Renewable Energy Technologies I

Exercise 2

Prof. A. Wokaun
Assistant: K. Volkart

27 September 2016

Instructions

- Please give the results in the units provided.
- Round your results to reasonable precision.
- Exercises do not have to be submitted for correction.
- Solutions of the exercises will be made available on October 4.
- If you have questions, please write an e-mail to: kathrin.volkart@psi.ch

1 Electricity generation costs

After the Fukushima disaster in 2011, the Swiss federal government decided to phase-out nuclear energy. In that year, nuclear energy contributed about 41% to the Swiss domestic electricity generation. Expecting constant or increasing electricity demands for the future, the nuclear generation capacity has to be (more than) compensated by non-nuclear generation. Two options for domestic electricity production are natural gas-fired and geothermal power plants. Table 1 shows the techno-economic characteristics of a natural gas-fired combined cycle and a geothermal power plant.

1.1 Annuity factor

Calculate the annuity factor *acc* for the two types of power plants. Assume a reasonable interest rate and comment on your selection.

1.2 Generation cost calculations

Calculate the electricity generation costs G of both types of power plants [Rp./kWh$_e$]. Which technology has higher generation costs? *Be careful with the units!*

Table 1: Technical characteristics of
the natural gas and geothermal power plants

	Natural gas	Geothermal
Power plant efficiency η_e	62%	11%
Life time n	30 yr	25 yr
Full load hours *load*	7500 h/yr	8000 h/yr
Investment costs I	950 CHF/kW$_e$	35000 CHF/kW$_e$
Levelised O&M costs OM	8.4 Rp./kWh$_e$	4.1 Rp./kWh$_e$
Natural gas price P	10 CHF/GJ$_{th}$	-

1.3 CO_2 tax

Switzerland has a CO_2 law with stringent domestic emission reduction targets. Natural gas-fired power plants emit significant amounts of CO_2 (300-400 g CO_2 /kWh$_e$). CO_2 taxes are a policy measure which incentivises low-CO_2 electricity generation.

Would a CO_2 tax of 10 CHF/GJ$_{th}$ on natural gas make geothermal power generation cost-competitive with natural gas power generation?

1.4 Investment subsidies

Another policy measure to incentivise investments in low-carbon power generation are subsidies on the investment costs. What investment subsidy (CHF/kW) would be required to make geothermal power generation cost-competitive with natural gas power generation?

1.5 Broader view

Natural gas power plants emit significant amounts of CO_2 and geothermal power plants have relatively high generation costs (see above). Can you think of other weaknesses of these technologies which could hinder their deployment in Switzerland? Think from a broader sustainability perspective, i.e. consider societal, technical, environmental and security of supply aspects.

2 Technology learning

New technologies are subject to so-called technology learning. With increasing capacity installed, the specific technology cost fall due to the gain in experience. The learning curve is an empirical function that relates total specific investment cost of technologies to their cumulative installed capacity.

2.1 Learning curves

Draw the following two lines in Figure 1 below and label them accordingly:

- Learning curve
- Floor cost curve

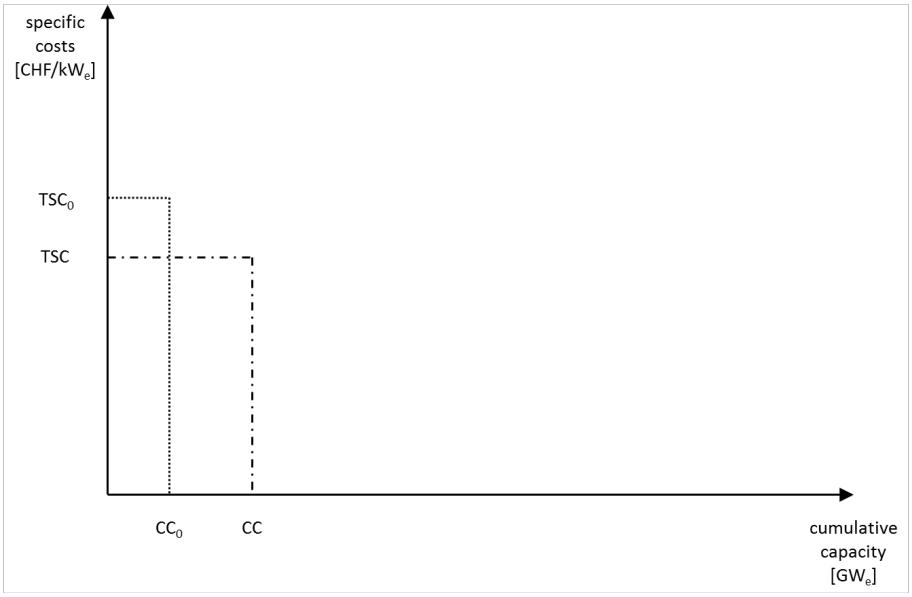

Figure 1: Learning curve

2.2 Learning index

Wind power is another option to expand domestic renewable electricity generation in Switzerland. Up to 2035, the technology is expected to become more competitive compared to conventional natural gas power plants as the currently immature technology undergoes so-called technology learning.

Calculate the learning index b of wind energy [-]. Assume the learning rate lr as stated in the lecture notes [1].

2.3 Technology learning calculations

Calculate the cumulative capacity CC [MW$_e$] of wind power which is required to achieve total specific costs TSC of 1500 CHF/kW$_e$ in 2035. Assume that 1000 CHF/kW$_e$ of the 2100 CHF/kW$_e$ investment costs TSC_0 in 2010 are the floor cost *floor*, whereas the rest of the investment cost SC_0 undergoes technology learning. The installed wind capacity CC_0 in 2010 was 18 MW$_e$.

2.4 Limitations of the approach

Which considerations have been omitted in the way previous question was formulated? Give arguments and propose a more realistic formulation for the technology learning for wind power.

[1] A learning rate of 20% implies that with the doubling of the cumulative capacity, the costs are reduced to 80% of their initial value.