SCHOOL OF ENGINEERING
MECHANICAL ENGINEERING
LRESE - Laboratory of Renewable Energy Sciences and Engineering

Renewable Energy: Introduction Exercise

This exercise will provide an insight into the numbers and dimension of the energy problem and proposed solutions. It deals with the question whether the global fossil energy consumption can be completely replaced by renewable sources such as biomass or solar.

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1. Estimate the CO_2 emission (M_{CO_2} = 44 g/mol) from the fossil sources oil, gas, and coal, and estimate their relative shares to the total world emission in 2018.

   (a) Consult the International Energy Agency publication on "Key World Energy Statistics 2019" and estimate the global primary energy supply of i) crude oil (in Mt), ii) natural gas (in Gm^3), and iii) coal (Mt)

   (b) How much CO_2 emission does every person emit on average?
   Assume: Oil equivalent chemical formula of $C_7H_{14}N_{0.1}O_{0.1}S_{0.3}$ (M_{oil}=110 g/mol, ρ=0.88 kg/L), natural gas equivalent of methane (M_{CH_4}=16 g/mol, ρ= 0.7 kg/m^3), and coal carbon content of 0.5 kg carbon/kg coal (M_C=12 g/mol, heating value 20 MJ/kg). World population in 2018 of 7.55 billion.

   (c) What is the average CO_2 emission per capita in i) Qatar, ii) USA, iii) Switzerland, iv) China, v) India, vi) Brasil, vii) Nicaragua, and viii) Tansania (use the IEA statistics)? What is the total emission per country (i to viii)?

   (d) Convert the 13972 Mtoe total primary energy consumption in 2017 to TW-equivalent (world), and to kW-equivalent/per person. What is the CO_2 emission intensity on average? The CO_2 emission intensity can be calculated by CO_2 emission per unit energy consumption.

   (e) How does the CO_2 emission intensity of countries i) to viii) compare to each other and to the average value of d)?

2. We want to replace, in energy-equivalent terms, all fossil fuel by renewable biomass:

   - coal by wood (for electricity) with coal plant electrical efficiency = 40%, but wood plant efficiency = 20%
   - oil by bioethanol (for transport fuels)
   - gas by biogas (for heating in buildings and industry)

Assuming simplified conversions:

- we can grow 2 kg wood per year per m^2 of forest, with the heating value = 17 MJ/kg
- we can obtain 3000 L bioethanol (heating value = 21 MJ/L, ρ = 0.78 kg/L) per year per hectare (=10'000 m^2) of biomass fields such as corn, sugar cane, manioc
- we can digest agro-wastes from 1 hectare of land to 2'000 m^3 of methane contained in biogas (heating value of methane CH_4 = 10 kWh/m^3)

(a) What would be the land-use for all this biomass to replace all fossil fuel?

(b) Compare the obtained result with the available forest and agricultural area (11% and 3% of the Earth surface, respectively).

(c) Compare it with the yearly biomass production of 32 Gtoe in forests and 3.6 Gtoe in agriculture.

(d) Between 1973 and 2017, the primary energy supply increased from 6'100 to 13'972 Mtoe. Would we be able to cover the increase in energy consumption between 1973 and 2017 by the available forest and agricultural area?

3. We want to replace, in energy-equivalent terms, all fossil fuel by renewable solar:

- coal by solar electricity with solar PV efficiency of 18%
- oil by solar fuels (for transport fuels) obtained by PV (efficiency 18%) combined with an electrolyzer (efficiency 75%)
- gas by solar heat (for heating in buildings and industry) using solar collectors with an efficiency of 65%

Assume averaged solar irradiation per day of 6 kWh/m^2

(a) What would be the land-use for a field of solar PV/absorbers to replace all fossil fuel?

(b) Compare the obtained result with the earth surface (land only, and land and ocean)

(c) Redo the calculation of a) using the solar irradiation data of Almeria, Spain (excel file on moodle). How big of an area in a region like southern Spain is required?