Investments in the future energy system

Modelling and analysis of Sustainable Energy Systems using Operations Research

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Handed out on November 7th at 13:00. The assignment is to be handed in on DTU Inside on December 8th before 23:59. The report should not be longer than 25 pages—including pictures, but excluding appendix!

1 Guidelines for writing the report

Before the main part of the report, please add a page where you mark clearly, who contributed with what:

- "We all contributed equally" is not enough
- "XX contributed with: modelling of YY, writing chapter ZZ" is what I want to see

In the main part of the report, you have the following sections:

- Describe the overall problem: What is the overall problem you will analyse (objective)? Why is this interesting (motivation)? How will you analyse it? (methodology) Which results do you expect?
- Formulate the model mathematically: State and explain your model assumptions. Define parameters and variables and explain. State the model. Explain the objective and the constraints.
- Data and data assumptions: Describe the data. Include your data sources, i.e. remember references. Explain your data assumptions and any modifications to the data.
- Presentation and analysis of model results: Report model results in tables, figures etc. Are there any specific results you want to highlight? What do the model results show? Was that what you expected? What does it tell you about the overall problem?

In appendix you only have:

- Code: Insert the code you have used in an appendix. Make a zip-file with all necessary code to run your model (including data files etc.) and upload it to Inside
- Please do not put pictures that are necessary for understanding your results!

2 Description of the main model

We aim to evaluate the competitiveness of different technologies in a future power system. A mathematical programming model can be used to find the optimal mix of different production, storage and transmission technologies. Among other things, this competitiveness depends on the assumptions made regarding technology costs, fuel prices and emission prices in the model.

The purpose of this assignment is to make a model for power system investments that includes various technologies and takes into account investment costs for each technology as well as fuel prices and emission prices when relevant.

Approach

- Formulate the model for power system investment mathematically and implement it in GAMS. For now, you may leave out unit commitment considerations. The model should include investments in both conventional power plants and wind power. To focus on the interactions between various technologies, in particular wind power and other technologies, the model should have an hourly time resolution. In principle, the time horizon of the model could be a year or a number of years. However, to facilitate computations, consider only a small number of representative weeks in a year, for example an average week during each season. Justify any other model assumptions you make.

- Construct a data set for the technologies included in the model. Note that if the time horizon is a year, investment costs can be annualized, and operations costs can be multiplied by the number of weeks in a year, a representative week covers (for an average week during each season, approximately 13). Wind power production and electricity demand can be found at www.energinet.dk, and technology data, fuel and emission prices at www.ens.dk.

- Solve the model to find the optimal power system configurations for varying assumptions on fuel and emission prices. You may for instance, solve the model with fuel and emission prices increased and decreased by 10%.

- Before you continue with the extensions, remember to check the results: How does the technology mix change when fuel and emission prices change? Does the model invest in variable renewables? If not, you could add a subsidy payment for wind power or wait to see if this is affected by your extensions.

3 Extensions to the model

The following sections should be seen as ideas for extensions to your models. You can freely choose an extension among these or defining your own way to go. Other ideas could be: Investments in electricity storages, adding more regions and investments in transmission lines, including unit commitment constraints.

Electric vehicles

A shift from conventional cars to electric cars could add a considerable flexibility in electricity demand, which would be valuable in connection with the integration of uncontrollable renewable energy generation such as wind power into the energy system.

The purpose of this extension is to include the modelling of electric cars and wind power in the model, and furthermore, to use this as a basis for analysing the effects of demand flexibility from electric vehicles on integration of variable renewables.

Approach

- Formulate the additional constraints necessary for including electric vehicles, and implement it in your investment model in GAMS. You may consider battery electric vehicles (driving on electricity only) only, or both these and hybrid electric vehicles (driving on fuel or electricity). You may want to revisit your time horizon from the base model. Justify any other model assumptions you make.

- Construct a data set for electric vehicles. Data for electric vehicles can be found in the references below, however, consider using updated data on battery sizes. Driving demands can be found on Inside. If you consider future years, remember to make assumptions on future demands from electric vehicles.

- Solve the model to obtain the optimal investments in the power system with and without the inclusion of electric cars.

- Present and discuss your results. The discussion should include the effects of demand flexibility from electric vehicles on integration of variable renewables. How are total costs affected? How does the consumption from electric vehicles and the variable renewables power generation complement each other? What is the impact on the operation of the conventional power generating units? How are electricity prices affected? Remember to make a sensitivity analysis on important parameters.

References

Juul, N., Meibom P. Optimal configuration of an integrated power and transport system, Energy 36(5), 2011. 3523-30.
Kristoffersen, T. K., Capion, K. Meibom, P. Optimal charging of electric drive vehicles in a market environment. Applied Energy 88, 2010. 1940-48.

Heat

By adding heat pumps or electric heat boilers in combination with heat storages in the district heating system, a significant electricity demand flexibility is added to the power system.

The purpose of this extension is therefore to add a district heating demand, combined heat-and-power units, electric heat boilers, and heat storages to the base model. This model can then be used for analysing effects of demand flexibility from electric heat production on integration of variable renewables.

Approach

- Formulate the additional constraints mathematically and in GAMS, including electric heat production. The model should include district heating demand, combined heat-and-power units, electric heat boilers, and heat storages. You may need to reconsider the time horizon from your base model. Justify any other model assumptions you make.
- Construct a data set for the heat production. Time series for hourly heat demand time series can be found on Inside.
- Solve the model to find the investments in the heat and power system with and without the inclusion of electric heat production.
- Present and discuss the results. The discussion should include the effects of demand flexibility from electric heat boilers and heat storages on integration of variable renewables. How are total costs affected? How does the consumption from electric heat production and the generation from variable renewables complement each other? What is the impact on the operation of the conventional power generating units? How are electricity prices affected? Remember to make a sensitivity analysis on important parameters.

Hydrogen

Hydrogen is frequently argued to be a promising new energy carrier that facilitates large-scale integration of uncontrollable electricity production such as wind and solar power. By including electrolysis plants and hydrogen storage in an energy system, and using the resulting hydrogen production in fuel cell power plants or gas turbines, considerable flexibility is added to power systems, although on the expense of large losses in hydrogen production.

The purpose of this extension is therefore to include electrolysis plants and hydrogen storage in the investment model, and use this a basis for analysing the effects of using hydrogen as an energy carrier.

Approach

- Formulate the necessary extra constraint mathematically and in GAMS. The model should include electrolysis plants and hydrogen storages. You may need to revise your time horizon from the base model. Justify any other model assumptions you make.
- Construct a data set that covers the hydrogen technologies included. Technology data can be found at www.ens.dk.
- Solve the model to find the optimal investments in the system with and without the inclusion of hydrogen production.
- Present and discuss the results. The discussion should include the effects of demand flexibility from electrolysis and hydrogen storage on wind power integration. How are total costs affected? How does the electricity consumption from hydrogen production and generation from variable renewables complement each other? What is the impact on the operation of the conventional power generating units? How are electricity prices affected? Remember to make a sensitivity analysis on important parameters.