Solutions to Chapter 10:

Hint: In the next exercises only estimations are done. There are different ways to the solution therefore the presented solutions are to be considered only as example solutions. However the alternative solutions should yield similar results.

Exercise 10.1: Potential Estimation for Pitched Roofs

a) From Figure 2.7: The Saarland is situated around Saarbrücken in South-West Germany:

$$H' \approx \underline{1075 \frac{\text{kWh}}{\text{m}^2 \cdot \text{a}}}$$

Theoretical Potential: $W_{\text{Theo}} = A \cdot H' = 2750\ \text{km}^2 \cdot 1075 \frac{\text{kWh}}{\text{m}^2 \cdot \text{a}} = 2.956 \cdot 10^{12} \frac{\text{kWh}}{\text{a}} \approx \underline{3 \cdot 10^{12}\,\text{kWh/a}}$

b) Roof surfaces: $A_{\text{Pitch}} \approx 0.3\,\% \cdot 2750\ \text{km}^2 = \underline{7.71\ \text{km}^2}$

Optical energy on pitched surface (incl. inclination losses of 15 %, see Table 10.1):

$$W_{\text{Optical\_Pitch}} \approx 1200 \frac{\text{kWh}}{\text{m}^2 \cdot \text{a}} \cdot 0.85 \cdot \frac{H'}{H} \cdot A_{\text{Pitch}} \approx 1200 \frac{\text{kWh}}{\text{m}^2 \cdot \text{a}} \cdot 0.85 \cdot \frac{1075}{1000} \cdot 7.71\ \text{km}^2 \approx \underline{8.45\ \text{TWh/a}}$$

c) Power: $P_{\text{STC}} = A_{\text{Pitch}} \cdot E_{\text{STC}} \cdot \eta_{\text{Module}} = 7.71\ \text{km}^2 \cdot 1000 \frac{\text{W}}{\text{m}^2} \cdot 0.2 = \underline{1.54\ \text{GWp}}$

Electrical Energy: $W_{\text{Elec\_Pitch}} = W_{\text{Optical\_Pitch}} \cdot \eta_{\text{System}} = 8.45 \cdot 10^9 \frac{\text{kWh}}{\text{a}} \cdot 0.18 = \underline{1.52\ \text{TWh/a}}$

Exercise 10.2: Potential Estimation for Free Areas

a) From Figure 2.7: The Saarland (around Saarbrücken) has a latitude of about 49 °,

Smallest noonday solar altitude in winter with Equation (2.6):

$$\gamma_{S\_Min} = 66.6\,° - \varphi = 66.6\,° - 49\,° = \underline{17.6\,°}$$

Area utilization factor with Equations (9.4) and (9.5):

$$f_{Util} = \frac{b}{d_{Min}} = \frac{\sin(\gamma_S)}{\sin(\gamma_S + \beta)} = \frac{\sin(17.6\,°)}{\sin(17.6\,° + 20\,°)} = 49.6\,\% \approx \underline{50\,\%}$$

b) Module area: $A_{Module} = f_{Util} \cdot A_{Free\_Area} = 0.5 \cdot 10\,000\ \text{m}^2 = \underline{5000\ \text{m}^2}$

PV-Power: $P_{STC} = A_{Module} \cdot E_{STC} \cdot \eta_{Module} = 5000\ \text{m}^2 \cdot 1000\ \frac{\text{W}}{\text{m}^2} \cdot 0.2 = \underline{1\ \text{MWp}}$

Electrical Energy with Equation (10.4): $W_{Electrical\_PV} = A_{Module} \cdot f_{Util} \cdot \eta_{Module} \cdot E_{STC} \cdot \frac{H'}{H} \cdot Y_F$

$$\Rightarrow W_{Electrical\_PV} = 10\,000\ \text{m}^2 \cdot 0.5 \cdot 0.2 \cdot 1000 \frac{\text{W}}{\text{m}^2} \cdot \frac{1075}{1000} \cdot 900 \frac{\text{kWh}}{\text{kWp} \cdot \text{a}} = \underline{967\,500\ \text{kWh/a}}$$

Alternative way of solution:

Electrical Energy: $W_{Electrical} = W_{Optical} \cdot \eta_{System}$

$$\Rightarrow W_{Electrical} = 1200 \frac{\text{kWh}}{\text{m}^2 \cdot \text{a}} \cdot \frac{H'}{H} \cdot A_{Module} \cdot \eta_{System} \approx 1200 \frac{\text{kWh}}{\text{m}^2 \cdot \text{a}} \cdot \frac{1075}{1000} \cdot 5000\ \text{m}^2 \cdot 0.18 \approx \underline{1.2\ \text{Mio. kWh/a}}$$

c) According to Section 10.1.4 energy corn yields an electrical energy of about 17 000 kWh/a.
Thus photovoltaics on the same area yields about the 57- to 70-fold of electrical energy!