The global energy system: energy demand and supply, climate protection goals, and the potential of renewables

This assignment does not need to be submitted for grading.
Questions may be directed to Mashael Yazdanie (mashael.yazdanie@psi.ch).

Question 1

Global primary energy demand is illustrated in Figure 1 for two climate change scenarios developed by the International Energy Agency (IEA). In IEA's 6-degree (6DS) and 2-degree (2DS) scenarios, the global average temperature increase until 2100 is limited to 6 degrees and 2 degrees, respectively.

Global population and GDP statistics are given in Table 1.

Figure 1: Global primary energy demand from different energy sources in 6-degree (6DS) and 2-degree (2DS) scenarios [1]

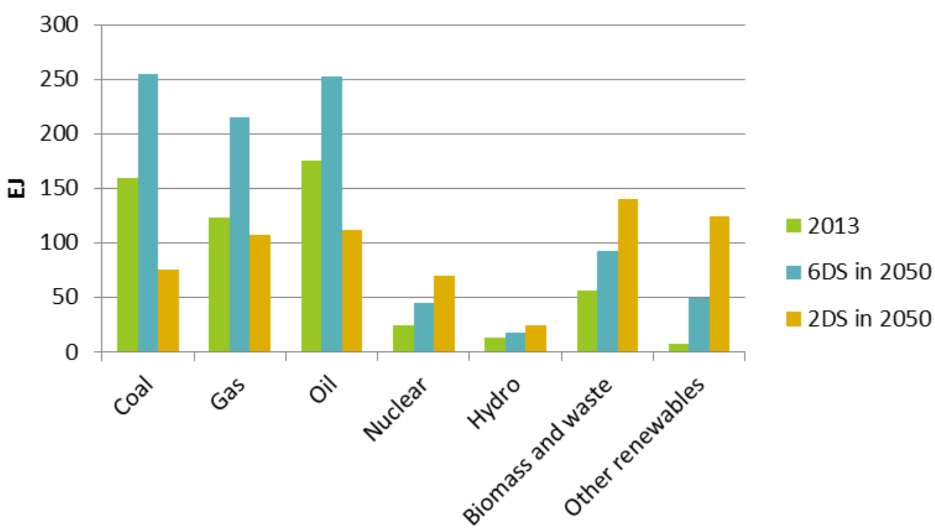

Table 1: World population and GDP statistics 2013 [2]

	World
Population (millions)	7118
Population 2050 (millions, projected)	9468
GDP (billion (=10^9) 2005 USD)	86334
Real GDP growth projection (2012-2050) – CAAGR[1]	3.20%

[1] compound average annual growth rate

a. Which energy source plays the most significant role in reducing global emissions according to Figure 1?

The substitution of fossil fuel resources (especially coal) with zero or low-emitting biomass and waste energy plays the most significant role in reducing global emissions according to Figure 1.

b. Calculate the global primary energy demand in 2050 assuming that energy use is dependent on GDP and population growth only. What is the percent increase in GDP per capita in 2050 compared to 2012?

	World
GDP 2050 (billion USD)	86334*(1+3.2/100)^(2050-2013) = 276905
GDP per capita 2050 (bill USD/mill people)	276905/9468 = 29
GDP per capita 2012 (bill USD/mill people)	86334/7118 = 12
Increase	(29/12 -1)*100 = **141%**
TPES in 2050 (EJ)	Total energy demand in 2013*(1+1.41) = 561*(1+1.41) = **1352**

c. Estimate the CO_2 emissions for each scenario using the emission factors for fossil fuels in Table 2. How much lower are 2DS emissions compared to the 6DS scenario? Hint: 1 kg C-equivalent = 44/12 kg CO_2-equivalent.

Table 2: Fossil fuel emission factors

Fuel	**Emissions (kg CE/GJ)**
Coal	26.8
Natural gas	15.5
Oil	19.8

6DS emissions = (255*26.8 + 215*15.5 + 252*19.8)*10^9 [EJ/GJ] / (10^9 [kg/Mt]) * 44/12 [kg CO_2-eq / kg C-eq] = **55572 Mt CO_2**

2DS emissions = (76*26.8 + 107*15.5 + 112*19.8)* 44/12 = **21681 Mt CO_2**

2DS emissions are **61% lower** than 6DS emissions in 2050

d. Calculate the emission intensity factor (kt CO_2/PJ) in each scenario.

6DS = 55572 [Mt CO_2] *1000 [kt/Mt] /928000 [PJ] = **60 kt CO_2/PJ**

2DS = **<u>33 kt CO_2/PJ</u>**

e. Consider a scenario (XDS) in which the emission intensity factor is 40 kt CO_2/PJ and the total primary energy demand is two-thirds of that in the 6DS scenario in 2050. Assume also that the share of energy from coal/oil/gas in the total XDS fossil fuel energy mix can be approximated as the average of the 6DS and 2DS fossil fuel share of coal/oil/gas in the respective scenarios. What is the total supply from carbon-free energy sources in 2050 in this scenario?

Energy 6DS 2050 = 928 EJ
Energy XDS 2050 = 928000*2/3 = 618666.7 PJ
Emissions XDS = 618666.7 * 40 = 24746667 kt CO_2

Share of energy in fossil fuel mix from each source in each scenario:

	6DS	2DS	XDS
Coal	255/722*100 = 35%	76/295*100 =26%	(35%+26%)/2 = 31%
Gas	30%	36%	33%
Oil	35%	38%	36%

Emissions = 24746667 = Fossil_E*(0.31*26.8 + 0.33*15.5 + 0.36*19.8)*44/12
Fossil_E = 328938.7 PJ
Carbon-free_E = 618666.7 – 328938.7 = **<u>289728 PJ</u>**

f. What is the Kaya identity? Define the relationship and its function.

See: https://en.wikipedia.org/wiki/Kaya_identity

The Kaya identity is an equation relating factors that determine the level of human impact on climate, in the form of emissions of the greenhouse gas carbon dioxide. This identity states that total emission level can be expressed as the product of four inputs: human population, GDP per capita, energy intensity (per unit of GDP), and carbon intensity (emissions per unit of energy consumed).

Kaya identity is expressed in the form:

$$F = P \times \frac{G}{P} \times \frac{E}{G} \times \frac{F}{E}$$

where:

F is global CO2 emissions from human sources

P is global population

G is world GDP

E is global energy consumption[4]

Question 2

In this exercise, you will analyze the energy supply to the industrial sector in Switzerland. The energy supply by industrial usage category and energy carrier is illustrated in Table 3 below in 2012.

Table 3: Energy supply (PJ) to the industrial sector in Switzerland 2012, based on [2], [3]

Industrial Energy Supply 2012 (PJ)								
	Space Heating	Water Heating	Process Heat	Lighting	Cooling	I&C	Other Process	Total
Coal	0.0	0.0	5.1	0.0	0.0	0.0	0.0	5.1
Natural Gas	6.5	1.4	27.4	0.0	0.0	0.0	0.4	35.6
Fuel Oil	11.0	1.1	15.0	0.0	0.0	0.0	0.7	27.8
Wastes	0.0	0.0	10.3	0.0	0.0	0.0	0.0	10.3
Wood	0.0	0.0	10.1	0.0	0.0	0.0	0.0	10.1
Biogas	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.4
Solar	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Geothermal	0.4	0.1	0.0	0.0	0.0	0.0	0.4	0.9
Electricity	0.3	0.0	22.2	6.2	1.1	0.8	37.9	68.5
Heat	5.2	1.4	0.0	0.0	0.0	0.0	0.0	6.5
Total	**23.3**	**3.9**	**91.5**	**6.2**	**1.1**	**0.8**	**39.9**	**165.3**

a. What is the most energy-intensive application in industry? Calculate its share as a percentage of the total industrial sector energy demand and the total heat energy demand (i.e., space, water and process heat).

Process heat is the most energy intensive.
Shares:
% of total demand = 91.5/165.3 *100 = **55%**
% of total heat demand = 91.5/118.6 *100 = **77%**

b. Suppose that Switzerland expects a compound average annual growth rate (CAAGR) of 0.5% in the industrial sector in future years [4]. What is the total industrial primary energy demand in 2050, and what is the relative increase in total industrial demand compared to 2012?

Energy demand in 2050 = 165.3*(1+0.05/100)^(2050-2012) = **200 PJ**
Relative increase = (200/165.3 – 1) *100 = **21%**

c. In the national New Energy Policy (NEP) energy scenario for Switzerland, total electricity demand is targeted to be 63.6 TWh in 2010, 65.3 TWh in 2015, and 57.4 TWh in 2050 [5]. Determine the industrial electricity demand in 2050 assuming the same relative reduction as in the NEP scenario compared to the electricity demand in 2050 if assuming the annual growth rate in (b). What percentage would efficiency measures need to reduce electricity demand by in order to meet the NEP target in 2050? Assume that electricity demand approximately decreases linearly between 2010 and 2015 in the NEP scenario.

NEP national electricity demand in 2012 = (65.3-63.6)*(2012-2010)/(2015-2010)+63.6 = 64.28 TWh
NEP scenario national electricity demand reduction relative to 2012 levels = (57.4/64.28-1)*100 = 10.7%
Industrial electricity demand in 2050 based on NEP = 68.5 * (1-0.107) = **61.2 PJ**
Industrial electricity demand in 2050 based on (b) = 68.5*(1+0.005)^(2050-2012) = **82.8 PJ**
Reduction required = (61.2/82.8 – 1)*100 = **-26.1%**

d. Using the emission factors in Table 2, calculate the total emissions due to coal, natural gas and oil from the industrial sector. If the industrial sector accounts for approximately 9% of national emissions, what are the total Swiss emissions in 2012?

Total emissions = coal_PJ*coal_factor + oil_PJ*oil_factor + gas_PJ*gas_factor

Industrial emissions = (5.1*26.8 + 35.6*15.5 + 27.8*19.8)*10^6 [GJ/PJ] / (10^9 [kg/Mt]) = **1.239 Mt CE**
Total emissions = 1239/9% = **13.763 Mt CE**

Question 3

a) Switzerland has a policy to phase-out nuclear energy by 2035, representing approximately 25.6 TWh/year in 2010 [5]. According to a national scenario, Switzerland has 11 TWh/year of unused PV potential [5]. Suppose that 60% of this potential is harnessed to replace nuclear energy, and the remainder is to be met with gas plants. How many 500 MW gas plants would be required if the annual average capacity factor for each plant is 85%? (Note: the capacity factor is defined as the ratio of a plant's actual output over a period of time, to its potential output if it were to operate continuously at full nameplate capacity over the same period.)

Energy covered by gas = 25.6 – 11*.6 = 19 TWh/year

gas plants = 19/(8760*500*.85)*10^6 =~ **5 plants**

b) What is the minimum PV panel efficiency required in order for the full PV plant potential to occupy less than 27000 hectares of land, assuming an average daily solar radiation of 2.1 kWh/m^2 and assuming that 30% of a PV plant's area is occupied by the panels?

annual_radiation = 2.1*365/10^9 = 7.66 E-07 TWh/m^2

PV panel efficiency = 11/(annual _radiation*27 E07*.30) = **18%**

c) What is the input solar energy required to achieve the full potential assuming the efficiency in (b)?

11/18% = **62.1 TWh**

d) What would the total installed PV capacity be assuming a capacity factor of 9%?

11/(8760*0.09)*10^3 = **14 GW**

References

[1] Energy Technology Perspectives 2016
https://www.iea.org/media/etp/etp2016/ETP2016_Webinar_ALL.pdf

[2] International Energy Agency (IEA), Statistics
http://www.iea.org/statistics/statisticssearch

[3] Swiss Federal Office of Energy (BFE) Energy Statistics
http://www.bfe.admin.ch/energie/00588/00589/00644/?lang=en&msg-id=39869

[4] US Energy Information Agency
http://www.eia.gov/forecasts/ieo/industrial.cfm

[5] Densing, M., Hirschberg, S., Turton, H. (2014). Review of Swiss Electricity Scenarios 2050, PSI-Report 14-05
https://www.psi.ch/eem/PublicationsTabelle/PSI-Bericht_14-05.pdf