Part IV

Applying Renewable Energy to Water Operations

To obtain clean water using solar PV and wind requires more than technology. Economising the systems is a key issue, discussed in Chapter 12. Even though costs for both solar PV and wind have decreased rapidly, there is a new kind of economy compared to traditional systems. The up-front capital cost is the dominating cost for renewables, while the "fuel" is free and maintenance much lower than for conventional energy systems. Thus, it becomes vital to find a financing system that takes the different cost structure into consideration.

In parallel with new technology there is a crucial need for education at many levels. The end user who has not previously enjoyed the opportunities that electricity can offer must be advised. Training at many levels of technical jobs is important if water operations using renewable energy are to be successful.

Energy systems require land areas. This issue is discussed in Chapter 13, and solar PV and wind energy land requirements are compared to land areas used for conventional energy systems.

Over the last few years a lot of experiences have been collected from using solar PV and wind for water operations. In Chapter 14 some cases illustrate how renewable energy has been applied to pumping and to desalination.

Chapter 12

Economy

"The dignity of each human person and the pursuit of the common good are concerns which ought to shape all economic policies."

Pope Francis' apostolic exhortation,
***Evangelii Gaudium* (The Joy of the Gospel).**

Three aspects of economy are considered in this chapter. Costs for renewable energy are compared to fossil fuels in 12.1. Renewable energy is creating a huge job market. This also requires a corresponding effort in education and training, discussed in 12.2. In 12.3 some financing and payment options are reviewed.

12.1 COST OF RENEWABLES

Comparing cost of solar PV and wind with conventional power generation using fossil fuels requires that both capital cost and operating costs are considered. The costs to human health and the environment are often not taken into consideration when various energy production systems are compared, as commented on in Chapters 1–3.

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12.1.1 Up-front capital cost versus fuel costs

In a renewable system the capital cost is the dominant cost, while the "fuel" for solar and wind is free.

A complete solar PV system consists of several elements to be connected with the solar modules. The solar cells usually represent the highest capital cost. The total cost for the system includes inverters (see Chapter 4.5), mounting structures and electric circuits. An important aspect is the cost of energy storage, in many cases a battery system, as demonstrated in Chapter 10.

Probably, all these components will be supplied by various vendors. It is crucial that the components are balanced for the best and most efficient operation. On top of this there are soft costs like a control system for power management, and labour costs for the installation.

With the dramatic decrease in the cost of solar cells it is obvious that the solar PV element of the system costs will be less dominant, so it is crucial to consider the total system cost.

The up-front capital cost is the dominant cost in a renewable energy system.

The capital cost is also the dominant cost for wind energy systems. For onshore wind the turbines make up the biggest portion of the capital cost. Turbine cost (including electric infrastructure and transportation) can represent a range of 64% to 84% of capital costs (IRENA, 2018). The main cost of operation and maintenance is related to the wind turbine itself, and is of the order of 50%. Unlike a solar PV the wind turbine has moving parts, which is always a more complicated operation from a maintenance point of view. Usually, turbine maintenance is done by the manufacturer, which also complicates the operation in remote areas.

12.1.2 Levelised cost of electricity

Levelised cost of electricity (LCOE) is way to express the lifetime costs divided by energy production and can be expressed in cost/kWh (see 1.4.5). The cost is defined as the present value of the total cost of building and operating a system over an assured lifetime. By using the LCOE concept different technologies can be compared, such as solar PV, wind, fossil fuels, nuclear etc., where the systems have different lifespans and project size as well as different capital costs, risks and capacities. Since the up-front capital cost does not take the whole picture into consideration the LCOE can help to make an informed decision to evaluate a project.

A simple LCOE calculation can be made using the expression

$$\mathrm{LCOE} = \frac{\sum_{t=1}^{n} \frac{c(t) + om(t) + f(t)}{(1+r)^t}}{\sum_{t=1}^{n} \frac{e(t)}{(1+r)^t}}$$

where

$c(t)$ = capital expenditures in year t,
$om(t)$ = operation and maintenance costs in year t,
$f(t)$ = fuel costs in year t,
$e(t)$ = electric energy generation in year t,
r = discount rate,
n = lifetime (years) of the system.

The numerator in the equation is the total cost over the lifetime, while the denominator is the energy generated over the same time.

A significant attractive feature of renewable energy is of course that the fuel costs are free. The initial capital cost and the capacity factor (Chapter 10) are two critical parameters. The discount rate and the annual operating expenses are essential parts of the financing costs. There are LCOE calculators available online and for free, for example from NREL (National Renewable Energy Laboratory) in the US (https://www.nrel.gov/analysis/tech-lcoe.html). Note that there are important factors that are not included in the LCOE calculation, such as the projected utilisation rate.

12.1.3 Levelised cost for solar PV

The cost of the PV modules is determined by the raw material cost (type of semiconductor, metal frame, junction boxes etc.). The average LCOE of residential PV systems without any battery storage has been estimated at (WEC, 2016, Chapter 8):

0.38–0.67 USD/kWh in 2008
0.14–0.47 USD/kWh in 2014

The price reduction for residential PV installations (typically 0–4 *kW*) has been of the same order of magnitude in most western countries, as illustrated in Table 12.1.

Table 12.1 LCOE reduction for residential PV installations.

Region	Price Reduction %	Time Period
California	42	2008–14
Other parts of U.S.	52	2008–14
Japan	42	2008–14
Italy	59	2008–13
Australia	52	2010–14

Source: Data from WEC (2016, Chapter 8).

In regions where there is a lot of sunshine the LCOE is apparently favourable. Moreover, if the demand profile during the day and the sunshine hours are similar the need for storage capacity is smaller.

12.1.4 Levelised cost for wind energy

WEC (2016) has estimated that global onshore wind LCOE has decreased from 380 USD/*MWh* in 1983 to 70 USD/*MWh* in 2015 (in 2015 USD values). Continued performance improvements mean that LCOE for onshore wind was, in late 2017, at a record low 45 USD/*MWh* (Lazard, 2017). There is a wide span of LCOE for onshore wind, as shown in Table 12.2. The weighted averages are the largest in Africa, Oceania and the Middle East and the lowest in China.

Table 12.2 LCOE for onshore wind energy in some major regions.

Region	USD/*MWh*	USD/*kWh*
North America and Brazil	31–130	0.03–0.13
Africa, Oceania and Middle East	95–99	0.095–0.1
China	50–72	0.05–0.072

Measured in LCOE, onshore wind energy boasts some of the lowest electricity costs among renewable energy sources, as shown in Figure

1.2 (WEC, 2016). Because of the intermittent production in off-grid installations the cost for storage must be considered.

For our applications onshore wind power is the most interesting. This technology is reaching cost competitiveness against conventional power generation technologies (WEC, 2016, Chapter 10). Therefore, within the wind power profession most attention today is paid to technology developments in the offshore applications.

It is estimated that the global LCOE of onshore wind is likely to decrease up to 26% between 2016 and 2025, mainly due to lower installation costs, higher capacity factors and declining operation and maintenance costs. Higher hub heights, rotor diameters and turbine rating will account for most of the decline in the LCOE of onshore wind. It should be noted, however, that large-scale installations have the highest potential for cost reductions.

Wind projects are developed with an assumed operational lifetime of 20–25 years.

12.2 JOB OPPORTUNITIES

In interviews with experts on renewable energy they have been asked how many jobs will be needed for the renewable energy industry by 2050, given that 8.1 million are employed today (see Figure 12.1). Among the experts, 73% believe that more than 25 million jobs will be needed and 41% estimate that more than 45 million jobs will be required (REN21, 2017a).

> Millions of jobs will be needed in the renewable energy sector.

Utilities in sub-Saharan countries and in south Asia will in the future serve two main customer segments. One is the many people living in urban areas in the developing world where electric power is delivered via a complex system of highly intertwined and often unrelated wires. These systems mostly have high network losses and many customers are unable to pay according to the power tariffs. The other category is all the people living in off-grid, remote areas. Many of these regions get support today from non-governmental organisations and local entrepreneurs. Utilities ought to spend more effort to bring off-grid electricity to these rural areas. It is apparent that the technical and managerial challenges are quite different for the two main categories of end users.

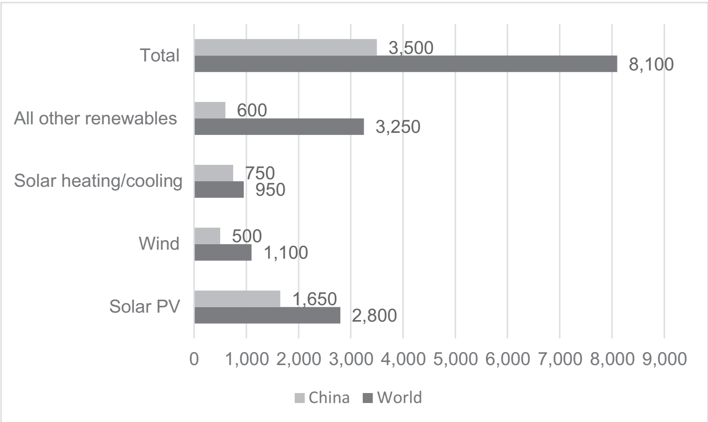

Figure 12.1 Estimated number of direct and indirect jobs in 2017 in the renewable industry (excluding large hydropower) in thousands. The upper bars show that China dominates the job market in the industry.
Source: Data from REN21 (2017a), Table 1.

Another estimate of job opportunities is presented by World Bank (2017). Many different job skills are required and are categorised in MCI (manufacturing, construction and installations) and O&M (operations and maintenance). Table 12.3 presents a selection of some estimates. Note that the estimates are based on relatively large installations.

12.2.1 Job creation in the solar industry

Almost three million people worldwide were employed (directly and indirectly) by the solar energy sector in 2016 (see Figure 12.1) and the industry continues to expand. As demonstrated in Figure 3.5, most of the solar equipment and the demand are located in Asia, so most of the jobs are there, while in Europe solar PV employment has decreased. Obviously, there is a high demand for jobs not only in manufacturing but also in O&M. In order to expand the use of renewable energy in remote areas it is apparent that not only will more jobs be created but also that the need for more education at all levels is urgent, as noted in Chapter 2 and Chapter 3.8 (Jones *et al.*, 2018). As the share of renewables is set to increase significantly, many more people will have to be employed and educated in the industry compared to today.

Table 12.3 Job opportunities in renewable energy systems.

Energy Source	**Construction Time** *Years*	**Construction + Installation** ***Job Years/MW***	**Manufacturing** ***Job Years/MW***	**Operation + Maintenance** ***Jobs/MW***
Wind onshore	2	2.5	6.1	0.2
Solar PV	1	9	11	0.2
Solar thermal	2	5.3	4	0.4
Solar heat		7.4		

Source: Data from World Bank (2017, Figure 4.15).

12.2.2 Job creation in the wind industry

The wind power industry employs more than a million people worldwide, and about half of them are in Asia (Figure 12.1). It is estimated (WEC, 2016, Chapter 10) that wind power alone could support more than four million jobs in 2030, a fourfold increase on today.

Elements of wind power installation require special competences and equipment that are not usually available locally. For example, mounting the turbine and the tower requires a lot more expertise than mounting a solar PV array. Furthermore, mounting tall wind towers may require either high cranes or helicopters. Other activities, such as site planning, can often rely on local labour.

Many parts of a wind turbine, particularly the blades and the nacelle, are large units. It is of course quite an advantage if these parts can be manufactured not too far away. However, this requires available raw material, skilled workers and, of course, a market that makes the manufacturing profitable. To transport large units long distances is costly and not possible in many remote areas.

Some activities require specific expertise and knowledge in the wind sector that are not necessarily available locally at the initial stages of development of the sector. Initial activities in the project planning phase include site selection, technical and financial tasks.

12.3 FINANCING

Financing is a key issue and financing research and development for small-scale operations of both energy generation and water operations needs more attention and funding. There is a risk that interest is focusing on large-scale operations. Lack of investment may be the biggest barrier to universal access to clean water systems powered by renewable energy systems.

Multilateral institutions like the World Bank, the Asian Development Bank (ADB) and the African Development Bank (AfDB) provide important funding to further develop and deploy renewable energy projects. There are also other important institutions like Deutsche Bank's Universal Green Access Program (UGEAP) for Africa. They work with local financial institutions that enable local banks to extend medium- and long-term loans to distributed renewable energy companies and initiatives.

It is still not recognised everywhere that water and energy operations must be handled simultaneously. The delivery chains of water and energy are mostly managed in 'silos', where the silos not only represent professions and sectors but also different institutions. It is apparent that our infrastructures of energy and water should be designed and operated in a more integrated way. This challenge goes all the way up to government agencies and ministries. The Malaysian government may serve as a good role model due to its Ministry of Energy, Green Technology and Water. Collaboration between stakeholders has also to be strengthened. The UN Sustainable Development Goals of clean water and clean energy for everybody are clear and their connection should be better recognised (see 2.1).

12.3.1 Funding in rural areas

Experiences of rural electrification have been reported in, for example, IEA (2013). It is obvious that some kind of subsidy system (where the end users do not pay the real cost of power) is needed in rural areas with low population density and scattered settlements. Since both capital and operating costs must be considered, both these aspects have been reflected in the subsidy systems. However, as noted before, the up-front capital cost is the dominant one in renewable systems. This means that the subsidy system has to change its emphasis towards the dominant capital cost. This is a significant change for the public authorities in charge of subsidising rural electrification. It also brings a change of perspective for the donor agencies.

Compared to traditional diesel-based generators the new technology carries greater technical risks in the sense that there are more components. The system contains not only the electrical devices necessary for solar PV or wind power but also water supply and water treatment components like pumps and desalination membranes. This raises the issue of available spare parts and distribution systems reaching rural areas.

A strong public-private partnership is needed to meet the challenges of new technology and to share the risks. The private sector can provide capacity-building and ensure a quality installation and maintenance of the equipment. The public sector can engage in subsidies and financial support, especially during the initial years, to build up skills and to develop the market. Experiences from successful installations, as documented in World Bank (2017), suggest some important success factors:

- Consideration of the demands, interest and restrictions of local customers, including the desire to pay with mobile payments systems;
- Strong partnerships along the whole supply chain, from the government to private-sector service providers; and
- Adaptation of market dynamics to local conditions to support successful, sustainable clean energy solutions.

12.3.2 Payment models

It is becoming increasingly common to use smartphones to pay for energy services in the developing world. In 2016 there were more than 32 companies in over 30 countries in Africa and developing Asia selling solar PV products to more than 700,000 households. The up-front fee and regular payments are made using mobile money transfers (IRENA, 2017a).

Pay-as-you-go (PAYG) models are becoming common. The key factor is a finance model that matches affordable pricing for the end user with an adequate return on investment for the supplier. For example, PAYG solar companies seek to provide energy services at a price that can compete with consumers' current spending on kerosene, candles, batteries and other low-quality energy services. This of course includes the water system equipment and the potential improvement that it provides, for example by increasing agriculture output using irrigation. Two methods for PAYG are typically offered:

- The end user pays a fee for the *possibility* of owning the system, but never actually owns it;
- The end user will own the system after paying off the system cost. They will make regular payments on a daily, weekly or monthly basis.

Investment in PAYG solar companies has increased from practically zero in 2012 to 223 million USD in 2016 (REN21, 2017).

12.4 FURTHER READING

Hoffman (2017b) presents an insightful analysis and description of the role of subsidies, very much talking from his own experience. The rest of the chapter is an informative description of solar PV financing from a US perspective.

Varadi *et al.* (2018), Chapter 6, is a valuable source of information for anybody who wishes to know more about financing renewable energy in Africa and the Middle East.

Huld *et al.* (2014) have calculated levelised cost of energy (LCOE) for PV systems in Africa and the Middle East, both grid-connected and off-grid PV systems.

IRENA (2017c) presents a lot of facts concerning jobs and renewable energy.

IEA (2016b) discusses the system value of solar PV and wind. The report emphasises the importance to maximise overall value to the power and wider energy system rather than minimising the generation cost of wind and solar power in isolation.

Chapter 13

Land use for energy

"Changes in land use associated with energy development can have a significant impact on the quality of the physical, social, economic, and visual environment. Local air quality, water quality, water availability, noise levels, the municipal tax base, land values, job opportunities, and the character of the community itself may be affected."

US Department of Energy Report about land use and energy in 1975.

Land use is a crucial issue when addressing the energy-water-food nexus. The competition for land is apparent in several ways. The world is facing increasing food demands due to both increasing average incomes and the rise in population. At the same time, it is feared that the agriculture yield will drop because of water scarcity.

It is argued that solar PV and wind power may require fertile land and consequently threaten food production. On the contrary, solar PV provides a large benefit by using not land but spare rooftops. The land area requirements for different types of electricity generation can be compared (Olsson, 2015). Large hydropower requires a certain area for the reservoir. Often there is a multi-purpose reservoir, used for water storage and flood protection besides hydropower. For wind power the total area enclosed by the site boundary is defined as the

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land use, although the area between the towers can often still be utilised for agriculture or forest. Offshore wind will of course have an environmental impact as well, but the area seldom competes with other uses. Solar PV does not necessarily need to occupy fertile land. Small-scale PV and solar heating installations have minimal land impact, as they are actively integrated into buildings and structures they serve.

The power and energy outputs from a given area are summarised in Table 13.1. It is obvious that solar PV is very competitive in regard to land use, even if the capacity factor is relatively low for the actual area. In the US the National Renewable Energy Laboratory (NREL) (www.solarindustrymag.com/online/issues/) has studied the land footprint of utility-scale solar generation. There is a wide range of total land use. The average total land use was estimated at 8.9 acres (around 36,000 m^2) per *MW*, or around 28 MW/km^2 (compare with Table 13.1).

Table 13.1 Energy output from a given area for different renewable sources (Olsson, 2015).

	Hydropower	**Wind**	**Solar PV**
Power density MW/km^2	0.1–17	5–8	20–110
Capacity factor	0.6	0.3	0.2
Annual energy output GWh/km^2	0.5–90	13–21	35–190

The wind power land use requirement depends on both the size of the turbines and the extent of the terrain. In a hilly area the wind turbines may be located along the ridgelines. Wind towers on flat terrain are often positioned more uniformly and may require a larger land area. The footprints for wind farms in the United States average around 333,000 m^2 per *MW* or a power density of 3 MW/km^2 (NREL, 2012b).

The space between the wind turbines on a farm can be large. However, only a small fraction (3–5%) of the land required is disturbed by the wind energy structures. The rest of the land could be utilised for agriculture and transport links. Naturally, in remote areas there will seldom be large wind farms; instead there will be stand-alone wind turbines, with quite a small land footprint.

The global share of rooftop PV systems is not known. In many countries there are no separate statistics for rooftop PV and utility-scale PV. World Energy Council (WEC, 2016, Table 7) reports that in only four major solar PV countries (Germany, Japan, the US and Australia) do the land savings as a result of rooftop installations exceed 200,000 acres or 85,000 hectares (=850 km^2).

Solar panels are used in innovative ways to save both land and water (see 8.3.4; WEC, 2016). In Japan the 13.7 *MW* Yamakura floating solar power station is composed of more than 50,000 solar modules, covering a water surface area of 180,000 m^2 : or 76 MW/km^2. They are mounted on the Yamakura Dam reservoir, located in the Chiba Prefecture east of Tokyo. The panels will reduce water evaporation from the dam as well as saving fertile land. The plant was put into full operation in March 2018.

A similar structure is being developed in India . In the first stage of a solar panel project in the province of Gujarat in north-western India, a 750 *m* section of a water canal is covered with solar panels, generating 1 *MW* of electric power. Covering the canal with solar panels will save agricultural land as well as decreasing the water loss via evaporation (Shukla *et al*., 2016). According to WEC (2016) the solar panels of this canal could save a lot of land, five acres per *MW*. This corresponds to a solar panel power of 50 MW/km^2 (compare Chapter 8.2–8.3).