21
PV System Economics and Ecology

21.1 PV system economy

We conclude our discussions on PV systems looking at several important topics on the economics of PV systems. The economics of PV can be discussed at several levels, such as the consumer level, the manufacturing level, the level of PV installers, and the technology level where PV is compared to other electricity generation technologies on the scale of the electricity grid.

21.1.1 Payback time

We will start this discussion with the definition of the *payback time*, which in finance is defined as the amount of time required to recover the cost of an investment. It can be calculated with

$$\text{payback time} = \frac{\text{initial investment}}{\text{annual return}}. \tag{21.1}$$

Translated to the consumer level, the payback time is the time it takes to recover the initial investment of the PV system as the system continuously reduces the electricity bill. Please note that the *financial* payback time is different from the *energy payback time* that we will discuss in Section 21.2 Let us look at an example:

Example

Let us assume that family Smith have installed a PV system with a power of 1 kW_p on their rooftop. The initial investment was €2000. Family Smith has an annual electricity bill of €2000. The installation of the PV system leads to an average annual reduction of the electricity bill of €250.

As a part of their consumed electricity is provided by their PV system, the electricity bill is therefore constantly reduced. Hence, the average annual return on their PV system is €250. As a consequence, the Smith's have earned the final investment back after 8 years; the payback time *is 8 years.*

The payback time is strongly influenced by the annual solar radiation on the PV system. As we have seen in Chapter 18, this is dependent on the orientation of the PV modules and on the location of the PV systems. In general we can say that the sunnier the location, the greater the PV yield and the shorter the payback time. Another factor that influences the payback time is the grid electricity costs: the higher these costs, the shorter the payback time. Finally, the payback time also is strongly dependent on the initial costs of the PV system.

In practice, often more factors must be taken into account than in the simple example above. This will increase the complexity of calculating the payback time. For instance, if we are considering a significant period of time, also the change of the value of money has to be taken into account, which is due to inflation. For example today €1000 will have a different *purchasing power* than in ten years time. Another factor that should be considered are policies regarding renewable energy. For example, subsidies and feed-in tariffs can affect the initial investments and savings.

21.1.2 Compensation schemes

There are different schemes to compensate owners of PV systems for electricity they deliver into the grid. We will discuss two schemes, net metering and feed-in tariffs. In households with PV systems installed, the electricity consumer also becomes an electricity producer, who wants to sell electricity that he does or cannot consume to the grid. Hence the consumer is turned into a producer/consumer of electricity, or a *prosumer*.

Net metering

Old-fashioned analog electricity meters can operate in both directions. If electricity is consumed from the electricity grid, the electricity counter increases. However, when the PV system produces more than actually is consumed in the house, electricity is delivered to the grid. In this case, the electricity counter decreases. In the end, only the net electricity consumption must be paid, hence, the energy consumed from the grid minus the energy delivered to the grid. Such a system is interesting for consumers, if the levelized cost of electricity (see below) of the PV system is lower than the price paid for electricity from the grid.

Nowadays, often *smart* digital electricity meters are used. These meters distinguish between electricity consumed from the grid and electricity delivered to the grid. This system allows not only to monitor the amount of electricity delivered to the grid from the PV system, but it also allows the grid utility to adapt its tariff system. For example, the electricity price often contains a certain fee for using the electricity grid. Such a fee also can be imposed on electricity delivered to the grid from the PV system.

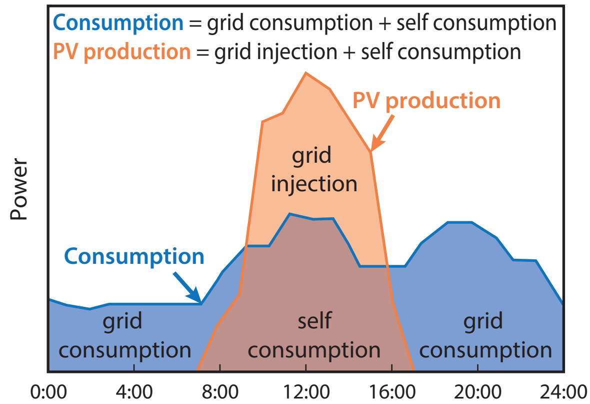

Figure 21.1: Illustrating grid consumption, grid injection and self consumption (Reproduced with kind permission from the European Photovoltaic Industry Association (EPIA)) [135].

Feed-in tariffs

With the system of *feed-in tariffs*, electricity generated by the PV system can be sold to the grid utility for a fixed price. For such a system, either two analog electricity meters (one measuring the power consumed from the grid the other measuring energy delivered to the grid) or one smart meter are required. We distinguish between two kinds of feed-in tariffs, gross and net. In the system of *gross* feed-in tariffs, all the electricity produced by the system is sold to the grid utility and all the electricity consumed by the household is bought from the grid. In contrast, for *net* feed-in tariffs the actual power consumption is subtracted from the PV power generation and only the surplus electricity is sold to the grid.

Feed-in tariffs allow to stimulate the installation of renewable electricity technologies such as PV, if the feed-in tariffs are above the electricity price. On the other hand, if they are set (slightly) below the electricity price from the grid, self consumption can be stimulated, as discussed below.

21.1.3 Self consumption

Self-consumption is an important aspect of PV systems. It is defined by the European Photovoltaic Industry Association as the possibility for any kind of electricity consumer to connect a PV system, with a capacity corresponding to their consumption, to their system for on-site consumption, while receiving value for non-consumed electricity [135]. In practice this refers to policies that allow a consumer to install a PV system without being charged a premium for connection to the grid.

As PV systems are penetrating the electricity grid power more and more, certain issues start to arise. Figure 21.1 shows how a household with an PV system interacts with the grid. Because of the unpredictable nature of PV electricity generation, the peaks and edges on this system will be very difficult to predict for utility companies that manage the electricity grids. The grid injection levels may exceed the current demand of a grid well before the PV penetration reaches 100%. This means that there are reasons to stimulate prosumers to directly consume the energy they produce in order to avoid grid instability issues. Utilising the generated PV electricity on site, rather than injecting it to the grid is known as *direct consumption*.

Direct consumption can be achieved in many ways. An unfavourable option would be to limit PV system size to make sure that the peak power produced is always lower than the peak power consumed. This, of course, would limit the allowed PV capacity an individual or a community. Other techniques include using storage in various ways, for example batteries. This way, the orange part of the curve in Fig. 21.1 will be used to charge the battery, which will be discharged in the "grid consumption" area.

Different policies can be introduced to encourage direct consumption. Pure net metering, which treats a prosumer equally in consumption and production does nothing to encourage self-consumption as it simply pays the prosumer retail costs of energy back to the grid. However, adjusting feed-in tariffs to be lower than retail energy is a typical scheme used by countries such as Germany and Italy to encourage direct consumption in PV systems.

It is worth repeating that the issue of grid instability can occur well before PV reaches penetrations of 100%. Even if as little as one third of a grid is being powered by PV, instantaneous power levels can easily rise above demand at peak hours causing energy to be curtailed. For this reason, companies, such as Solar City in the United States are already making plans to include batteries with PV systems as early as 2015 [176].

21.1.4 Levelized cost of electricity

Another very important concept is the *Levelized Cost of Electricity* (LCoE), which is defined as the cost per kWh of electricity produced by a power generation facility. It is usually used to compare the lifetime costs of different electricity generation technologies. To be able to estimate the effective price per kWh, the concept of LCoE allocates the costs of an energy plant across its full lifecycle. It is somehow similar to averaging the upfront costs of production over a long period of time. Depending on the number of variables that are to be taken into account, calculating the LCoE can become very complex. In a simple case the LCoE can be determined with

$$\text{LCoE} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}. \tag{21.2}$$

The sums expand across the whole lifetime of the system n, every year accounts for one summand. I_t are the investment expenditures in the year t, M_t are the operational and maintenance expenditures in the year t, and F_t are the fuel expenditures in the year t. Of course, for PV $F_t \equiv 0$. Further, E_t is the electricity yield in the year t. Finally, r is the discount rate which is a factor used to discount future costs and translating them into the present value.

Figure 21.2 shows the estimated LCoE for different methods of electricity generation that enter service in 2019. The values are national averages for the U.S. We see that the LCoE of wind energy is lowest, it is even below the LCoE of fossil fuel and nuclear based electricity. The LCoE of PV generated electricity is still slightly above that of the non-renewable technologies.

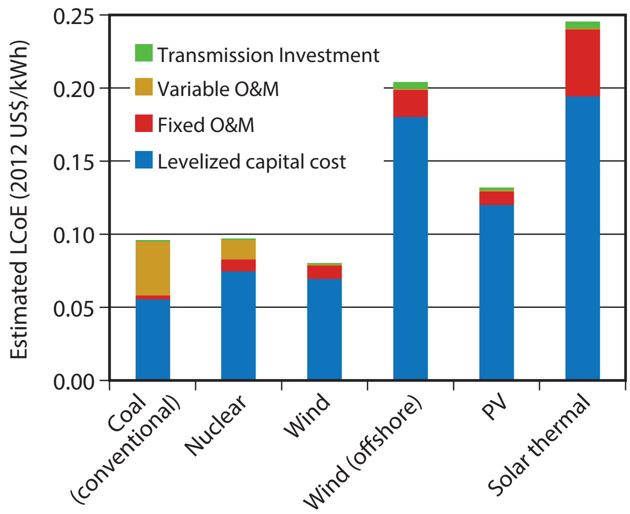

Figure 21.2: The estimated levelized cost of electricity for different electricity generation technologies that enter service in 2019 (Data: [177]).

Depending on the location and the initial investment required for the PV system, the LCoE for PV can vary a lot between different projects. Additionally, the discount rate r used for the calculation will strongly influence the LCoE.

For the electricity supplier, the LCoE is a valuable indicator of the cost competitiveness of a certain energy technology. It is also a good indicator for determining the electricity price: for making profit this price must be above the LCoE. Surely, the supplier cannot determine the electricity price independently, as it is strongly influenced by policy factors such as feed-in tariffs, subsidies and other incentives.

21.1.5 Grid and Socket Parity

It is very important to investigate whether electricity generated with PV is competitive to electricity generated by other means. For this purpose, the concepts of grid parity and socket parity are used. We want to warn the reader that many authors use these two concepts interchangeably. However, only a clear distinction between the two concepts allows a well-grounded judgement of the economic viability of PV generated electricity.

The owners of large-scale PV power plants have to compare the LCoE of their system to the cost of electricity production of other sources, ignoring subsidies and other incentives. The point, at which the cost of PV electricity is equal to the cost other electricity generation technologies is called *grid parity*. Of course, if the PV electricity price is below the grid price, the situation becomes even better,

$$\mathrm{LCoE}_{\mathrm{PV}} \leq \mathrm{LCoE}_{\mathrm{conventional}}. \tag{21.3}$$

In principle, the concept of grid parity can be generalised to the other renewable technologies as well. However, there is one significant difference between PV and other renew-

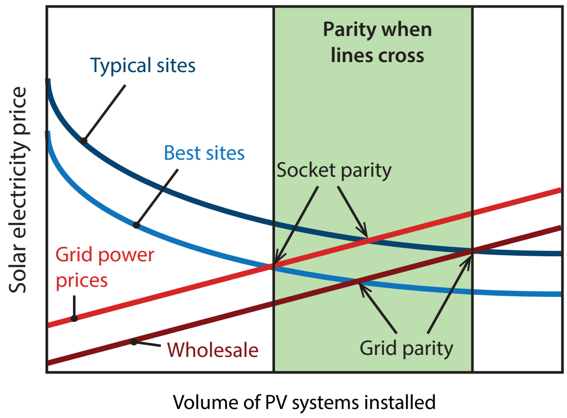

Figure 21.3: Grid and socket parity for PV systems (Adapted with kind permission from P. R. Wolfe [178]).

able technologies such as wind and hydro electricity. Wind and hydro electricity installations usually only can be financed by companies but are no option for a single consumer. In contrast, PV can be scaled down to the level of a single module, such that a house owner can become an electricity producer with his small scalable PV installation on his roof. The residential electricity price often also includes grid maintenance fees as well as taxes. The point, at which the LCoE of a PV system is equal to the price the consumer pays for electricity from the grid is called *socket parity* [179].

Distinguishing between grid parity and socket parity is useful in order to avoid confusion with the cost of energy production. Since residential costs are always higher than production costs, an area will reach socket parity before reaching grid parity, as illustrated in Fig. 21.3. The graph is showing the volume of installed PV systems versus the price of PV electricity. The installed volume can be directly correlated with time, as the past decade has seen the implemented PV volume rise tremendously. As capital costs decline with increasing volumes, the price of PV generated electricity is expected to decrease in the future. On the other hand, the price of fossil fuels is expected to rise because of increasing scarcity and cost linked to the right to emit CO_2 emissions into the atmosphere. These trends will lead to increasing prices for electricity generated with combusting fossil fuels.

To conclude, grid parity and socket parity are very useful concept to indicate the feasibility of a renewable energy technology. The closer a technology is to grid parity, the easier it can be integrated in the electricity mix. With the advancements in technology and the maturity of manufacturing processes, grid parity for solar is expected to be reached at many locations around the World in the next years.

21.2 PV system ecology

Besides discussing the economics of PV systems, it also is very important to consider their ecological and environmental aspects. The main reason for that is that the aim of photovoltaics is to generate electricity without any considerable effect on the environment. It is