

Decarbonizing electricity systems case of the Quantitative Sustainability course

Asger Bech Abrahamsen, Senior Researcher

DTU Wind and Energy Systems, DTU Risø Campus, Roskilde

Technical University of Denmark

E-mail : asab@dtu.dk

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Introduction

This document describes the instructions for the Decarbonizing electricity systems case study of the course Quantitative Sustainability (12105&12106) and the requirements of the group project for the fall semester 2024 at the Technical University of Denmark (DTU).

The students should be able to perform the following learning objectives after the completion of the Decarbonizing electricity systems case project:

- **Describe** the technology mix used for electricity production in 3 different countries selected by the students as well as the global mix (Denmark must be one of the countries).
- **Describe** the change of the technology mix of the 3 countries and the world during the last two years when information is available.
- **Discuss** if knowledge of the global warming potential of certain electricity producing technologies are missing from the analysis tool and provide an estimate of the emission in term of g CO₂e/kWh. (An example is electricity production from burning oil if oil is in the country electricity technology mix)
- **Estimate** the resulting CO₂ emission of the electricity mix when producing 1 kWh electricity in the 3 countries and the world now and in 2050 by specifying the electricity consumption, the size of the populations and a student suggestion of the 2050 mix of the countries and the world.
- **Analyse** the expected CO₂ emission from 3 countries and the world by comparing the Global Warming Potential of the 3 countries and the world now and in 2050 with the UN CO₂ emission scenarios of 1.5 °C global warming by end of the century.
- **Evaluate** if the planetary CO₂ boundary is violated in 2050 by the resulting electricity generation of the world and when scaling the countries to planet scale?
- **Explain** the arguments for the student suggested technology mix of 2050

This is done by the groups working on the decarbonizing electricity systems case by selecting 3 countries to investigate in terms of the current electricity technology mix and suggestions on the future electricity

mix by 2050. The Global warming potential of the countries must be scaled to global level and compared to the planetary boundary as formulated in the Paris agreement of the 1.5 degree global warming scenario. One of the countries must be Denmark and the others are free of choice if sufficient information can be found. The groups have to propose an electricity technology mix of each country as well as the world for 2050 in order to comply with the 1.5 degree Paris Agreement scenario. The Excel sheet provided in the lecture on decarbonizing energy systems should be used for the numerical analysis.

Preparation

- 1) Start reviewing the lectures of the module called “Decarbonizing energy system” of the Quantitative sustainability course.
- 2) Perform the exercise of the module “Decarbonizing energy systems”, because this will provide an analysis Excel sheet (see figure 1) suitable for calculating CO₂ emissions from an electricity system and also for evaluating if the planetary CO₂ boundaries have been violated. The groups are encouraged to familiarize themselves with this analysis Excel sheet, since it is considered a tool for solving the case study.

1	World Green	Type	Electricity mix start $f_{s,i}$ [%]	Electricity mix end $f_{e,i}$ [%]
2				
3	Hard coal	PC, without CCS	39	10
4	Hard coal	IGCC, without CCS	0	0
5	Hard coal	SC, without CCS	0	0
6	Natural gas	NGCC, without CCS	23	23
7	Hard coal	PC, with CCS	0	0
8	Hard coal	IGCC, with CCS	0	0
9	Hard coal	SC, with CCS	0	0
10	Natural gas	NGCC, with CCS	0	0
11	Hydro	660 MW	0	0
12	Hydro	360 MW	15	15
13	Nuclear	average	9	9
14	Concentrated Solar Power (CSP)	tower	1	1
15	Concentrated Solar Power (CSP)	trough	0	0
16	Photo Voltaic (PV)	poly-Si, ground-mounted	5	5
17	Photo Voltaic (PV)	poly-Si, roof-mounted	0	0
18	Photo Voltaic (PV)	CdTe, ground-mounted	0	0
19	Photo Voltaic (PV)	CdTe, roof-mounted	0	0
20	Photo Voltaic (PV)	CIGS, ground-mounted	0	0
21	Photo Voltaic (PV)	CIGS, roof-mounted	0	0
22	Wind	onshore	7	36
23	Wind	offshore, concrete foundation	0	0
24	Wind	offshore, steel foundation	1	1
25	Total		100	100
26				
27	Start & End year		2023	2050
28	Start & End production [kWh/year]	World	2,25E+13	4,50E+13
29	Start & End population [Citizenz]	World	8,00E+09	8,4E+09

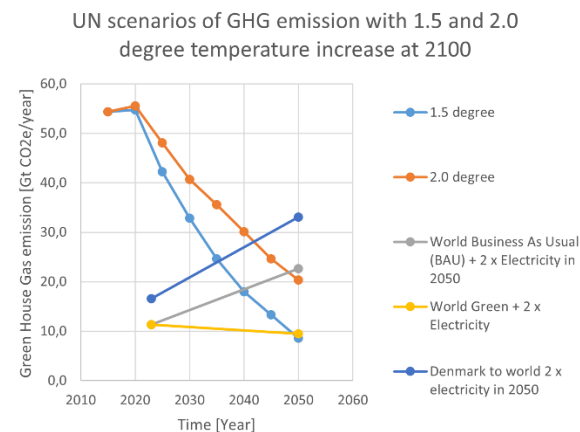


Figure 1. Illustration of the input of a green mix of electricity-producing technologies in 2050 of the analysis Excel sheet (Left) and the determined Global Warming Potential (CO₂ emission) compared to the 1.5 Degree global warming planetary boundary of the Paris Agreement (Right). As can be seen then the green electricity mix proposal shown for the world is just violating the planetary boundary in 2050. The students are encourage to propose other scenarios for 2050 and investigate if the planetary CO₂ boundary is violated.

Instruction for writing task reports

The following 3 Task reports must be written during the case modules of the course. The first two reports are reviewed by other student groups, who will provide feedback. The Task III Report is handed-in on learn at the end of the course in one pdf file incorporating the findings of the Task I and Task II reports. The reviews of the Task I and Task II reports are performed by other groups working on the decarbonizing electricity case and they will provide feedback in an e-mail or other channels. This is done by each group sending their report to the next group with the same topic on the group list of DTU Learn and feedback is provided one week after the exchange. The last group on the group list sends their report to the first group on the list. The review of the submitted combined Task III report is done by the case teaching assistants and teachers of the case. The evaluation criteria are outlined at the end of this document.

Week 3	Task I report (student review)
Week 8	Task II report (student review)
Week 13	Task III report (review for grade)

Task I report: Introduction and data

The first task is done by the groups in the first case module and results in handing in a 2-page report on the obtained results. The work covers the selection of 2 countries and Denmark for further analysis of the electricity systems as well as the initial information collection of the selected countries. The Task I work must include the following points:

- 1) The group should select 2 countries in the world and also Denmark for an analysis of the electricity systems of these countries. The groups are free to choose any country based on interests or relations to the countries of the group.
- 2) Find information about the mix of technologies used for electricity production of the selected 2 countries and Denmark as well as the world. Evaluate the differences of the mix in the last two years. If information about the country's electricity systems is hard to obtain, then other countries should be considered for the selection in 1).
- 3) Compare the technologies of the countries with the technologies outlined in the analysis Excel sheet obtained in the preparation and list if there are technologies not included in the list (an example can be electricity production by burning oil, wood pellets or garbage).
- 4) Add a representative title to the Task I report, add authors and add date to the report.
- 5) Write an introduction section to the Task I report, where the groups provide the reasons for choosing the countries of the analysis.
- 6) Create a bar plot, which shows the electricity mix in the unit of [%] of the 2 countries, Denmark and the World in the last two years. Insert the bar plot in the Task I report including the references to where the information was obtained.
- 7) Write a data section to the Task I report, where the electricity technology mix of the 3 countries and the world are briefly described as well as the changes in the last two years. Use the plot of point 6) to support this description.
- 8) Include a section to the Task I report, where electricity technologies not found in the list of the Excel sheet are identified for specific countries and explain what these technologies are.
- 9) Find information about the population of the 2 selected countries, Denmark and the world in the last two years.
- 10) Find information about the electricity consumption of the 2 countries, Denmark and the world in the last two years. What is the electricity consumption per citizen?
- 11) Find information about the expected population of the selected countries and the world in 2050.
- 12) By assuming that the electricity consumption per citizen will double due to electrification in 2050, estimate the expected electricity consumption of the 2 countries, Denmark and the world, in 2050.
- 13) Make a table holding the population, the electricity consumption, the electricity consumption per citizen of the 2 countries, Denmark and the world as of today and 2050.
- 14) Write an assumption section to the Task I report where the table of point 13) is inserted. Describe the numbers and include references to the sources used.
- 15) This concludes the Task I report, which has a page limit of 3 pages excluding references.

Task II report: Results

The Task II report focuses on calculating the environmental impacts of the electricity systems selected in the Task I report. This is done by expanding the analysis Excel sheet from preparation point 2) with the two additional countries and possibly also with additional technologies not in the Excel sheet list as identified in the Task I report. Secondly the groups should formulate proposals on the future electricity mix of the selected countries with the aim of reducing the Global Warming Potential or CO₂ emission per kWh produced in 2050. The Task II report should contain the following points:

- 1) Make a copy of the analysis Excel sheet provided in the preparation point 2).
- 2) If the task I report identified additional electricity technologies to be added to the list, then you can add these to the list by inserting new technology rows in the analysis Excel sheet. You will have to search for information about the global warming potential if these additional technologies.
- 3) Copy the analysis sub-sheets of Denmark to two new sub-sheets and rename them by the 2 additional selected countries.
- 4) Update the world and 3 country sub-sheets with the electricity technology mix of today and the group proposals of the 2050 technology mix.
- 5) Make a table, which summarizes the CO₂ emissions per kWh produced today and in 2050 for the world and the 3 countries.
- 6) Write a result section for the Task II report, where the group accounts for additional electricity technologies and add the estimate of the resulting CO₂ emissions per kWh produced by the technology. This can be done by referring to the literature and additional calculations done by the group. Include references and calculations to support your findings.
- 7) Include the table from point 5) and a section describing the resulting CO₂ emissions per kWh of the technology mix used today and in 2050 for 3 countries and the World.
- 8) Include a discussion of how large a reduction in the CO₂ emission per kWh that the 2050 mix will result in.
- 9) This concludes the Task II report, which has a page limitation of 3 pages excluding references.

Task III report: Results, discussion and conclusions

The task III report will perform the comparison of the Global Warming Potential emission found in the Task II report with the planetary boundaries as formulated by the Paris agreement and evaluate if the planetary boundary has been violated by the proposed 2050 technology mix of the 3 countries and the world. This is done by inserting the estimated population number of the 3 countries and the world, whereby scaling to planetary emissions can be obtained. The final reporting of the task is a plot of the planetary Global Warming Potential boundary along with the prediction of the 3 countries as well the world today and in 2050. The Task III report should contain the following points:

- 1) Insert the population today and estimated 2050 of the world and the 3 countries into the analysis Excel sheet used in the Task II report.
- 2) Insert the electricity consumption today and in 2050 of the 3 countries and the world as found in the Task II report into the analysis Excel sheet.
- 3) Estimate the resulting planetary Global Warming Potential in 2050 of the world and the 3 countries by scaling the country emission by the ratio of the world population and the country population.
- 4) Examine the result plot showing the planetary global warming limit as a function of time in the analysis Excel sheet and investigate if your emission estimates of Denmark and the world today and in 2050 are plotted correctly. Now add the two other countries to the plot in order to show the consequence of the future technology mix suggested by the group. This plot is expected to show the entire analysis of the Decarbonizing electricity system case.
- 5) Write a result section to the Task III report, where the final group proposal on the technology mix today and in 2050 of the world and the 3 countries are shown in a plot. Add a section that explains the resulting emission as shown by inserting the plot from point 4). Add a paragraph, where the emissions are compared to the planetary boundaries and report if the planetary boundary is violated by the proposed electricity mix of the world and the 3 countries in 2050.
- 6) Add a discussion section, where the group should evaluate if the proposed technology mix of the world and the 3 countries in 2050 can be realized or if barriers are expected to limit the implementation.
- 7) Add a conclusion section, where the group summarize the proposed technology mix in 2050 and if this will comply to the planetary global warming boundary.
- 8) This concludes the Task III report and the case, which has a page limitation of 9 pages excluding references, since the Task II report should contain the information of the Task I and Task II report in the beginning.

Evaluation of the Decarbonizing electricity systems cases

The 3 task reports of the decarbonizing electricity systems case will be reviewed in combination as if they constitute a paper for a journal. The max score will be given if the points described above are included in a well documented format that will allow other groups to reproduce the results if they are following the case instruction.

Figures and tables must have numbers and a caption text explaining the content. The units of all values in the plots, tables and equations must be provided. References must be provided to show where the input data is obtained. Finally the page limitation must be followed.