Project proposal: Near optimum solution modelling and optimal portfolio theory for a highly renewable Europe.

Kristoffer H. Aden

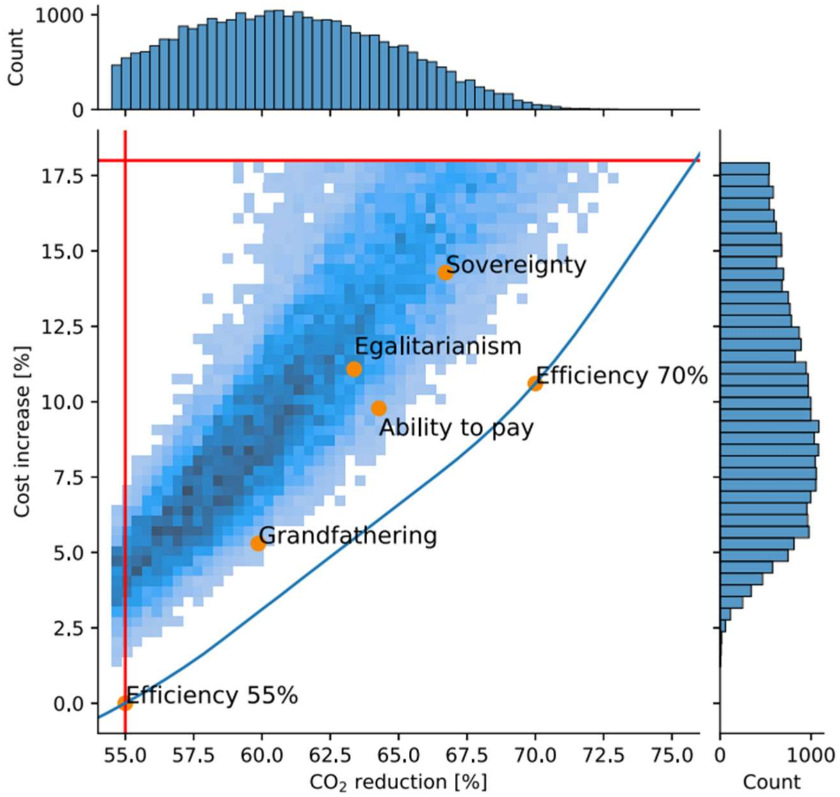
Problem summary

Mitigating the effects of manmade climate change is a challenging problem, that we have been aware of for many years without having been able to slow the rate of change significantly. One reason for this is that despite the issue being a global problem it must be resolved by close collaboration between individual governing bodies across the globe with different access to resources, ideologies, strategies and interests. This has meant that the issue has largely been approached on a country-to country basis even though a great deal of resources could be saved, such as reducing the necessity of backup power generation for an increasingly renewable reliant European energy network[1], by a principle of unity. This, however, gives rise to political issues of self-sustainability and reliance upon other nations. When modelling the future of the European energy network, there is a tendency to decrease self-sustainability in favor of consolidating renewable energy production in the countries who have the highest renewable energy potential[2]. This, while it being the mathematically optimal solution, is difficult to implement on a pan-European scale as countries tend to dislike relying on others for their energy production.

Inspiration

Recent research has been published that categorizes the scale of this issue by analyzing the near optimum solution space to map how slightly sub-optimal solutions, that might be more politically viable, measure up to the global optimal solution. One such paper[3] modelled the near optimal solution space using an implementation of the MAA method (modelling all alternatives) to "address the difficulties in ensuring distributional justice in the transformation of the European electricity sector- ". This work was based on the PyPSA-Eur-Sec model on the European energy system and allocated local CO_2 prices based on five principal effort sharing schemes: Grandfathering, Sovereignty, Efficiency, Egalitarianism, and Ability to pay. Having sampled the near optimal solution space, the following figure was produced:

[1] (Rodriguez R.A. D. M., 2015)
[2] (Eriksen E.H., 2017)
[3] (Pedersen T.T., 2023)



Here the 30.000 near optimal solutions are plotted as a function of their percentage cost increase and their achieved CO_2 reduction. The blue line is the cost optimal front which, for this paper, was found by using a uniform emission pricing while decreasing the targeted joint CO_2 emissions. Off specific interest to this project proposal is the unsampled area between the cost optimal front representing the global optimal solution, and the near optimum sampled space. While there is no restriction keeping the sampler from finding a solution closer to the cost optimal line it has not happened since to achieve such a solution requires an extremely specific configuration and coordination of the nations CO_2 prices. This can also be observed on the distributions on the axes of the figure above where the number of solutions found decreased drastically towards the tails. This area is however interesting as it will give an idea of the "shape" of the solution space. In other words, if the solution is a peak on a mountain, the unsampled space will tell you the shape of the mountain.

Proposed methodologies

The first thing needed to analyze the unsampled space is a model of the European energy system as it is today. This model will be based on the PyPSA-Eur electricity grid model but simplified to reduce the complexity of the problem. This could either be achieved by selecting a subsection of the model to use or by other means. The model would be based on the concept of degree-, Adjacency, Laplacian-Incidence- and cycle-matrixes that can be used to map the connectivity of nodes in a network. The PyPSA-Eur model does not include the option for imposing constraints on CO_2-prices on a per-country basis, and this will have to be implemented manually.

To optimize the models based on reducing system costs and finding the cost optimal front the commercial solver Gurobi will be used as it has proven to be fast, efficient and has a free academic license. The Gurobi solver algorithm is based on many different principles of optimization such as the Simplex method and Branch-and-Bound method, but the exact makeup of the solver is not known as it is patented. If another solver was to be used an obvious choice is the newly released HiGHS open-source solver which uses some of the same optimization techniques, albeit slightly slower. HiGHS, however, has the advantage of being open source and therefore much more transparent when it comes to the makeup of the optimization algorithm.

Once the cost optimal front has been found and the specific configurations of local emission-prices are known, the near optimum solution space will be sampled through concepts from Optimal Portfolio Theory[4]. This approach seeks to find a balance between risk and reward by varying local CO_2 prices, targeting solutions that maintain a close approximation to the cost optimal solution while allowing for more politically feasible deviations. Here the reward could be modelled as reducing the increase in overall system costs when finding solutions and thus be defined by the system model. The risk could be modelled as the variance of the variance of the localized CO_2 prices as a more homogeneous pricing scheme could be easier to implement. Then by allowing a small deviation from the cost optimal configuration the near optimum solutions will be analyzed by finding the configurations with the highest rewards and lowest associated risks. By including a covariance matrix in the modelling of the efficient frontier in the near-optimal space the natural correlations of the countries CO_2 prices may also be included. This way individual characteristics of each nation's energy mix will be considered. The results would, hopefully, reflect a range of configurations where both self-sustainability and EU collaboration come together to produce more politically feasible solutions.

Finally, once the space between the cost optimal front and the nearest samples is found, this space will be explored through interpolation results from nearby regions in combination with variance analysis to study the governing interactions in this unmapped space. The interpolation method could be a simple one-parameter interpolation like in[5] or a more advanced approach like Gaussian Processes for Regression (GPR) which also returns a measure of the uncertainty of the interpolation.

Planned deliverables and project structure.

This project includes many different moving parts and keeping the project structure clear and distinct will therefore be of paramount importance. The project will span over two semesters: Spring 2025 and Autumn 2025.

Formally the project will be split into two distinct courses. In the spring it would be a Research and Development Project in Mechanical Engineering, 20 ECTS focusing on building the energy system model and making sure it is robust. If necessary, this means that the sampling and data extraction, which may prove time consuming due to its computationally intensive nature, can be supplemented or performed over the summer break 2025. At the end of the spring semester a report documenting this work will be submitted. It is, however, important to notice that the subsequent master's thesis may use the previous work as a source but may not include redundancy and overlap.

For the Autumn semester of 2025 the rest of the project will then be performed as the official master's project and end with the submission of a master's thesis documenting this work.

The final purpose of the project is then to have a better understanding of the more politically feasible solutions in the near optimum solution space for policy makers to make more informed decisions and to inspire further research on the subject. To further emphasize this goal the project will be performed as open science to increase transparency and reproducibility. The research will be performed under the Creative Commons Attribution 4.0 International open license and the data and code will be made available for download through a GitHub- and Zenodo-repository.

Primary supervision will be performed by Alexander Kies with weekly meetings and check-ins while secondary supervision will be performed by Martin Greiner as necessary.

[4] (Eriksen E.H., 2017)
[5] (Eriksen E.H., 2017)

Bibliography and further readings

Eriksen E.H., S.-N. L. (2017). Optimal heterogeneity in a simplified highly renewable European electricity system. *Energy.*

Neumann F., B. T. (2021). The near-optimal feasible space of a renewable power system model. *Electric Power Systems Research*.

Pedersen T.T., A. M. (2023). Using Modeling All Alternatives to explore 55% decarbonization scenarios of the European electricity sector. *iScience*.

Rodriguez R.A., B. S. (2015). Cost-optimal design of a simplified, highly renewable pan-European electricity system. *Energy*.

Rodriguez R.A., D. M. (2015). Localized vs. synchronized exports across a highly renewable pan-European transmission network. *Energ Sustain Soc.*

Schwenk-Nebbe L.J., V. M. (2021). CO2 quota attribution effects on the European electricity system comprised of self-centred actors. *Advances in Applied Energy.*