in the next ten-largest European countries combined. Most other renewable energy technologies added a small number of jobs. However, solar PV employment was down to about 35 800 jobs in 2016, from 38 100 in 2015 (O'Sullivan *et al.*, 2018). The 1.53 GW and 1.75 GW of capacity newly installed in 2016 and 2017, respectively, was less than a quarter of the 2012 peak of 7.6 GW (BSW, 2016, 2018). It also falls short of the government's target of 2.5 GW (Enkhardt, 2018).

The **United Kingdom** ranks second in Europe for its number of renewable energy jobs. The Renewable Energy Association (REA, 2017) puts total employment at 118 200 jobs for 2015/16[25]. The largest sector is wind power, with 41 800 jobs.

Solar PV accounts for 13 700 jobs, while biofuels and solid biomass each contribute about 10 000 jobs. Solar heating and cooling is just below the 10 000 threshold.

France is Europe's third-largest renewables employer, with 107 000 jobs; solid biomass and biofuels each employ more than 30 000 people. Poland, Spain and Italy were the fourth-, fifth- and sixth-largest European employers.

22 Deloitte and Wind Europe (2017) provides a more conservative estimate of about 263 000 jobs. This is based on the number of jobs reported by each wind energy company's financial statement (direct jobs) and indices of productivity per MW installed and serviced (indirect jobs). This study estimates that manufacturing accounted for 53% of all direct jobs in 2016; services represented 27%, wind farm development contributed 15% and the remainder of jobs related to the production and installation of offshore substructures.

23 Eurobserv'ER includes CSP in the solar thermal category.

24 EurObserv'ER includes the growing heat pump sector in its reporting on renewable energy employment and published an estimate of 249 400 jobs in 2016 for all three types of equipment, ground source, hydrothermal and air source pumps. However, the largest segment by far, air source pumps, cannot unambiguously be assumed to be renewable in character. Consequently, IRENA adjusted its own figure to the much smaller number reported. This is of particular consequence for Italy, Spain and France.

25 Waste-to-energy technologies add another 7 700 jobs.

In a number of countries in various parts of Asia – including Bangladesh, Japan, Malaysia, the Philippines, the Republic of Korea, Singapore and Turkey – most renewable energy jobs are related to solar PV. In other regions of the world, Australia, Mexico and South Africa also report significant numbers of solar PV jobs.

Bangladesh's solar home systems programme has successfully deployed more than 4 million systems in rural areas. However, lack of coordination among government entities in rural electrification has recently been causing difficulties. Following grid connection through Bangladesh's Rural Electrification Board, many households stopped making instalment payments on their system. New installations have reportedly fallen to an average of 2 000 a month from as high as 60 000 to 70 000 in earlier years. The Infrastructure Development Company Limited's (IDCOL's) programme was also weakened by the free distribution of solar panels under the government's TR-Kabikha project (The Asian Age, 2018). All of this has translated into reduced solar PV employment, estimated by IRENA at 133 000 jobs.

Japanese demand for solar PV declined by 10% in 2017, following a 23% decline in 2016. The most recent decline was the lingering result of reductions in feed-in tariffs, land shortages and limited grid access for new projects. Existing projects already in the pipeline are being completed and few new, large commercial and utility-scale projects are being approved (Bermudez, 2018). According to a private credit analysis firm, Tokyo Shoko Research (TSR), there were 88 bankruptcies in Japan's solar industry during 2017, a sharp increase of 35% over 2016. According to TSR, 42 of the 88 companies cited "poor sales" as the main cause for entering bankruptcy proceedings (EnergyTrend, 2018). IRENA estimates 2017 employment at some 271 500 jobs, a reduction of around 30 000 jobs from 2016[27].

Malaysia's domestic solar PV market is quite small, but its PV manufacturing industry is significant. Most of the facilities were set up as a result of foreign direct investment by companies in China, Japan, the Republic of Korea and the United States. Supported by the Malaysian Investment Development Authority, Malaysia has some 250 companies involved in upstream activities such as polysilicon, wafer, cell and module production, and also in components such as inverters and system integrators (IEA-PVPS, 2017). The country's Sustainable Energy Development Authority estimates that solar PV provides some 40 300 jobs. SEDA (2018) puts biomass energy and biogas employment at about 10 700 jobs, and small hydropower at more than 6 100 jobs. Further, IRENA's employment-factor-based calculation estimated close to 30 000 jobs in biodiesel development, for a total of about 87 400 renewable energy jobs.

26 This figure excludes large hydropower but includes waste-to-energy technologies.

27 In the absence of direct employment data, this calculation is based on the assumption that employment closely tracks the 10% reduction in demand during 2017.

The **Philippines** reports having more than 34 000 people working in the solar PV industry, a number similar to the IRENA estimate of the country's biofuels employment if informal jobs in the agricultural supply chain are included. In addition, the Philippines has about 33 000 jobs in small hydro and more than 14 000 in wind power (Neri, 2018).

The **Republic of Korea** employs about 8 100 people in the manufacturing and distribution of solar PV (Korea Energy Agency, 2018).

Singapore reports 4 300 PV jobs, up from 3 900 in 2015.

In Western Asia, **Turkey** has seen its solar PV sector expand with the help of local content rules (Hirtenstein and Ant, 2016). New installations in 2017 reached 2.6 GW, assisted by a year-end installations rush before feed-in tariff rates were set to be reduced at the beginning of 2018 (Bhambhani, 2018). Turkey had 33 400 people working in the solar PV sector and another 16 600 people in solar heating and cooling in 2017. Wind power provided about 14 200 jobs and small hydro, geothermal power and biogas accounted for another 18 000 jobs. Altogether, the number of people working in renewable energy thus totals about 84 000[26] (Akata, 2018).

Australia added 1.3 GW of utility-scale solar PV capacity during 2017, a record. The country is likely to install more than 3.5 GW during 2018. It is estimated that this activity directly supported the employment of about 4 400 people during 2017. Another 5 500 people were directly employed in the design, sale and installation of roof-top solar systems. The wind power sector accounts for 11 200 jobs (Green Energy Markets, 2018), for a total of about 21 000. This uptick comes after a number of years during which Australia's renewable energy employment had declined.

Mexico reports about 10 940 solar PV and about 18 000 wind jobs, many of them producing equipment for the neighbouring US market. The country also has about 17 700 people in the small hydro sector, 14 400 in solid biomass and 7 600 in geothermal power, for a combined total of 68 600 jobs (Vega, 2018).

Information on renewable energy employment on the African continent remains limited.

According to government estimates, **Egypt** has some 3 000 solar PV jobs.

In **Ghana**, Africa's largest solar PV project, the 155 MW Nzema plant, was estimated to have created 500 jobs during its 2-year construction, and 200 permanent operations jobs. The facility was likely to induce another 2 100 local jobs through sub-contracting and demand for goods and services (Blue Energy, 2015).

The largest level of employment on the continent is found in **South Africa**, which, with the help of domestic content legislation, has generated an estimated 15 000 jobs in solar PV and close to 8 900 in the concentrated solar power (CSP) industry. Wind power adds another 10 400 jobs. Including much smaller employment in the small hydro sector, the country has close to 35 000 renewable energy sector jobs (Nxumalo, 2018).

Important developments are taking place in the off-grid sector (Box 3).

BOX 3. OFF-GRID DEVELOPMENTS

New business models such as the "pay-as-you-go" (PAYG) approach that is spreading in parts of Sub-Saharan Africa are increasing the affordability of small solar home systems for poorer rural households.

In the PAYG model, consumers use their phones to pay a fixed up-front cost for a solar home system (typically a small solar panel bundled with a battery, lights, mobile phone chargers and possibly appliances), and subsequently regular instalments until the cost of the system is paid off.

These business models are supported in some countries by the removal of import tariffs and other taxes or fees on solar PV panels and other components. As growing numbers of panels are sold, employment is generated in segments of the supply chain, especially in sales and distribution, installation and O&M.

However, as long as there is only a limited domestic capacity (or none at all) to assemble equipment or manufacture components, economic multipliers and the resulting employment and other benefits will accrue elsewhere, and efforts to boost rural development will remain limited. Indeed, the availability of cheap imports acts as a powerful restraint against the development of even a limited local industry. As solar deployments scale up, the import bill rises as well. Removing tariffs on imports of raw materials or components needed to produce this equipment could shift the economics and spur development of a local industry. This could be further supported by policies to certify qualified supplier firms, establish product quality standards (to avoid the spread of poor-quality products) and provide worker education and training programmes (Mama, 2017).

In East Africa, M-KOPA and other start-ups have been the main protagonists of the PAYG model. Until recently, the company exclusively sold imported PV panels. During 2016-17, however, M-KOPA reported selling more than 100 000 solar PV panels that were made in Kenya by Solinc East Africa. Cumulatively, these panels have a generating capacity of close to 2 MW. In coming years, the company hopes to source all its panels from Kenya – over the next two years, this will amount to half a million panels representing 6.6 MW of power. The benefits include a shorter supply chain and (facilitated also by government-required product certifications [Mama, 2017]) a greater degree of quality control.

Starting operations in 2011, Solinc's PV module factory in Naivasha was the first such plant in East and Central Africa, and currently serves markets in Kenya, Uganda and the United Republic of Tanzania. Majority Kenyan-owned since 2015, it employs 130 Kenyans, with plans to hire an additional 30 engineers over the next two years to fulfill growing M-KOPA orders (M-KOPA, 2018; Solinc East Africa, n.d.). The company has weathered repeated changes in value-added tax (VAT) and import duty regulations on solar products and components during 2013-15 that affected pricing and demand (Mulupi, 2016).

For all but the leading PAYG companies such as M-KOPA, BBOXX, Fenix or d.light, a key challenge is how to raise sufficient capital to finance the upfront cost of solar panels while households' payments are spread out over many instalments. A particular difficulty is that local financial institutions have been reluctant to provide financing. The resulting reliance on international investors has meant that the inherent transaction costs and currency risks, along with profit expectations, are translating into solar home system prices in East Africa that cost twice as much as comparable systems in Bangladesh, where a successful microcredit model has led to the installation of more than 4 million solar home systems (Sanyal *et al.*, 2016). Higher costs prevent greater uptake of decentralised off-grid solutions and that in turn limits employment opportunities.

The International Finance Corporation (IFC, 2018) observes that since 2016, there has been a somewhat greater prevalence of local currency financing, mostly via agreements between the World Bank and Sub-Saharan African countries. Further, in early 2018, a potentially ground-breaking financing deal was announced under which the off-grid solar company BBOXX secured USD 4 million worth of debt financing from the Union Togolaise de Banque (UTB), the first such deal involving a local Sub-Saharan African bank. In late 2017, BBOXX won a contract from the Togolese government to provide 300 000 solar systems by 2022. The company aims to create more than 1 000 direct jobs in Togo over five years (Kenning, 2018).

Domestic sourcing of solar panels and components spurs rural development and creates jobs.

Local currency financing can lower the cost of renewables for households.

THE WAY FORWARD

The role of renewables in the global energy system keeps expanding. This process is key to stabilising the global climate, avoiding environmental degradation, and improving human health. As the global transition towards a more sustainable energy system unfolds, the world's renewable energy workforce will continue to expand. IRENA's analysis suggests that jobs in the sector could rise from 10.3 million in 2017 to 23.6 million in 2030 and 28.8 million in 2050, in line with IRENA's more sustainable energy pathway (IRENA, 2018a).

A better understanding of employment along the value chain helps decision makers formulate appropriate policies to support the expansion of the renewable energy sector. This entails not just deployment and industrial policies, but also education and training of new workers, efforts to retain skilled and experienced employees (who demand attractive wages, good working conditions and opportunities for career advancement), and policies to ensure a just and fair transition from the present energy system to one that features renewables more strongly.

IRENA will continue to provide sound data and analysis on the topic through further editions of this publication and by contributing to the growing knowledge base on the socio-economic benefits of renewables, including its report series on *Leveraging Local Capacities* to analyse skill requirements along the segments of the value chain of different renewable energy technologies (Figure 9).

FIGURE 9. **IRENA'S KNOWLEDGE BASE ON RENEWABLE ENERGY EMPLOYMENT**

TABLE 1. **ESTIMATED DIRECT AND INDIRECT JOBS IN RENEWABLE ENERGY WORLDWIDE, BY INDUSTRY, 2016-17**

	World	China	Brazil	United States	India	Germany	Japan	Total European Union[k]
Solar Photovoltaic	**3 365**	2 216	10	233	164	36	272	100
Liquid Biofuels	**1 931**	51	795[g]	299[h]	35	24	3	200
Wind Power	**1 148**	510	34	106	61	160	5	344
Solar Heating/ Cooling	**807**	670	42	13	17	8.9	0.7	34
Solid Biomass[a,b]	**780**	180		80[i]	58	41		389
Biogas	**344**	145		7	85	41		71
Hydropower (Small)[c]	**290**	95	12	9.3	12	7.3[j]		74[l]
Geothermal Energy[a,d]	**93**	1.5		35		6.5	2	25
CSP	**34**	11		5.2		0.6		6
Total (excluding Large Hydropower)	**8 829**[f]	**3 880**	**893**	**786**	**432**	**332**	**283**	**1 268**
Hydropower (Large)[c, e]	**1 514**	312	184	26	289	7.3[j]	20	74[l]
Total (including Large Hydropower)	**10 343**	**4 192**	**1 076**	**812**	**721**	**332**[j]	**303**	**1 268**[l]

Source: IRENA jobs database.

Note: *Figures provided in the table are the result of a comprehensive review of primary information sources by national entities such as ministries and statistical agencies, and secondary data sources such as regional and global studies. This is an on-going effort to update and refine available knowledge. Totals may not add up due to rounding.*

a. Power and heat applications.
b. Traditional biomass is not included.
c. Although 10 MW is often used as a threshold, definitions are inconsistent across countries.
d. Includes ground-based heat pumps for EU countries.
e. Direct jobs only.
f. Includes waste-to-energy (28 000), ocean energy (1 000) and jobs which are not technology specific (8 000).
g. About 225 400 jobs in sugarcane processing and 168 000 in ethanol processing in 2016; also includes rough estimate of 200 000 indirect jobs in equipment manufacturing, and 202 000 jobs in biodiesel in 2017.
h. Includes 237 000 jobs for ethanol and about 62 200 jobs for biodiesel in 2017.
i. Based on employment-factor calculations for biomass power and CHP.
j. Combines small and large hydropower. Hence the country total with large hydropower is the same as the total without large hydropower.
k. All EU data are from 2016, and include Germany. The figure is derived from EurObserv'ER data, adjusted with national data for Germany, the United Kingdom and Austria, as well as IRENA calculations.
l. EU hydropower data combine small and large facilities. Hence the regional total with large hydropower is the same as the total without large hydropower.

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IRENA Headquarters

Masdar City
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