Chapter 3

The renewable energy revolution

"I'd put my money on the sun and solar energy.
What a source of power!
I hope that we don't have to wait until oil and coal run out
before we tackle that.
I wish I had more years left!"

Thomas A. Edison (1847–1931).

The technical and economic development of renewable energy will have an impact on many different aspects related to electricity availability and climate change, as well as links to water, water supply and treatment. It is no longer out of reach for poor people or those living in remote regions. The development will also have an impact on many social and economic aspects like gender issues, health hazards and consumer power. In 3.1 we illustrate the global picture of renewable energy. The off-grid development is of particular interest here, as emphasised in 3.2. Scalability of renewable energy is a key property that will give the end user control of the production, Section 3.3. The phenomenal cost development of solar PV and wind is illustrated in 3.4. This is linked with the expansion of solar PV all over the world, as we see in Section 3.5. The expansion of wind power is discussed in 3.6. The radical development of solar PV and wind already has geopolitical consequences, as illustrated

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solar PV and wind already has geopolitical consequences, as illustrated in 3.7. The renewables have already created massive job opportunities, both in manufacturing and in assembling and mounting the renewable energy systems, as illustrated in 3.8.

3.1 THE GLOBAL PICTURE

There is a dramatic change under way in the energy sector. Already 173 countries have established targets for renewable energy (IRENA, 2017a). In 2015 154 *GW* of new energy capacity was added globally: 61% came from renewables, and 90% of the investments in renewables came from wind and solar power (IRENA, 2017a). In 2016 almost two-thirds of the net new global power capacity of almost 165 *GW* coming online was renewable, a new record year. The solar PV development, driven by sharp cost reductions and policy support, was a key factor in this development. In 2016 new solar PV capacity around the world grew by 50%, reaching 74 *GW*. Solar PV additions were larger than any other electric energy source in 2016, even surpassing coal (IEA, 2017b).

Most of the global power capacity coming online today is renewable.

Renewables have increased almost exponentially over the last decade. Figure 3.1 shows how renewables (mostly solar, wind and hydropower) have developed. Notably, solar and wind have increased remarkably. In the period 2017–22 it is expected that solar PV will have the largest growth of all (www.iea.org/renewables). The IEA (International Energy Agency) forecasts that the share of renewables in global power generation will reach 30% in 2022, up from 24% in 2016.

The growth rate of solar PV is exceptional compared to other electric energy sources, with an average growth rate of 41% between 2010 and 2015, admittedly from low levels (39 to 219 *GW* globally). This corresponds to 20% of all newly installed electric power capacity. During the same period wind offshore (outside the coast) has increased 30% per year and wind onshore (on land) almost 18% per year. Total wind power grew from 180 to 405 *GW*. As a comparison, hydropower grew 3.3% per year (IRENA, 2017a).

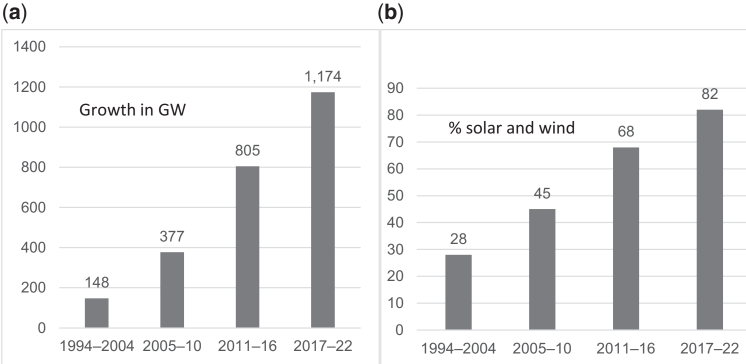

Figure 3.1 (a) Total renewable energy capacity growth (in *GW*) in four periods. The 2017–2022 growth is predicted. Most of the growth is in wind, solar and hydro. (b) The percentage of solar and wind in the total renewable power growth. Data source IEA (2017b).

China is the undisputed leader of renewable energy with more than 40% of the world's renewable capacity growth. One important driving force is the concern about air pollution. China surpassed its 2020 solar PV target in 2017, and it is expected that the wind target for 2020 will be reached in 2019 (IEA, 2017b). Chinese government agencies note that in the first half of 2017, renewables accounted for 70% of new capacity added (a sharp increase from 52% in 2016), thermal sources (mainly coal) 28% and nuclear just 2%. In late 2017 Beijing announced plans to stop or delay work on 95 *GW* of planned and under-construction coal-fired power plants, so the 70% renewables figure is set to see a healthy boost (Mathews & Huang, 2018).

3.2 OFF-GRID DEVELOPMENTS

Renewable electric power production in 2015 was dominated by large-scale generation (*MW*-scale and up). However, the market for small-scale generation outside existing power grids has been taking off. Bangladesh is the world leader in solar home systems. Small-scale renewables, mainly for lighting, are increasing rapidly in many developing countries, notably in Kenya, Uganda and Tanzania in Africa, China, India and Nepal in Asia, and Brazil and Guyana in Latin America (REN21, 2017a).

Renewable energy solutions, either off-grid or in mini-grid systems, are becoming economically feasible for many remote and rural areas (IRENA, 2015a; Varadi *et al*., 2018, Chapter 3) where electric grid extension is not economically feasible. Considering the pace of grid-extension efforts globally it is likely that nearly 60% of the additional electricity needs to come from off-grid solutions, to attain the goal of electric power for all in 2030 (IRENA, 2017a).

Another reason for considering off-grid solutions is the relatively poor reliability of existing electric transmission lines. Around two-thirds of the sub-Saharan countries have transmission lines where at least half of the lines are more than 30 years old. Even in South Africa one-third of the transmission lines have been in operation more than 30 years. Aging infrastructure and lack of maintenance contribute to low reliability and common brown-outs or blackouts in sub-Saharan Africa (IRENA, 2016d). Furthermore, some systems are disrupted by wars and conflicts and it takes years to bring the systems back to full operation. Again, off-grid solutions can offer the end users opportunities to take control of their own energy supply.

As shown by Varadi *et al.* (2018), only a small fraction of people in Africa have access to the electrical grid.

Population growth in sub-Saharan countries is the biggest in the world. This, together with rising standards of living in Africa, means that a lot of new investments in electric energy are required just to keep a balance between demand and supply.

A mini-grid is defined as a structure of a size between an individual home system and a conventional power grid. Such a system may include a generation capacity in the range of around 1 *kW* to the order of 10 *MW* (sometimes power utilities call them "micro-grids" or "pico-grids"). They will supply electric power to several customers but operate in isolation from the national grid. In rural and remote areas, a mini-grid is often considered an attractive solution to provide lighting, water pumping and power for small production units.

Based on calculations made in 2010 by the IEA, UNDP (United Nations Development Programme) and UNIDO (United Nations Industrial Development Organization), the additional electric generation required to achieve electric power for all by 2030 is 468 *TWh* for developing Asia, 463 *TWh* in Africa and 10 *TWh* in Latin America.

The electric power will be delivered via either stand-alone systems, mini-grids or national grids, as illustrated in Figure 3.2.

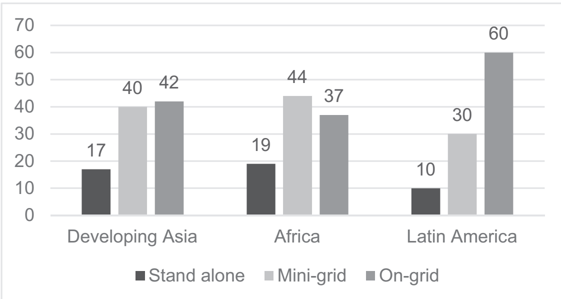

Figure 3.2 Structure of additional electric power supply (in %) to achieve electricity for all in 2030. It is apparent that most of the additional power will be added outside the traditional electric power grids (on-grid). Data from IEA, UNDP and UNIDO.

As noted in 3.1, solar PV and wind will dominate the development of renewable energy in the coming years. Solar is well above both wind and hydro. Already today almost 30 million people benefit from solar lighting products in Africa (Lighting Africa, 2013). The radical consequences for productivity, education, health services and quality of life are well documented. Almost 100 million people in developing countries have at least one solar PV lighting product in their home (BNEF and Lighting Global, 2016).

IEA made a forecast of renewables for developing Asia and sub-Saharan Africa in 2017 (IEA, 2017b). It is predicted that off-grid capacity will almost triple in the years 2017–2022, as shown in Figure 3.3. The off-grid growth is only a small share of the total PV capacity installed, but its socio-economic impact will be significant. Solar home systems (SHS) are expected to bring basic electricity to almost 70 million people in these regions over the five-year period. This will provide energy for lighting and small appliances, typically 20–100 *W*.

Low-income people can purchase this kind of service on pay-as-you-go schemes (see also Chapter 12.3). The energy cost is usually similar to or lower than the cost of traditional sources like kerosene lanterns. It should be noted that most SHS deliver DC power. Such a system needs no inverter (see glossary) to convert the DC power to AC but requires battery backup for use during the night. The DC system can supply power directly to DC-powered appliances like LED lights, radios, TV sets and mobile phone charging units. For larger power ratings, needed for water pumping and cleaning, AC power will be needed. Then DC/AC inverters will be needed; see Chapter 4.5.

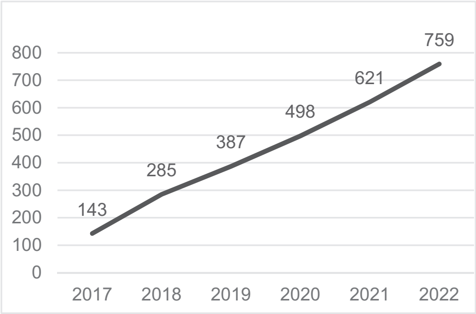

Figure 3.3 Predicted cumulative growth (in *MW*) of off-grid solar home systems in sub-Saharan Africa and developing Asia. The growth in mini-grids and industrial solar systems is of the same order of magnitude as the solar home systems. Data from IEA (2017b).

The progress of solar home systems is largely attributable to highly efficient LED lamps. Professors Isamu Akasaki, Hiroshi Amano and Shuji Nakamura made the first blue LEDs in the early 1990s. This enabled a new generation of bright, energy-efficient white lamps, as well as colour LED screens. As the Royal Swedish Academy of Sciences said when presenting the 2014 Nobel Prize in Physics to this trio of scientists: "The LED lamp holds great promise for increasing quality of life for over 1.5 billion people around the world who lack access to electricity grids. Due to low power requirements, it can be powered by cheap local solar power."

Another contribution to quality of life is the comparison of the light from solar-powered LED lights compared to the light quality from kerosene wick lamps. A LED light of 2 *W* will produce 380–400 lumens compared to 8–40 lumens for a kerosene wick lamp. The price per unit of useful light is anywhere between 3 and 100 times more expensive for the equivalent light from a kerosene lamp (IRENA, 2016d).

> Solar-powered LED lights provide much more useful light than kerosene lamps for the same cost.

The increased energy efficiency of lighting and home appliances can make larger off-grid solar home systems more affordable.

According to an interview with Adnan Amin, head of IRENA (Beckman, 2016):

> *I do believe that people are underestimating what is happening in off-grid. When we looked into this recently we discovered there is a lot of investment going into solar home systems, particularly in developing countries. You don't see this in the energy statistics; that's why we looked at the trade statistics. There are thousands of these home systems developed by entrepreneurs. They provide very low-cost basic power services for cell phone charging, refrigeration, and that sort of thing … We need to improve the investment framework in developing countries. The aid model doesn't work. We need to incentivize entrepreneurs to start new businesses.*

It is worth noting that electrification with renewables in remote areas does not necessarily depend on any national decision but on private initiatives. Of course, financing needs to be encouraged at all levels, including the national leadership.

> "People are underestimating what is happening in off-grid." Adnan Amin, head of IRENA.

The real driver of the renewable energy revolution is simply the reduction of costs for generating power. It is competitive with traditional fossil fuels and with a promise of even lower future costs. And even more important: the fact of diminishing carbon emissions gives hope for the future climate.

There is a huge potential for electrification of rural areas in Africa and developing Asia, as Figure 3.4 illustrates. Even in high-income countries off-grid solar is becoming more attractive. In countries and regions like Australia and California, and even parts of India, off-grid solar PV is becoming cheaper than purchasing the electric power from the power grid (WEC, 2016, Chapter 8). Naturally, being connected to the grid means a guarantee of electric power even if the off-grid systems break down.

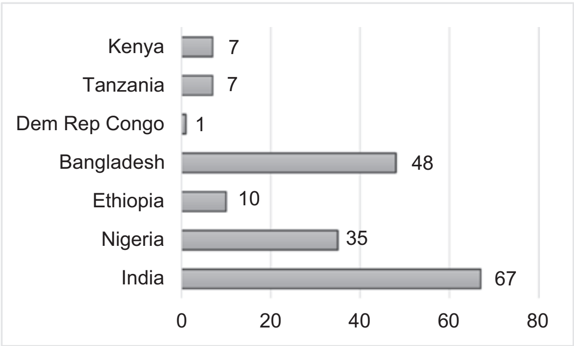

Figure 3.4 Rural electrification rates (%) in some developing countries. Data from IEA (2013).

It ought to be emphasised that increased electrification and rising electric energy use from renewable sources will not increase global warming. The production of CO_2 from fossil fuels must be decreased. So, any replacement of diesel generators and wood burning will make a positive contribution to the climate.

3.3 SCALABILITY OF RENEWABLE ENERGY

The scalability of renewables is remarkable, in particular for solar PV. The systems can be highly modular and can provide options for both off-grid and on-grid solutions. The scale can vary from very small lighting systems in remote areas to residential and commercial rooftop systems at utility scale. The size can vary from the *kW* range to hundreds of *MW*. In remote areas renewables can negate reliance on fossil fuels, like kerosene and diesel, which has not only an economic impact but also an effect on health.

A solar home system will start to fulfil basic needs such as lighting and low-load appliances. Adding more electric production capacity will allow power for water pumping, irrigation and treatment for water supply and water reuse.

Power delivery can be considered from three perspectives:

- Complexity,
- Hazardous and risky operation, and
- Customer power.

Solar PV systems can be from 1 to 100 to 1,000 solar panels. If the power capacity is too low, then new panels can be added; and conversely, if capacity is unnecessarily high, panels can be moved to another consumer.

An interesting feature of solar PV is that the panels are replicated, which means that the complexity of the system does not increase with the size, and its efficiency is not sacrificed with the power rating. This is not true for thermal power plants, which have an optimal operating size.

> The scalability of renewable systems is remarkable, in particular that of solar PV. The systems can be highly modular.

In general, solar-powered systems do not present any hazards due to materials or operations. However, some chemicals are reason for concern, such as cadmium in Cd-Te solar cells and the components of most types of batteries.

The operational risk is yet another important factor. As renewables are scaled up they do not present increasingly greater hazards. Conventional methods of thermal power generation, nuclear or coal, have a typical optimum size for best efficiency. Usually this is quite a large power station, which also means greater system complexity. It is not profitable to build a 50 *MW* nuclear reactor. Renewables, on the other hand, are relatively benign technologies, without serious risks.

Scalability increases consumers' power. With local access to energy the individual citizen is empowered and is no longer dependent on a central authority. The promise of energy and water decentralisation is a democratic force that should not be underestimated. It is possible to start with a small investment in power generation. When there is demand for increased power generation, then more modules can be added. An important issue is project lead times; solar PV has the shortest of any power-generation technology. Furthermore, the mounting of solar PV panels does not require sophisticated equipment or highly trained personnel. Scaling up the power capacity in the future is also possible.

3.4 COST DEVELOPMENT OF SOLAR PV AND WIND

The falling cost of renewable energy technologies, notably solar and wind power, contributes considerably to the growing competitiveness of renewables versus conventional fossil fuels, as shown in Figure 1.2. Already today renewables like onshore wind, biomass, geothermal and hydropower energy are all competitive with or cheaper than any fossil fuel power stations, even without subsidies and despite relatively low oil prices (IRENA, 2017a). For obvious reasons, offshore wind and small-scale rooftop solar are about twice as expensive as onshore wind and utility-scale PV.

Costs for renewable energy technologies have fallen dramatically in recent years. The cost of solar PV modules decreased by 80% between 2009 and 2016. The prices for wind turbines declined by some 40% over the same period (IRENA, 2017a). This does not include the costs of balancing the grid system or compensating for the intermittent production. This will be the next economic challenge for solar and wind systems. As well as the solar panels or wind turbines the cost includes electrical system costs, costs for permits and installation. In an off-grid system the cost for energy storage should be taken into consideration (see also Chapter 10).

If the high social costs of pollution from extracting and burning natural gas or coal are taken into consideration, then renewables are even more competitive. This is demonstrated in China, where wind power already exceeded the contribution from nuclear power in terms of capacity in 2009 and in terms of electric energy generated in 2012 (Mathews, 2016).

> Traditional cost estimates for electric energy do not consider the high social costs of pollution from extracting and burning coal or natural gas.

There have been auctions to implement renewable energy in many countries. At the end of 2016, 67 countries had arranged such auctions and record low prices had been achieved for both solar PV and wind. For example, in Morocco a median price for solar PV of 30 USD per *MW* (or 0.03 USD/*W*) was achieved, while a record low of 24.2 USD/*MW* (or 0.024 USD/*W*) was offered for 300 *MW* in Abu Dhabi (IRENA, 2017a). This also means that there have been record low *energy* prices in auctions, as low as 30 USD/*MWh* or 0.03 USD/*kWh* (IEA, 2017a).

Solar PV is the most realistic and least expensive power source, and not only for remote areas outside the electric grids (compare Figure 1.2). Already today, in several countries electricity from small-scale distributed PV is cheaper than power from the grid. Solar PV has become cheaper than diesel-fuelled generation or lighting provided by kerosene. At the same time, it saves the user from the social and environmental problems associated with fossil fuels, including the transportation costs to provide them.

The cost of wind energy is also competitive with conventional power production (Figure 1.2). For example, in New Zealand in 2011 the long-term marginal cost for existing wind farms was in the range of 56–75 USD per *MWh*. The comparable electric energy price in the same period was 53–60 USD per *MWh*. Since then the cost of wind power has declined much more (WEC, 2016, Chapter 10).

Several experts were interviewed concerning the future of renewables compared to fossil fuels (REN21, 2017b). One question was whether or not the cost for renewables would continue to fall and will outpace all fossil fuels within the next ten years. Among the experts 67% agreed or strongly agreed with this statement and only 13% disagreed, while 20% neither agreed nor disagreed. The experts were quite uncertain about future oil prices. In contrast, future renewable energy costs were considered predictable and certain.

Even if solar PV and wind energy are already cheaper than diesel generator energy, it will be a challenging task to replace traditional generators in many places. The reason is that diesel generators have long been the technology of choice in off-grid areas. The diesel generator market and its supply chain are mature. In 2015, developing countries bought and installed some 600,000 units with a total capacity of 29 *GW*. About half of the power comes from units smaller than 0.3 *MW* (Climatescope, 2017). Furthermore, the carbon footprint from diesel-generated power is about twice as high as the average footprint from grid-connected power in Africa.

Despite the low cost of solar PV there is still an unfavourable competition with diesel generators. One important reason is lack of financing possibilities (see also Chapter 12). Diesel-generated power is two to three times more expensive than solar PV and the fuel cost is a significant contributor. For solar PV the up-front cost is higher while the fuel is free. So, even if diesel-generating power is more expensive to operate in the long run, diesel generators are cheap to buy.

3.5 SOLAR PV GLOBAL EXPANSION

The energy available from solar radiation is huge. The global average solar radiation received by the average m^2 can in one year produce the same amount of energy as a barrel (159 litres) of oil, 200 *kg* of coal or 140 m^3 of natural gas.

The solar energy obtained directly from the sun is termed solar radiation. There are two types of solar energy technologies: photovoltaic (PV) and thermal collectors. A PV cell will produce electricity directly from the solar radiation. Solar thermal collectors have been used for a long time for domestic heating and for providing hot water. The term solar *irradiance* is the measure of *power* from the sun over a certain area, typically measured in W/m^2. Solar insolation is a measure of the energy from the sun and is averaged over a long time, and expressed in Ws/m^2 per day or kWh/m^2 per year. The use of the two terms across literature is not fully consistent.

Global installed capacity for solar-powered electricity has seen an exponential growth, reaching around 227 GW_p (gigawatt peak electric) at the end of 2015 (WEC, 2016, Chapter 8). At the end of 2016 320 GW_p had been installed (Fraunhofer, 2016). It produced 1% of all electricity used globally. Solar PV installations are certainly not distributed equally over the continents; they are led by China, India, Germany and the United States (IEA, 2016a). Figure 3.5 shows that major solar installations have been made in regions with relatively less in terms of solar resource (Europe and China), while potential in high-resource regions (Africa and the Middle East) remains untapped (WEC, 2016, Chapter 8). There is a huge potential for solar PV in Africa, developing Asia and South America, where sunshine is abundant. This is further illustrated in Chapter 8.

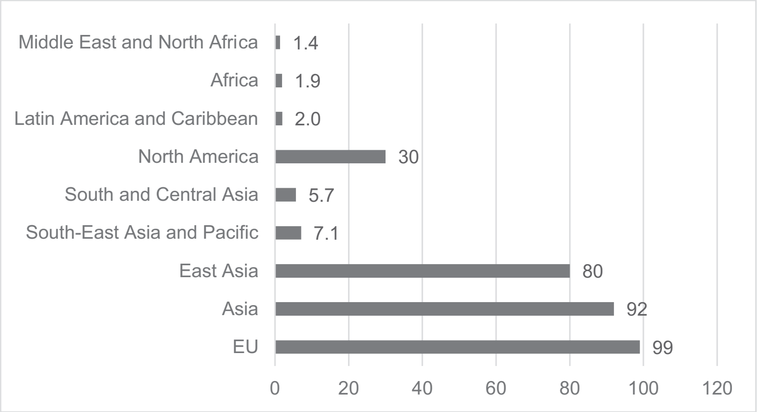

Figure 3.5 Solar data on installed capacity (*GW*) in different regions of the world at the end of 2015. Asia is shown both as a total and split into three major regions. Data source IEA (2016a).

3.6 WIND POWER GLOBAL EXPANSION

Global wind generation capacity at the end of 2015 reached 435 *GW*, which is around 7% of the world generation capacity (WEC 2016, Chapter 10). In just one year, 2015, the growth rate was more than 17%. Wind power capacity is estimated to increase to 977 *GW* by 2030. Most of the wind power (905 *GW*) will be onshore while 72 *GW* is expected to be offshore (*ibid*.).

Most of the wind power capacity in 2015, 422 *GW*, is from large onshore wind units, where the average machine size is 2 *MW*. Offshore wind, around 12 *GW*, is generated from 4,000 machines with an average size of 3 *MW*. Small onshore wind capacity makes a very minor contribution, less than 1 *GW*. The 800,000 small turbines produce an average of 1.25 *kW* (*ibid*.).

Naturally, wind resources vary between regions. According to IRENA (2016d) the northern, eastern and southern regions of Africa have excellent wind resources. This, however, is not reflected by the amount of installed wind turbine energy in these countries, as illustrated in Figure 3.6. The potential for harvesting wind energy ought to be enormous. The challenge is not the geographical conditions but the financial opportunities.

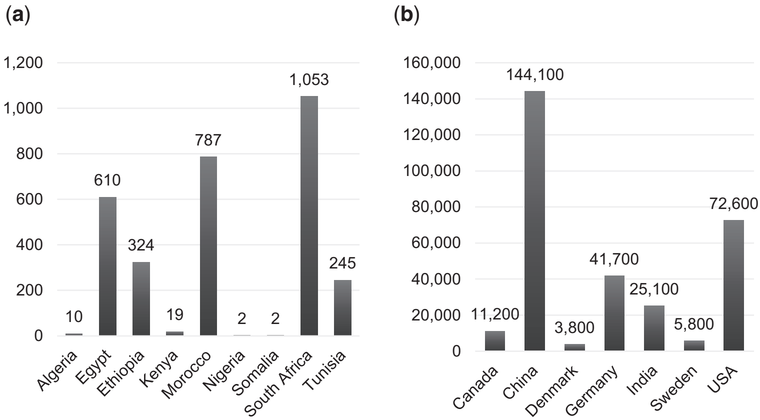

Figure 3.6 Installed onshore wind power (MW) in some African countries (a) compared to installed onshore wind power in some high-income countries (b). Note that the scales differ by two orders of magnitude. Data from WEC (2016), Table 11.

Wind capacity additions are led by China and the European Union. China's COP21 commitment indicated that wind capacity is to be expanded to 200 *GW* by 2020 and solar power to 100 *GW*. There are already signs that China is pushing for higher targets for 2020: a possible 30–50 *GW* increase for both wind and solar PV (IEA, 2016a). This will almost surely have a global impact. Small-scale turbines are used for a variety of applications, including rural electrification and water pumping. They are installed increasingly to displace diesel generators in remote locations. In the five largest countries with small-scale turbines the upper capacity limit is between 15 and 100 *kW* (WWEA, 2016).

The rapidly declining cost of competing technologies, such as solar, also poses challenges to small wind deployment. From these challenges, however, emerge innovation opportunities to increase the efficiency and reduce the costs of small wind technology.

Wind energy produced 226 *TWh* in 2016, which avoided an estimated 160 million tons of CO_2 and could displace fossil fuel plant generation. This is equivalent to reducing the power sector's CO_2 emissions by 9% (AWEA, 2017). (The AWEA calculations are based on the EPA "AVoided Emissions and geneRation Tool", AVERT. AVERT calculates the pollution reductions provided by renewable energy and energy efficiency by statistically determining which fossil-fired power plants are most likely to have their output reduced due to the addition of renewable energy or energy efficiency). Also, land use is minimal since wind power generation can share the land with other activities (see also Chapter 13).

Due to the intermittent nature of both wind and solar PV (see Chapter 10), there are always issues of both lack of production and excess energy. DNV GL (2017) explains that there is too little economic consideration of what effect temporary surpluses of wind and solar power will have on the economics of renewables: "*we have not yet shown what the impact is of that*." However:

> "*we will also need to decarbonise heat, so it makes sense to store the surplus renewable energy, for example to heat water with it or to convert it into gas, to be used for heating. It is not yet clear what the most economic route will be*."

3.7 GEOPOLITICAL AND ECONOMIC IMPLICATIONS

Renewable energy has an impact on two important factors: economy and geopolitics. Renewable energy sources are products of manufacturing (Mathews & Tan, 2014). Using mass manufacturing means that the cost is related to economy of scale. Furthermore, as more experience is gained, manufacturing efficiency can be improved and can follow the scaling pattern characteristic of industrial learning curves. An increase of the production volume will almost surely imply a cost reduction. It seems to be a rule of thumb for a surprisingly big range of products that a doubling of the production volume leads to a 20% reduction in unit cost. There are surely other factors except production volume that will affect the price.

The fact that manufacturing can in principle be conducted anywhere means that renewables can offer genuine energy security. There is no geopolitical pressure where one country has deposits of a fossil fuel, but another does not. Renewables promise an end to energy security being closely related to geopolitics.

In Table 3.1 we list the top two countries in terms of total capacity or generation.

Table 3.1 The top two countries in terms of renewable energy total capacity or generation.

Type of Electric Power	1st Country	2nd Country
Renewable power excl. hydropower	China	United States
Renewable power capacity per capita (excl. hydropower)	Denmark	Germany
Solar PV capacity	China	Germany
Solar PV capacity per capita	Germany	Italy
Wind power capacity	China	United States
Wind power capacity per capita	Denmark	Sweden

Source: Data from REN21 (2017a).

Renewables promise an end to energy security being closely related to geopolitics.

Resources for energy are traded all over the world. This is dramatically illustrated on the website published by the British Royal Institute of International Affairs, known as Chatham House, https://resourcetrade.earth/. To generate traditional electricity requires international trade in coal, natural gas, petroleum and uranium. Now we see new competitors that cannot be traded internationally: wind and sunlight. Unlike commodity fuels, metals and other materials, which can be extracted in one place and transported for use somewhere else, including internationally, wind and sunlight are immaterial and are typically used where they are. Both wind power and solar power are nevertheless becoming steadily more significant contributors to electricity generation.

3.8 JOB SKILLS TO MOUNT AND OPERATE SMALL UNITS

The time needed to mount solar panels and additional equipment is very short compared to all other energy production types. While it takes several years to complete a large thermal power plant (nuclear- or coal-fired), a solar panel system for a small application can be finished in weeks, or even days. Most of the mounting work can be performed by non-specialist workers, who can mostly be recruited locally. This means that assembling renewable energy systems can offer both rural and urban employment.

To mount large wind turbines requires more special equipment and trained personnel. Naturally the need for advanced equipment is not as high for smaller wind turbines.

> Mounting of solar panels does not require highly skilled specialists or advanced equipment.

It is apparent that off-grid renewable energy deployment cannot be successful without technical assistance and human capacity-building. Education at different levels is a key ingredient. In a recent publication concerning electrification Dr Lawrence Jones, Vice President of International Programs at the Edison Electric Institute, suggested (Jones, 2018) that in order to achieve electric energy for all we need to think in terms of a metric expressed as "the number of engineers, technicians etc. per *MW*". Jones also points out that sub-Saharan Africa and south Asia need to substantially boost the number and capacity of engineers and technicians who can develop, install, operate and repair the components of both grid and off-grid equipment. An extensive analysis of job opportunities in the renewable energy industry in India is presented in CEEW (2017). Job opportunities in renewable energy are further examined in Chapter 12.2.

3.9 FURTHER READING

IEA and IRENA are key sources for a lot of information concerning renewable energy. IEA (2017b), IRENA (2016c, 2017a) and REN21 (2017a, 2017b) provide a lot of data. IRENA (2016a) contains statistical information on renewable energy for each country.

Solar home systems are described in detail in Lighting Africa (2013) and BNEF and Lighting Global (2016). The World Energy Council is a rich source of information on solar and wind development (WEC, 2016).

Varadi (2017) and Varadi *et al.* (2018) provide inside information and a broad overview of solar energy and its role in Africa and in the Middle East.

The newsletter *Energy Post* (http://energypost.eu/) is an excellent source of information about the rapidly changing arena of renewable energy.

There are several publications on mini-grids for rural areas. The National Rural Electric Cooperative Association (NRECA) has published a mini-grid design manual for rural areas (Inversin, 2000). A good guidebook for the connection of mini-grids (or pico-grids) smaller than 200 *kW* has been published by Greacen *et al.* (2013). A comprehensive report from USAID (2014) documents important lessons on rural mini-grids in developing countries. The challenges are a combination of technology, financing and organisation. A valuable record of seven case studies of micro-grids for rural electrification is documented in a UN report, prepared by Schnitzer *et al.* (2014). Five electrification cases from India and one each from Malaysia and Haiti are documented in detail. Experiences of mini-grids in rural electrification have been reported for Kenya (Kirubi *et al*., 2009), Bangladesh (Yadoo & Cruickshank, 2010) and Nepal (Palit & Chaurey, 2011). It is essential to note that the technical issues are only part of the complete solution. Financing possibilities, high and unexpected expenses and lack of competence and of trust can cause systems to fail, even if the technical aspects are satisfactory (Cust *et al*., 2007).