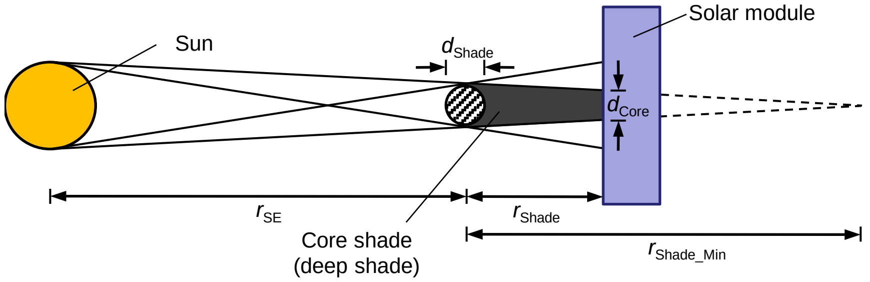
Solutions to Chapter 9:

Exercise 9.1: Shading

a) $r_{\text{Shade\_Min}} = 107 \cdot d_{\text{Shade}} = 107 \cdot 5\text{ cm} = \underline{5.35\text{ m}} > r_{\text{Shade}} = 2\text{ m}$

Thus there will be a deep shade.

b)



With the sketch and intercept theorem:

$$\frac{d_{\text{Shade}}}{r_{\text{Shade\_Min}}} = \frac{d_{\text{Core}}}{r_{\text{Shade\_Min}} - r_{\text{Shade}}} \Rightarrow d_{\text{Core}} = d_{\text{Shade}} \cdot \frac{r_{\text{Shade\_Min}} - r_{\text{Shade}}}{r_{\text{Shade\_Min}}} = 5\text{ cm} \cdot \frac{5.35\text{ m} - 2\text{ m}}{5.35\text{ m}} = \underline{3.1\text{ cm}}$$

c) The modules should be positioned vertically if possible. Typically the cells are switched in series in the longitudinal direction of the module. In case of a vertically aligned module the deep shade only turns off one cell string as the other cell strings can still work due to the bypass diodes. In case of a horizontally aligned module the aerial tube will shade cells in every cell string so that the whole module is affected.

Exercise 9.2: Yield Estimation

a) With Table 2.4: Y_F = 93.4 % · 900 kWh/(kWp·a) = <u>840.6 kWh/(kWp·a)</u>

b) With Figure 2.7: H´ ≈ 970 kWh/(m²·a)

$$\Rightarrow Y_F' = \frac{H'}{H} \cdot Y_F = \frac{970}{1000} \cdot 840.6 \frac{\text{kWh}}{\text{kWp} \cdot \text{a}} = \underline{815.4 \frac{\text{kWh}}{\text{kWp} \cdot \text{a}}}$$

c) Result from PVGIS: $H'' = 2850 \frac{\text{Wh}}{\text{m}^2 \cdot \text{d}} = 2.85 \frac{\text{kWh}}{\text{m}^2 \cdot \text{d}} \cdot \frac{365\text{ d}}{\text{a}} = \underline{1040.25 \frac{\text{kWh}}{\text{m}^2 \cdot \text{a}}}$

$$\Rightarrow Y_F'' = \frac{H''}{H} \cdot Y_F = \frac{1040.25}{1000} \cdot 840.6 \frac{\text{kWh}}{\text{kWp} \cdot \text{a}} = \underline{874.4 \frac{\text{kWh}}{\text{kWp} \cdot \text{a}}}$$

d) Result is <u>840 kWh/(kWp·a)</u>

Conclusion: The most realistic are probably the results of a) and d). Possibly the real yield is slightly higher; this depends on the concrete components of the plant (especially the inverters). PVGIS calculates in subitem d) with a performance ratio von 77 %; if this is enhanced to 80 % a yield of 870 kWh/(kWp·a) will result.

Exercise 9.3: Return Calculation

a) Annual Income: $C_{\text{Inc}} = w_{\text{Year}} \cdot P_{\text{STC}} \cdot c_{\text{EEG}} = 848 \dfrac{\text{kWh}}{\text{kWp} \cdot \text{a}} \cdot 30\ \text{kWp} \cdot 0.287\ \dfrac{\text{Euro}}{\text{kWh}} = \underline{7301.28\ \text{Euro/a}}$

Annual operating costs: $C_{\text{Oper}} = 1.5\ \% \cdot C_0 = 1.5\ \% \cdot 60\ 000\ \text{Euro} = \underline{900\ \text{Euro/a}}$

Amortization time: $T_{\text{Amort}} = \dfrac{C_0}{C_{\text{Inc}} - C_{\text{Oper}}} = \dfrac{C_0}{C_{\text{Surplus}}} = \dfrac{60\ 000\ \text{Euro}}{6401\ \text{Euro/a}} = \underline{9.37\ \text{a}}$

b) We calculate the money C_{20} that has summed up after 20 years in each case with Equation (9.9) and (9.11). The interest factor is varied until no difference rests between both amounts:

Difference: $D = C_0 \cdot q^{20} - C_{\text{Surplus}} \cdot \dfrac{q^{20} - 1}{q - 1} = 60\ 000\ \text{Euro} \cdot q^{20} - 6401\ \text{Euro} \cdot \dfrac{q^{20} - 1}{q - 1}$

Variation results in: $q = 1.086$; thus $\underline{p = 8.6\ \%}$

Exercise 9.4: Plant Monitoring

a) The expression *Sun full load hours* describes generally the full load hours that the Sun annually supplies on a horizontal surface. The *reference yield* in contrast describes the full load hours that the Sun annually supplies at the generator level (or in other words: at a surface orientated like the solar generator).

b) This is not generally predictable. The orientation has no direct influence on the performance ratio, as this is defined as the final yield divided by referenced yield (thus the optical energy that is incident on the generator).

c) About 80 to 85 %.