Solution 2

Exercise 1: LCOE for a modern roof-top solar system

Consider you are buying new solar modules for roof-top mounting and (partial) self-consumption. The modules that you consider are 260€, measure $1.7\,\mathrm{m}^2$, and deliver $350\,\mathrm{W_p}$. Your roof is pointed south, in Switzerland, and you can assume 1200h full sun equivalent per year. A 12 kW inverter is 1369€ and a 20 kW inverter is 1529€. Both have an efficiency of 97%.

a) Calculate how many modules you would need, how much the full system would cost, and how much power would be generated per year for both a $12\,\mathrm{kW_p}$ system and a $20\,\mathrm{kW_p}$ system.

Solution:

$$(12\,\mathrm{kW_p}\text{ desired}) / 350\,\mathrm{W_p}\text{ per module}) = 35\text{ modules}$$
$$35\text{ modules} \cdot 260€\text{ per module} + 1\,369€\text{ converter} = 10\,469€$$
$$35\text{ modules} \cdot 350\,\mathrm{W_p} \cdot 1\,200\text{ h sun per year} \cdot 97\%\text{ inverter efficiency} = 14\,259\,\mathrm{kW\,h\,yr^{-1}}$$
$$\text{for } 20\,\mathrm{kW_p}\text{ system: 58 modules, } 16\,609€\text{, and } 23\,629\,\mathrm{kW\,h\,yr^{-1}}$$

b) Assume you save 20€cts per kWh that you don't purchase from the grid (it is unrealistic to 100% self consume, but calculating for grid buy-back or battery storage is complex). How many years would it take to repay the total <u>initial</u> cost of each system?

Solution:

$$14\,259\,\mathrm{kW\,h\,yr^{-1}} \cdot 0.2€\text{ per kWh} = 2\,852\text{ € per year}$$
$$10\,469€\text{ initial cost} / 2\,852\text{ € per year} = 3.67\text{ years}$$
$$\text{for } 20\,\mathrm{kW_p}\text{ system: } 3.51\text{ years}$$

c) Assume roughly 50€ per year in cleaning and maintenance costs, and 0.4% yearly loss in power output. What is the LCOE for each system, assuming a 25 year lifetime?

Solution:

$$10\,469€\text{ initial cost} + 25\text{ years} \cdot 50€\text{ per year} = 11\,719€\text{ total cost}$$
$$0.4\%\text{ degradation per year} \cdot 25\text{ years} = 10\%\text{ total performance loss}$$
$$100\%\text{ perf. in year 1 to } 90\%\text{ perf. in year 25} = 95\%\text{ average perf. over 25 years}$$
$$14\,259\,\mathrm{kW\,h\,yr^{-1}} \cdot 25\text{ years} \cdot \text{average } 95\%\text{ performance} = 338\,651\,\mathrm{kW\,h}\text{ total}$$
$$\text{LCOE } (12\,\mathrm{kW_p}\text{ system}) = 3.4€\text{cts/kWh}$$
$$\text{LCOE } (20\,\mathrm{kW_p}\text{ system}) = 3.2€\text{cts/kWh}$$

Exercise 2:

a) Explain the behaviour of the thin film market share during the years. Why do silicon-based PV modules (i.e. made of Si wafers) currently rule the market (over thin films)?

Solution:

Thin film PV modules is one of the main PV technology, along with crystalline Silicon (c-Si) based solar panels (and III-V junctions). The peculiarity of this type of technology is the possibility to directly deposit the material (with a thickness of only few micro-meters) on the internal surface of the modules glass (i.e. the glass is used as a substrate for the deposition). There are 3 different classes of thin films that has been industrialised: CIGS, a-Si (amorphous Silicon) and CdTe (Cadmium-Telluride). Even quite attractive, in the last decade they almost disappear from the market due to the lower efficiency potential compared to c-Si (13-20% VS 22-25%). Moreover, the constant decrease of the price of Silicon make it the dominant technology on the market.

b) What is the main technology used for aerospace applications? What are the main differences in optimization strategies with respect to terrestrial solar cells?

Solution:

In the early '80, silicon based PV panels were used for aerospace application. Their cost was so high that actually this was the only market at that time. However, Silicon wafers suffer the harsh conditions of the out space (i.e. strong radiation) leading to a fast degradation of the panel. Nowadays, III-V junction technology has replaced c-Si modules for space application thanks to their stronger resistance to space conditions.

c) Assuming a transition towards electricity replacing all fossil fuel, with an averaged improved efficiency by a factor 3, and assuming we keep our primary energy needs constant at 166'000 TWh per year. How many W of solar panels placed in the desert would you need ? (yield of 1800 kWh/kW) How many W of offshore wind turbine ? (yield of 3500 kWh/kW) How many Small nuclear reactor of 100 MW ? (assuming 90% operational time).

Solution:

- 16'000 TWh = X W modules * Yield = X * 1800 kWh/kW
  X = 92.22 * 10^{12} W of solar panels
- 166'000 TWh = X W turbines * Yield = X * 3500 kWh/kW
  X = 47.43 * 10^{12} W of wind turbines
- 166'000 TWh = X times nuclear reactor * Power of a reactor * operational time * hours in year
  X = 166'000 * 10^{12}/ ((X)*0.9*8640 h*100 MW)
  X = 213'477 nuclear reactors (without factor)
  213'477/3= 71'159 nuclear reactors