The process of testing a PV system to confirm that it is producing electricity and interacting correctly with the electricity grid is known as system commissioning. Before an installer leaves the system to the customer it should be tested and inspected to ensure that the system is compliant with national and local standards and regulations, that all components have been safely installed and that all components are functioning as expected. Many utilities have rules or procedures that must be followed during the system commissioning process and in some cases the utility may wish to conduct a commissioning inspection. These requirements should already have been discussed with the utility when the interconnection agreement is made (see Chapter 10).

System documentation

At the completion of the installation the owner should be supplied with a system manual that includes information on the system. Local codes generally specify the documentation that should be provided; however, a general guide is given below.

- List of equipment supplied: the system manual should include a full itemized list of all the components that have been installed including PV modules, inverters, array frames, PV combiner boxes, string isolators, fuses or circuit breakers and the DC and AC main disconnects/isolators. The list should include the quantities of equipment items used.
- System diagrams: a basic circuit diagram and a wiring diagram should be included in the manual. Architectural drawings or the site plan showing the major components are also useful.
- System performance estimate: the manual should include the expected yield of the system as calculated by the designer. It may also include information on local financial incentives (see Chapter 13) and what these mean for the system in terms of income and/or savings on electricity bills. It is also important to emphasize that this is purely an estimate and some variation from year to year is common.

- Operating instructions for the system and its components: the manual should include a brief overview of the system, the function of each of the main components and how the system operates. Any information important to that particular system should be included in the manual. It is important to explain to the owner that the system will turn off when the grid fails, i.e. when there is no power available from the grid.
- Shutdown and isolation procedures for emergency and maintenance: the manual should include procedures for maintenance and emergency. Depending on the size of the system, maintenance procedures might not involve the complete shutdown of the system.
- Maintenance procedure and timetable: Chapter 12 details the maintenance requirements for a grid-connected PV system, including tables that should be included in maintenance logbooks. This information should be incorporated into the system manual.
- Installation and commissioning records: these should be all signed and included in the system manual.

- Monitoring of system: a section of the manual should advise the system owner how to monitor the system to ensure that it is operating correctly. Many inverters have monitoring capabilities. If the inverter includes these features, instructions on how to use them should be provided. If a separate monitoring unit has been supplied with the system, the manual must include information on its operation.
- Warranty information: a grid-connected PV system comprises individual products connected together by a system installer to create the system. There are four types of warranties applicable to such a system, these are:
  1. product warranties covering defects in manufacture;
  2. product warranties related to output performance over time;

3 system warranties relating to proper operation of the installed system over time;
4 energy performance warranties relating to the guaranteed energy output of the grid-connected PV system over a period of time, typically one year (see Chapter 3).

The first two warranties in this list are the responsibility of the equipment manufacturer, but a system owner could contact the installer for help if a warranty claim is required. The last two warranties are provided by the system installation company. Details of all the warranties offered should be included in the system manual.

Equipment manufacturers' documentation and handbooks: all product manuals provided by the various manufacturers should be included in the system manual. Examples include inverter manuals, PV module data sheets and technical information on any balance of system (BOS) equipment.

Final inspection of system installation

Before the PV system is commissioned, a final inspection should be undertaken to ensure the system is ready to be tested. If any issues are identified they should be addressed before any part of the system is switched on and/or tested. The equipment and installation should be checked to ensure that:

- Equipment and components are not damaged.
- The system matches the design documents and all equipment has been correctly connected according to the wiring diagrams.
- Equipment and components comply with local safety standards and are suitable for use in a utility-interactive PV system.
- The site has been left clean and tidy and presents no hazards for the general public.
- The signs and warning labels required by local codes are present.

The array and array frame should be inspected to ensure that they have been installed correctly and are suitable for the location. This includes checking that the frame is sturdy, is appropriately rated for local wind and snow conditions, and has been installed so that any roof penetrations are properly sealed and weatherproofed (see Chapter 6).

The inverter should be inspected prior to commissioning to ensure that it is securely mounted and all electrical connections in and out of the unit are firm. The location of the inverter should also be considered during this inspection to ensure that it is accessible for maintenance and emergency disconnection, has been appropriately weatherproofed, and that allowances have been made to ensure sufficient ventilation. Weatherproofing can be verified by checking the IP or NEMA rating of the inverter (see Chapter 8 for further information about this). Ventilation should also be checked against the manufacturer's recommendations.

The wiring and electrical components should also be inspected. The inspection should ensure that all wiring and components are securely installed and adequately protected against mechanical and environmental damage. It should be ensured that they are fully operational, are correctly sized and installed in accordance with standards and regulations. All disconnects/isolators must be easily accessible in case of an emergency.

This inspection process should be documented and a copy of the documentation should be left with the customer for their records.

Table 12.1 Recommended maintenance for PV array

Activity	Frequency
Clean modules	As required
Check mechanical security of the array structure	Annually
Check all cabling for mechanical damage	Annually
Check output voltage and current of each string of the array and compare to the expected output under existing conditions	Annually
Check electrical wiring for loose connections	Annually
Check the operation of the PV DC main disconnect/isolator (only after AC main disconnect/isolator has been switched off)	Annually

Table 12.2 Example of a PV array logsheet

Date	Cleaned modules	Array structure OK	Array cabling: mechanical	Array cabling: electrical	Output voltage	Output current	PV DC main disconnect/ isolator	Comments
	☐	☐	☐	☐	...V	...A	☐	
	☐	☐	☐	☐	...V	...A	☐	
	☐	☐	☐	☐	...V	...A	☐	

PV has many unique features among electricity-generating technologies that contribute to its popularity today:

- PV is reliable and low-maintenance; it contains no moving parts and the modules are robust, often coming with a 20–25 year guarantee.
- PV is good for the environment. Some people may suggest that a PV system cannot generate enough energy in its lifetime to equate to the amount of energy required in its production; this is not accurate. The energy required is retrieved in 2–7 years, depending on the system components, design, installation and its location. In addition this energy is clean and renewable, and will further reduce greenhouse gas emissions. PV modules are also recyclable.
- Grid-connected PV systems are easy and quick to install. PV's modular nature also makes it very easy to work with, installations can be of any size without any major manufacturing changes and modules can usually be added or removed during the lifetime of the installation.

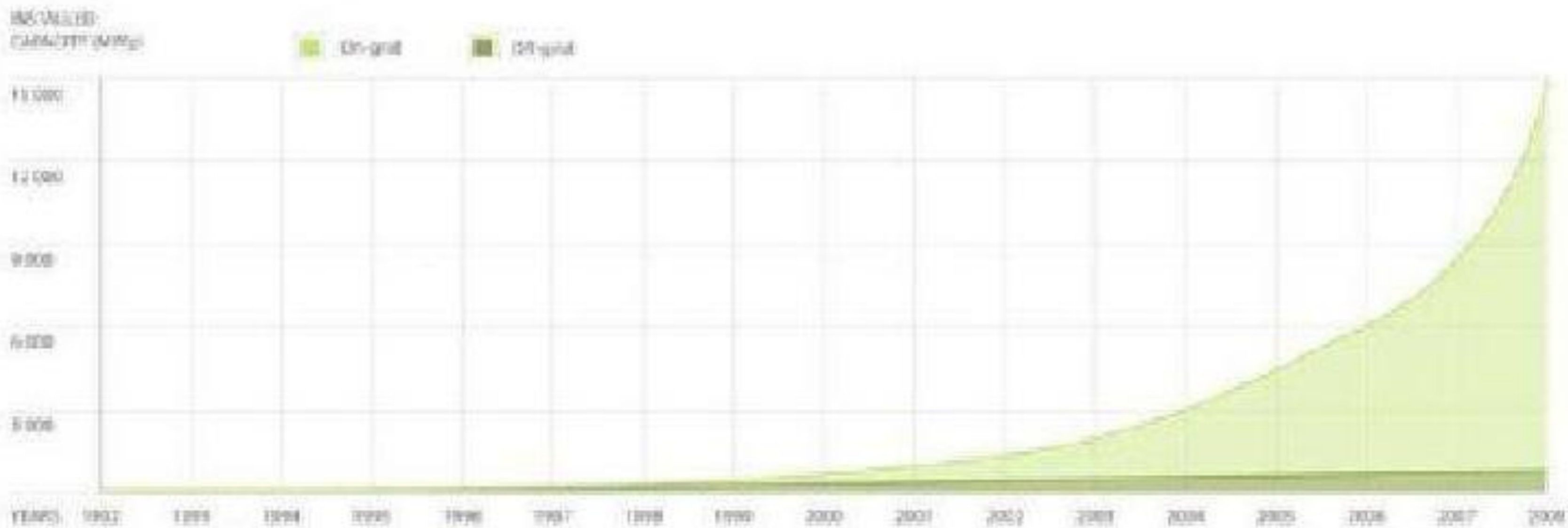


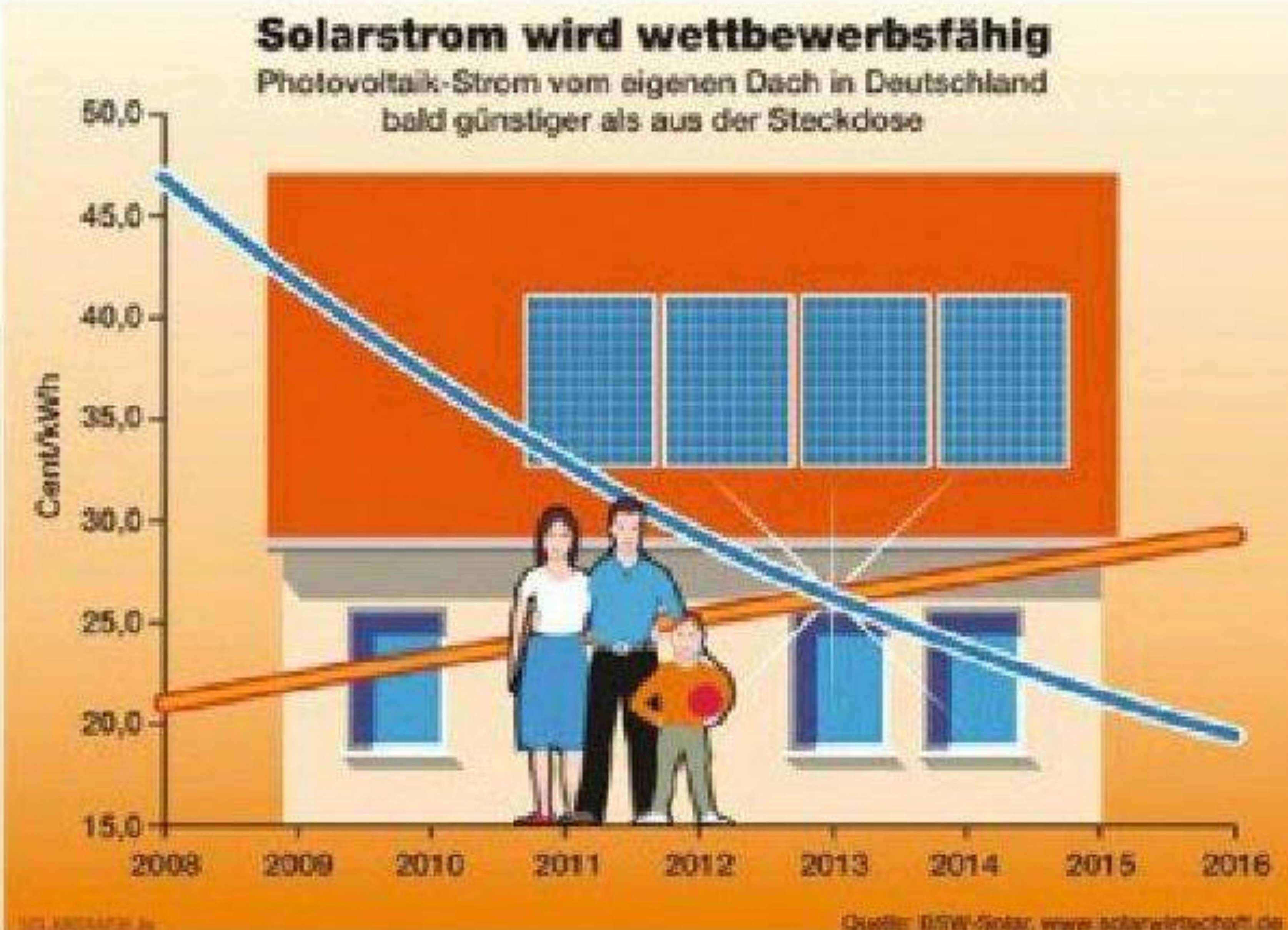
Figure 13.5 Graph showing the global cumulative installed PV capacity up to 2008. On-grid connections have increase dramatically over the last few years while off-grid has remained quite steady

- PV can represent a good investment: a system can add value to the building where it is installed and many of the financial incentives available such as FiTs are legislated for a certain period of time.
- PV is useful as a public demonstration of commitment to sustainability and reducing greenhouse gas emissions. This may be desirable for a company marketing itself as green because PV is an easy and highly visible way to make a statement and reduce a company's carbon footprint.

Despite these positive attributes there are still some strong barriers to PV technology, these include:

- High capital costs: the high capital cost of a system can be a major deterrent for investment or render a PV system unattainable for some people. Rebates and green loan programmes are attempting to address this.
- Lack of public knowledge and advertising: there are many myths surrounding PV such as it being too expensive to even consider putting on a home and that the amount of energy produced by the system is less than the energy consumed in its manufacture. The PV industry needs to be proactive about education to dispel these myths.
- Lack of industry: The grid-connect PV industry is still very much in its infancy in most parts of the world. There are a limited number of companies providing training and installation, and standards and regulations are still being developed.
- Lack of planning: As already discussed the amount of solar radiation a module receives is strongly affected by its orientation, but the installation is often governed by the orientation of the roof. When many towns were planned and built the roof orientation was not considered with respect to future PV installations.

- Utility regulations based on mains supply: Most electricity markets are unaccustomed to dealing with distributed generation, i.e. small-scale PV. Sometimes people seeking to install a small rooftop PV system have been required to complete the same paperwork as those planning to connect a large-scale coal-fired power station to the grid. Over time utilities are becoming more accustomed to dealing with distributed generation and streamlining the process of interconnection.
- Well-integrated fossil fuels: Well-established systems that favour fossil fuels are a key barrier to PV. Despite PV's numerous advantages, fossil fuels remain a more cost-effective option. Policies that put a price on the environmental damage of fossil fuels, such as emissions trading schemes and carbon taxes intend to drive up the price of fossil-fuel-generated electricity, making PV and other renewable energy sources more competitive.


Solarstrom wird wettbewerbsfähig
Photovoltaik-Strom vom eigenen Dach in Deutschland
bald günstiger als aus der Steckdose
Cent/kWh
50,0
45,0
40,0
35,0
30,0
25,0
20,0
15,0
2008
2009
2010
2011
2012
2013
2014
2015
2016
Quelle: BSW-Solar, www.solarwirtschaft.de

- Capital costs: The upfront purchase of all system equipment including PV modules and balance of system equipment makes up approximately 80 per cent of total system costs. The modules are the most expensive item by far, but inverters can still be costly; grid-interactive inverters range from US$500/kW to US$2000/kW. Smaller inverters generally used in residential applications are in the more expensive end of the spectrum because they are smaller. In areas where utilities are obliged to offer free net metering (as is the case in most US states) to customers with a PV system a new meter can be acquired free of charge, but in areas where the policy does not exist (i.e. Australia) it is often necessary to purchase a new meter with the system. The remaining 20 per cent of system cost is for the actual installation (excluding a small ongoing maintenance cost).

- Maintenance costs: 1 per cent of system cost is comprised of maintenance costs. Maintenance should be undertaken every 6–12 months; if the modules and inverter have been installed correctly then maintenance costs should be minimal. The array should last at least 20 years, and most modules are covered by a 20–25 year warranty so if premature failure does occur it is often possible to replace or repair the modules free of charge. The inverter is likely to require repair during its lifetime; inverters generally carry a 5–10 year warranty with an option to extend the warranty a further 5–10 years.

- Replacement costs: PV modules are expected to last at least 25 years and most system components are expected to last at least 20 years. Some system components may not last as long as the panels and will require replacement. Inverters have warranties that commonly last 5–10 years but can mostly be repaired should they fail beyond this period. Terminal failure of a correctly installed and properly sized inverter is uncommon, but possible. The designer should ask the manufacturer about the expected life of the inverter they are installing in the system. If it is less than the expected life of a system, then a replacement should be accounted for in costing. Other components may require replacement: monitoring equipment, bypass diodes, cable, plugs/sockets etc. Protection from the elements and wildlife will increase the lifetime of this equipment and hence reduce these costs.

Valuing a PV system

Valuing a PV system is an important process that allows for comparison across systems. The preferred method for assessing the capital cost of a PV system is in dollars per watt ($/W) and as such looks only at the upfront cost of the system. To calculate $/W the following formula is used:

$$\$/W = \frac{\text{Upfront cost of the PV system (\$)}}{\text{Rated Peak Power of the PV System (W)}}$$

This method is only used for upfront costs. Currently it is the standard method of comparing system and equipment costs in Europe and is becoming increasingly common around the rest of the world.

Simple payback

The simplest method for examining the economics of PV grid-connected systems is the *simple payback* method. People are often interested in the payback period of the installation. This is calculated using the following formula:

$$\text{Time (years)} = \frac{\text{Capital cost (\$)}}{\text{Savings from avoided electricity purchase (\$)}}$$

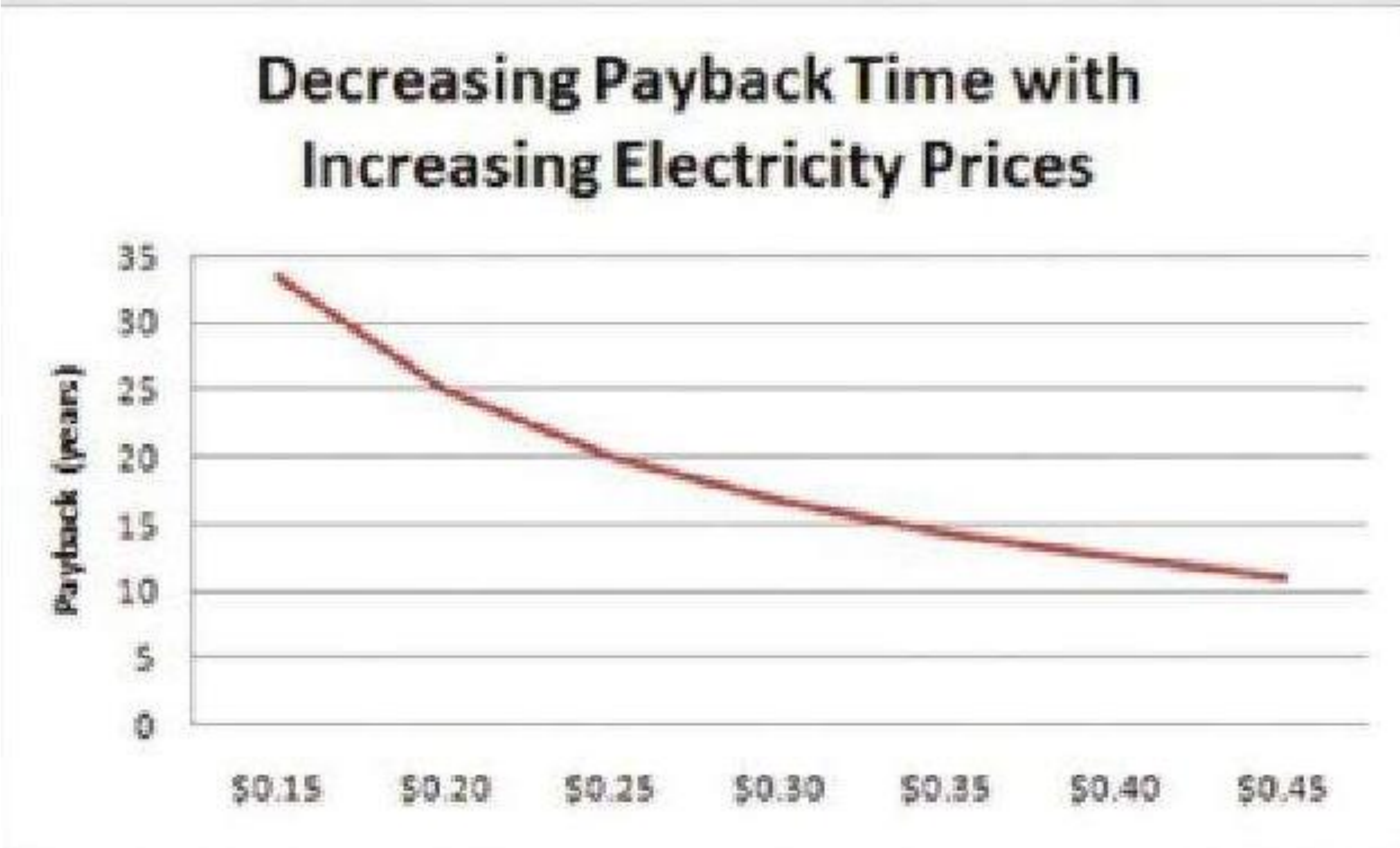
Example:

A 1kWp grid-connected system produces about 1200kWh per year. The system costs currently \$6,000.00. The average projected costs for residential electricity is \$0.15/kWh, therefore the savings per year will be \$180 (1200 × 0.15).

The simple payback time is: $T = \frac{\$6000}{\$180} = 33\ \textit{years}$

Feed-in tariffs

A Feed-in tariff (FiT) is a monetary reward for feeding electricity generated by PV into the grid. It can either be equal to the retail electricity rate or greater than this rate (known as an enhanced FiT). FiTs are usually financed by a levy added to all electricity bills. Small-scale PV is generally most successful in locations that have FiTs, such as Germany; however, it is important for these FiTs to be stable in order to encourage sustainable growth in the industry. In


Decreasing Payback Time with
Increasing Electricity Prices
Payback (years)
35
30
25
20
15
10
5
0
$0.15
$0.20
$0.25
$0.30
$0.35
$0.40
$0.45