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Publication date

2017

Document Version

Final published version

Published in

Proceedings of the ESSA Social Simulation Conference 2017

Citation (APA)

Chappin, E., Korevaar, G., & Pelka, S. (2017). Teaching the Modelling of Integrated Energy Systems – Course Design and First Experience. In *Proceedings of the ESSA Social Simulation Conference 2017* (pp. 1-4)

Important note

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Teaching the Modelling of Integrated Energy Systems – Course Design and First Experience

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Abstract: In order to design interventions in energy systems, it is key to combine existing models and simulations. As the interplay of different steps along the energy value chain, various actors and regional scopes makes it difficult for one model or model owner to cover the entire complexity of the system, the usage of present resources instead of creating new ones is a consequential approach to tackle today's and tomorrow's challenges. Identifying suitable models, combining them and critically analysing their outcomes are essential skills in this context. This is taught in the course “Design of Integrated Energy Systems” at TU Delft. During the course, groups of students define their own design problem they want to address, develop a modelling strategy for it and translate it with the existing models and simulations. A range of existing models from students themselves, from researchers and from the energy industry are provided. Self-reflection, peer-review, the academic debate on modelling and feedback by the teachers after presenting preliminary results are key elements for stimulating the progress of the group work. Both students and model owners have expressed their enthusiasm for this approach, the students have learned a lot from this confrontation with reality, the model owners gained valuable insight from the fresh eye that the students could deliver on their modelling practice.

Keywords: Education, Energy systems, Modelling strategy, Design, Multi-modelling

1 Introduction

Ranging from ensuring a stable electricity infrastructure under the high penetration of renewables, upscaling of reliable ways for energy storage to the usage of fossil fuels, feasible and creative solutions are needed for challenges of the energy transition. The interplay of different steps along the energy value chain, various actors and regional scopes makes it difficult for one entity to capture the entire complexity of the system. Reversely, it is also almost impossible to delineate the system to isolate and study individual processes validly. Especially in context of models and simulations, a pragmatic approach to handle this complexity is to use and combine the existing resources instead of creating new ones. In this way, the available knowledge and strengths can be merged for designing robust and good interventions. We developed such an approach in order to teach MSc students following the Energy track in the System Engineering, Policy Analysis and Management programme at TU Delft. This paper discusses the approach for the course findings from the first run of 18 students in six project groups in the second semester of their first year, during the academic year 2016-2017.

2 Course design: “Design of Integrated Energy Systems”

2.1 Course goal and project definition

The goal of the course is to equip students for designing interventions for today's and tomorrow's issues in energy systems by selecting, developing and using quantitative simulation models and reflecting on aspects outside the design space. Acquiring critical reflection of the outcome and the creation of a well-structured procedure are essential parts of the course as well.

These skills are acquired by the students during a project, which focuses on the decarbonisation of the energy system in the first half of the 21st century. The specific research topic of the design project is

chosen by the groups individually. In general, it connects various energy carriers, multiple infrastructures and time scales.

Students are expected to realise and deal with following three challenges:

- 1) **It is hard to accurately observe and predict.** It cannot precisely be measured what system components do/did/will do. Responses of actors to interventions are not perfectly known or predictable. Technical and social complexities matter.
- 2) **Systems are hard to study in isolation.** Systems are essentially systems of systems, where elements interact on various scales. Infrastructures get more and more intertwined. Vast uncertainties exist, and they are often dominant for the dynamics in energy systems.
- 3) **Models are imperfect.** It is not always clear what data sets are required to execute a model and whether data sources are available, it is not always clear whether they are complete and up to date. Systems are too large to be captured by individual models or simulations. It is difficult to model all needed time scales or system levels.

As students learn to address these only on theoretical basis, but experience it during their project, critical thinking and reflection of the models and its outcome is encouraged. Several teaching methods, which are explained below, stimulate this procedure.

2.3 The method students apply in their projects

In order to make decisions on design interventions for integrated energy systems, it is necessary to not only understand the technical aspects within the network, but also their institutional aspects (e.g. policy). The overall approach of the course can be summarised with six iterative steps:

1. **Exploration of the problem:** an inventory of acute/known problems/issues and list how to measure their improvement is made. This defines the problem space and also possible quantitative and qualitative indicators by which the success of newly proposed designs (from step 2) can be assessed and evaluated.
2. **Generation of alternatives:** possible interconnections between networks, flows and behaviour that relate to these problems are collected via brainstorming. The different system levels and the design space with several solutions are considered. It is important to be explicit about intervention types (policy, artefact, etc.) and where they act on the system and its levels.
3. **Selection of a modelling strategy:** the available models are evaluated, selected and matched with assumptions and needed data in order to compose a feasible modelling strategy that defines the relations between models and the feasibility of the assessment.
4. **Run and assess the system:** the models that have been selected will each be applied according the modelling strategy of step 3, including gathering and analysing input data, validation of the modelling strategy and obtaining of the modelling outcomes. This will assess quantitatively how the proposed designs from step 2 perform against the quantitative indicators defined in step
5. **Evaluation of the system:** the models, underlying assumptions and other system insights are used to evaluate the system in its wider context, including an evaluation of the qualitative indicators as defined in step 1. Students discuss what is the overall judgement of the alternative designs.
6. **Communication of the results:** for refining the analysis the earlier steps will be iterated. The final product of the project is an intuitive, clear and valid/just presentation of the quantitative and qualitative results and conclusions.

2.4 Developing a modelling strategy

A crucial challenge is to define a modelling strategy which results in a specified approach for the

remainder of the project. This composes of the following steps:

- 1) **Describe relevance of given models.** On the basis of the information for the given models, the students explore how each of the models is relevant to their design. Some models may be more directly related to the design than others. Other models can be considered as well, as far as they are available and production-ready.
- 2) **Make a selection** from the models available by discussing the result of the previous steps. This selection can be revisited later if needed.
- 3) **Consider data needs** and data availability. Two aspects are relevant in context of data to make each model valid for partly analysing the design proposed. First, find the data needed. Second, to have a clear concept of how the in- and output of the models is connected.
- 4) **Match core assumptions** of the selected models. Assumptions shall be determined, brought in line and set into relation with each other.
- 5) **Define and visualize relations** between selected models. The result of this step in the approach is a visualization of the modelling strategy, which is an overview of how the models will be related in the study and what the information flows from and to the models will be. Different typology of strategies can be used (e.g. figure 1). The abstract character of the flow charts help the student to have a clear idea about the interaction of models and identify trouble spots or missing data. Students are encouraged to make all relations explicit.

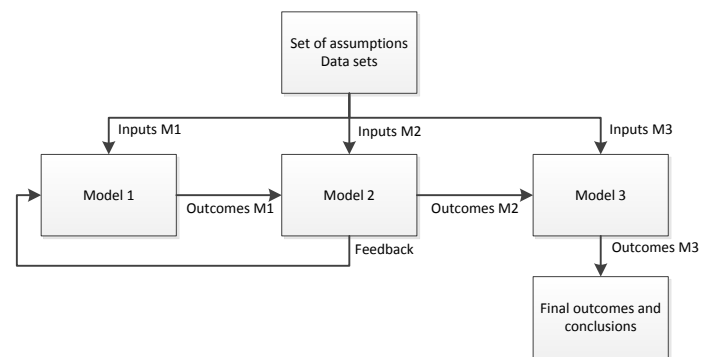


Figure 1: Modelling strategy with feedback loop

2.5 Teaching methods

In general, the design of the course gives the students a great degree of freedom to organise their group work. At the beginning, more guidance is provided. It consists of a general introduction to the course, a peer review after a first pitch and an individual meeting with the lecturers and with the developers of the models in the course – which are researchers at the university and employees of companies in the energy industry – in order to discuss the design proposal. The range of actors ensures that feedback is given from different perspectives. The involvement of the students in the feedback process does not only help the students receiving the feedback, but also the ones giving the feedback, as they are encouraged to reflect on the project in general. Interaction with companies in the energy industry is explicitly covered which gives students a unique insight in how models are developed and used in companies and force students to reflect and explain on how the model use is different with respect to the company's perspective.

With increasing maturity of the project the degree of freedom increases. During this time, voluntarily visit hours of the lecturers are offered to receive another individual feedback or discuss pain points of the project.

Later in the course a preliminary and final presentation is given by the groups to present the results. On the basis of the project work, peer review, participation, an individual appendix on the lessons learnt and an individual oral examination, individual grades are determined. Thereby, the students reflect not only on the results of their project, but also on the procedure of their group.

3 First experience

3.1 Input: Given models and simulations

A set of 19 models and simulations is provided for the students. The set consists of four categories of models: Agent-based models, network-tools based on Maple, energy system analyses and scenario tools (the last two are mostly based on Excel). Some are developed by students in earlier courses, some are developed by researchers in the group and some are from companies and consultancies (e.g. Alliander, Stedin, CE Delft). The implementation of models, their size/complexity and scope range from model to model. They focus on different parts of the energy value chain (e.g. network, energy dispatch) and outputs (e.g. financial indicators like net present value, energy market price, network topology).

3.2 Output: Results of the projects

Essential to the learning process are 1) learning to define an adequate research question, 2) gaining experience in translating this research question into a modelling strategy, and 3) the implementation of that strategy using existing models. By giving the students the broad leading theme decarbonisation and a range of models and simulations, the scope and results of the projects show a great variety. In total, six well defined and interesting research questions were the result of lively discussions, specification and narrowing down. The topics varied widely: electrification in India, the role of hydro-energy in Ontario, the business case of energy storage, demand side management, shale gas in the Netherlands, and the end of natural gas in Amsterdam. In the first phase, where students get familiar with the available resources, they are forced to break down the research question down into feasible working packages (and searching for the most exciting topics). The group on energy storage was forced to adapt their focus, i.e. they went from an economic efficiency evaluation for storage towards identifying tipping points, because they realised during the research that the uncertainties involved would make a forecast infeasible. Another key insight for the students was to evaluate the robustness of the final results. As no “unique best solution” exists, the art of modelling is not to eliminate uncertainties, but to identify them, find their consequences and make those presentable. This is done by e.g. giving a price range for solar home systems. For the topic of rural electrification in India, an on-grid solution based on the grid topology (network model) and the needed PV capacity (dispatch model) were compared to an off-grid solution (diffusion of innovation model).

4 Conclusion

The course “Design of Integrated Energy Systems” at TU Delft teaches a pragmatic approach of using sets of existing models in projects to evaluate design problems related to the energy transition that groups decide to address. Students are taught to develop and execute a modelling strategy on the basis of a range of existing models. Self-reflection, peer-review, the academic debate on modelling and feedback by the teachers after presenting preliminary results are key elements for stimulating the progress of the group work.

The experience shows that students learned to adopt, modify and use the given models and integrate their outputs according to the needs for their research topics. All in all, the approach of adapting and applying existing models in a modeling strategy allowed the students to 1) climb a steep learning curve with respect to modelling, 2) debate crucial assumptions, 3) understand energy models used in research and the industry, 4) deal with a broad range of topics and 5) model with a relatively high level of detail, considering the overall project time of 7 weeks.

The students have expressed frequently that this hands-on approach with a guided confrontation to modelling practice has taught them interesting insights. The model owners are impressed by the quality of the work done by the students and see this as a valuable addition to their industrial practice.