Optimal Integration of Renewable Energy Sources: Non-Linear Programming and Control Theory Approaches

- Candidate: Magda Mirescu

- Examiners:
  1. Prof. Dr. Vladimir Veliov
  2. Prof. Dr. Andreas Novak

In a world where climate change has slowly ceased to be a threat but an unfortunate reality, many countries around the globe are forced to re-evaluate their current situations and find solutions that both help mitigate climate change and enable economic growth. Most of the anthropogenic greenhouse gas emissions stem from electricity generation and industrial processes (such as the production of cement, steel and paper), as a result of the intensive use of fossil or non-renewable resources, which in addition to being pollution-intensive also have the problem that they are only finitely available on the planet. Aside from the issues on the supply-side described so far, the non-industrial demand-side also brings some challenges of its own: the overall demand for electricity is assumed to increase for developing countries due to urbanisation, whereas for developed countries, a coupling of the electricity sector with both the transportation and the heating sectors is foreseen, which will most likely only slightly increase the demand for electricity as well. Thus, regardless of the motivation (be it demand or supply driven), re-evaluating the electricity generation sector is imperative.
This work focuses on the supply-side and offers a step-by-step instruction manual to reaching a 100% green electricity generation portfolio. To make a fair assessment of renewable energy sources, we assume that their integration into the electricity market generates so-called system costs, which are properly integrated in the models constructed in this thesis.
First, a static, convex, non-quadratic optimisation model is developed, where the system costs function is assumed to represent the balancing costs accrued from the forecasting errors of the renewable energy input. In a portfolio optimisation setting originally inspired from finance, the optimal bundle of generation technologies covering the electricity demand for a year is determined by a risk-averse social planner. The non-quadratic non-linearity arises from the system costs function that is monotonically increasing in the share of renewable energy. This complexity restricts the number of constraints allowed, which is why, prior to stating this model, a closer look is taken at the best way to optimally discretise the load duration curve, a prerequisite of the demand. Conventional technologies are successively eliminated until a portfolio of two technologies is achieved, where one technology is fossil while the other one is renewable. The main result is that the elimination of technologies from the electricity generation portfolio will increase both the costs and the risk of electricity generation, with this effect being further magnified if system costs are considered.
The ultimate transition to a fossil-free electricity generation is given in the second part, which continues the problem where the portfolio optimisation model left off. Therefore, in a dynamic non-linear optimisation setting, various optimal control theory models are developed, in which different effects for the backstop technology are successively incorporated. The ultimate model considers a social planner wishing to maximse utility generated from electricity through both the non-renewable and the backstop technology, while accounting for environmental, extraction and scarcity costs for the non-renewable resource and for investment costs in the backstop technology decreased through learning-by-doing as well as for system costs that the backstop technology may entail. System costs are now assumed to comprise investment costs in grid expansion, balancing as well as profile and connection costs, thus being a wider variety of costs, that are relevant if the planning horizon is long, as is the case with dynamic models. The re-

sults range from a manifold of equilibria, emerging through history-dependence, to indifference thresholds of the Skiba and weak Skiba type.