PHY 555 Energy & Environment - 2022

Homework
To be submitted on Moodle before Friday, November 11th

The aim of this exercise is to use public data to estimate, analyze and interpret the evolution of French Greehouse Gases (GHG) national emissions over the last 30 years.

To facilitate the correction of your homework, everytime you need to plot a graph, choose a specific year (randomly) and write down the numerical value of the considered quantity for that year.

Question 1: European Environment Agency publishes, in the context of the UNFCCC, the national GHG emissions as reported by the state members. Go to the EEA website, find the data for France, and plot the aggregated national GHG emissions on the 1990 – 2019 period. Comment your result.

Question 2 : Following the IPCC guidelines (https://www.ipcc-nggip.iges.or.jp/), emissions can be split into 4 main categories: Energy, Industrial Processes and Product Use, Agriculture, Forestry and Other Land Use and Waste. Using the same data as before, show that the behavior observed is essentially due to one of the sectors, on which we will focus the analysis.

Question 3 : In order to understand what causes (or opposes) the observed behavior, we first apply a Kaya analysis. The Kaya equation expresses the emissions as the product of the population, the GDP per capita, the energy intensity of the economy, and the carbon intensity of the energy mix.

a. Show that the product of these four factors does indeed correspond to the CO2 emissions

b. To compute these factors, we need additional data on GDP, population and energy. Furthermore, emission data should also be adjusted to account for yearly weather variations. All these data are available on public websites (INSEE and SDES), and have been collected and prepared on Moodle (PHY555-data.csv). Using these data, plot the relative evolution of the 4 factors over time, taking the year 1990 as reference (ie the value in 1990 is taken to be 100 by definition). Should you rather use a linear or a log scale?

c. Comment the results

Question 4 : We want to analyze the decrease in the carbon content of primary energy as the contributions of 3 factors : 1/ the reduction of CO2 emission from fossil production, 2/ the increasing share of nuclear energy and 3/ the increasing share of renewable energy.

a. How are these three factors motivated physically?

b. Show that the two expressions below correspond to this analysis

$$\frac{CO_2}{E_{primary}} = \frac{CO_2}{E_{Fossil}} \times (1 - r_{nuclear}) \times \frac{r_{fossile}}{r_{fossile} + r_{renewable}}$$

$$\frac{CO_2}{E_{primary}} = \frac{CO_2}{E_{Fossil}} \times (1 - r_{renewable}) \times \frac{r_{fossile}}{r_{fossile} + r_{nuclear}}$$

where $r_i = E_i / E_{primary}$ is the share of energy i in the primary supply

c. These two expressions don't treat equally nuclear and renewable energy productions. Show that they are equivalent in a mix with a large share of fossil production, but can be significantly different in a mix with a reduced fossil production. Which one gives more weight to the renewable production?

d. Suggest a decomposition which treats both sectors equally

e. Plot the analysis is a graph similar to that of question 3 and comment your result.

Question 5 : We want to analyze the improvement of the energy intensity of the economy. To do so, we will focus on the emissions of the productive sector only, which can be separated in three subsectors: manufacturing industry, agriculture and tertiary. Data related to these subsectors are available on Moodle, in the same file as before (PHY555-data.csv)

Using an analysis similar to Kaya's, we write the total emission of the productive sector during year n as

$$CO_2(n) = \sum_i CO_2^i(n) = A(n) \sum_i S_i(n) I_i(n) C_i(n)$$

where the sum runs over the three subsectors, A is the total activity of the productive sector (in €), S_i is the activity share of subsector i, I_i is the energy intensity of subsector i and C_i is the carbon intensity of the energy used by sector i.

a. What qualitatively are the 4 possible mechanisms leading to a change in CO2 emissions according to this analysis?

Unlike Kaya's analysis, this decomposition is not a simple product, but involves the sum of several terms. It is therefore not straightforward to quantify the impact of each of the four mechanisms discussed above. A standard method to quantify the impact of each mechanism is called the Logarithmic Mean Divisia Index (LMDI) method. It consists in expression the evolution of CO2 as compared to a reference year (1990 in our case) as

$$\frac{CO_2(n)}{CO_2(ref)} = D_{Act}(n) \times D_{Str}(n) \times D_{Int}(n) \times D_{Carb}(n)$$

With

$$D_{Act} = \exp\left(\sum w_i(n) \times \ln\frac{A(n)}{A(ref)}\right),$$

$$D_{Str} = \exp\left(\sum w_i(n) \times \ln\frac{S_i(n)}{S_i(ref)}\right)$$

$$D_{Int} = \exp\left(\sum w_i(n) \times \ln\frac{I_i(n)}{I_i(ref)}\right)$$

$$D_{Carb} = \exp\left(\sum w_i(n) \times \ln\frac{C_i(n)}{C_i(ref)}\right)$$

And the weight of sector i is given by

$$w_i(n) = \frac{CO_2^i(n) - CO_2^i(ref)}{CO_2(n) - CO_2(ref)} \times \frac{\ln(CO_2(n)/CO_2(ref))}{\ln(CO_2^i(n)/CO_2^i(ref))}$$

b. To get more familiar with the LMDI analysis,

i. Show that the product of the 4 factors does indeed give the ratio between emissions over year n, and over the reference year.

ii. Show that, if the energy intensity or the carbon intensity of all sectors is multiplied by the same factor between year n and the reference year, the LMDI analysis gives an expected result.

iii. Show that, if the only difference between year n and the reference year is a change in the energy intensity, or the carbon intensity of one of the sector, the LMDI analysis gives an expected result.

c. Compute and plot the impact of each of the four mechanisms according to the LMDI method. To illustrate the relevance of the method, compare the change in energy intensity of the productive sector estimated as the total activity divided by the total energy, and the estimation from the corresponding LMDI factor.

d. Comment and conclude