Industrial Ecology Open Online Course (IEooc)

Part III: Application

Application part 4: Energy and Sustainability

http://www.teaching.industrialecology.uni-freiburg.de/

IEooc_Application4_Exercise5: Energy Supply Scenarios

Sample solution

Goal: *Estimate RE potential and assess how a given energy demand can be met using different RE sources. Estimate the GHG mitigation potential and land use of a given RE scenario.*

Task: Create a simple energy supply scenario for a country/region of your choice for 2040! The scenario (both the amount of energy, the split into different energy carriers, and the electricity mix) should be a likely one according to your judgement.

1) **Assess the GHG intensity and area usage of that scenario and compare it to set or debated policy targets, if existent. Future energy demand can be estimated, e.g., by first looking at energy demand by sector in 2022 (IEA energy statistics!) and then assuming sector-specific growth rates until 2040.**
2) **How much electricity is generated each year in your scenario? This quantity can be reported as amount, like '500 TWh' or as energy flow '500 TWh/yr'.**
3) **Assuming this electricity is generated only by onshore wind turbines, which operate 2000 hours per year, how large is the installed capacity and what unit does it have?**
4) **Assuming that the wind turbines have a lifetime of 20 years and the capacity stock is in a steady state (constant stock and constant inflow = outflow each year), how much capacity is added and demolished each year and what is the unit of this quantity?**

Table 1 lists typical values for the specific global warming potential and the specific land use for a number of RE and fossil-based energy carriers. Not that actual impacts are often site-specific and vary substantially!

Table 1: Specific GWP and land requirement of RE and fossil-based energy carriers.

Energy carrier/source	**Spec. global warming potential, GWP, kg CO2-eq. per MWh**	**Spec. land use, m^2/MWh**
PV electricity	25	10
Hydro electricity	25	20
Wind electricity	15	2
Coal electricity	800	25
Natural gas electricity	500	2
Coal electricity plus CCS	200	25
Natural gas electricity plus CCS	200	2
Biofuels	130	450
Coal (fuel use)	400	10
Natural gas (fuel use)	260	0.8

CCS: Carbon capture and storage.

Additional possible considerations:

a) Could the primary energy demand determined be met with domestic fossil energy? How many resources would have to be mined and how long would they last?

b) Could the primary energy demand determined be met with domestic renewable energy? How much area would be needed (for solar, wind, biomass, and geothermal) or how many dams (for hydropower)?

c) How feasible and realistic is a 100% renewable energy scenario for 2040 in the region that you considered?

Task 1: For the sample solution case study for the residential heat, passenger transport, and material production scenarios in Germany, which was developed for the energy demand exercise, the following energy supply scenarios were created (Table 2). If this exercise is not carried out, the values in Table 2 can simply be a starting point for the analysis here. As an alternative, future energy demand can be estimated, e.g., by first looking at energy demand by sector in 2022 (IEA energy statistics!) and then assuming sector-specific growth rates until 2040.

Table 2: Energy supply scenarios for the demand scenario generated under the energy demand exercise.

Energy supply, TWh	Base case	Conservative, little RE electricity	RE scenario w. solar + N.G. CCS	RE scenario w. solar + N.G. CCS
PV electricity	0	0	87	0
Hydro electricity	0	0	0	0
Wind electricity	0	0	0	87
Coal electricity	0	0	0	87
Natural gas electricity	35	92	0	0
Coal electricity plus CCS	0	0	0	0
Natural gas electricity plus CCS	0	0	87	0
Biofuels	140	199	164	164
Coal (fuel use)	140	140	0	0
Natural gas (fuel use)	861	437	112	112
Total	1177	868	449	449

In the **base case scenario,** the actual energy supply as observed around 2015 was taken. For the **conservative transition scenario** developed in the energy demand exercise, it was assumed that natural gas will be the dominant fuel in 2040, but coal will still have to be used in material production, notably, in steel making. For the **RE scenario** developed in the energy demand exercise, it was **first** assumed that all electricity consists of a 50% mix of solar PV and Natural gas with CCS, to compensate for the intermittency of the PV. A **second** supply scenario was created for this case, this time, assuming a 50% combination of wind and coal-fired power (by extending the lifetime of existing assets).

Table 3 lists the resulting GHG emissions and land use.

Table 3: Total GHG emissions and land use for the different energy supply scenarios.

Base case	GWP, Mt CO2-eq	Land use, km2
Buildings	141	54623
Pass. Veh.	101	9283
Materials	74	1428
Total	**316**	**65334**

Conservative, little RE electricity	GWP, Mt CO2-eq	Land use, km2
Buildings	88	35847
Pass. Veh.	80	54088
Materials	74	1428
Total	**241**	**91363**

RE scenario w. solar + N.G. CCS	GWP, Mt CO2-eq	Land use, km2
Buildings	23	45045
Pass. Veh.	23	19098
Materials	24	10696
Total	**70**	**74839**

RE scenario w. solar + N.G. CCS	GWP, Mt CO2-eq	Land use, km2
Buildings	50	45738
Pass. Veh.	40	19534
Materials	31	10871
Total	**121**	**76143**

According to our rough estimate, the baseline emissions were about 300 Mt of CO_2-eq. That is roughly 40% of Germany's total emissions. In the least ambitious of the scenarios presented, emissions could decline to 241 Mt, but land use would increase to ca. 90.000 km², which is roughly 25% of the country's area. Emissions could further decline, down to 121 Mt or a 62% reduction, if demand is reduced, a shift to electricity as central energy source occurs, and this electricity is made up of 50% wind power next to

50% coal-fired base load. The largest reduction of 78% can be seen if the existing coal-fired power stations are replaced by CCS-coupled natural gas fired power stations.

The latter scenario requires a wide basket of policies developed and technologies deployed to manage energy demand, enable a transition to other energy carriers and more efficient energy conversion, and facilitate further deployment of renewable and other low-carbon energy supply technologies.

An 78% reduction could be on track with the 80, 85, or even 95% reduction targets for 2050 that are under debate.

Task 2: For the third scenario, RE scenario w. solar + N.G. CCS,

174 TWh of electricity

are generated each year. The unit is TWh (as energy quantity) or TWh/yr (as flow).

Task 3: With an unkown capacity C and a known operation time T (2000 hours), we can say that C*T = 174 TWh, from which follows:

$$C = 174 \text{ TWh}/2000 \text{ h} = 0.087 \text{ TW} = 87 \text{ GW}.$$

The unit is GW, the unit of power.

Task 4: With a lifetime τ = 20 years and the given stationary state conditions, 1/20 of the stock is exchanged each year. The annual capacity turnover therefore is $C\_flow = C / \tau$.

$$C\_flow = 87 \text{ GW}/20 \text{ yr} = 4.35 \text{ GW/yr}.$$

The unit is GW/yr, or installed power per year.