MSc Thesis

Transporting an overproduction of locally generated renewable energy in an island context

SET 3901: Graduation Project

Berat Kaya

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Transporting an overproduction of locally generated renewable energy in an island context

Student Name	Student Number
Berat Kaya	4482603

Responsible Supervisor:	S. Pfenninger
Second Supervisor:	B. Pickering
Project Duration:	30 weeks
Faculty:	TPM, Delft

TUDelft

Preface

This report was written by me, a Sustainable Energy Technology student at Delft University of Technology, as part of my Thesis Project.

For my final project in this program, I chose to tackle a complex topic about commodity transport. With a strong focus on renewable energy throughout my studies, the challenge of energy system modeling, particularly in addressing a real-world issue, offered a fascinating area to investigate. Moreover, the project's emphasis on Linear and Mixed-Integer Programming, combined with the use of Python, aligned perfectly with my interests in both mathematics and programming.

Project such as these carry an invaluable significance as the world confronts the pressing need for clean energy solutions and the looming impacts of climate change. Managing the overproduction of renewable energy is becoming increasingly critical and finding efficient ways to transport surplus energy is essential to realizing a sustainable energy future.

Finally, I would like to thank my supervisors Stefan Pfenninger and Bryn Pickering for their help and support during my Thesis Project.

Berat Kaya
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Abstract

An abstract...

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1 Introduction

The global push to combat climate change and reduce greenhouse gas emissions has led to a significant focus on decarbonising the energy systems worldwide. In Europe, the transition towards a low-carbon energy system is a central pillar of the European Union's sustainability goals. Despite the numerous benefits of decarbonising the energy system, this transition is not without its challenges and trade-offs, as described by Pickering et al. (2022). One of the key challenges is the intermittency of renewable energy sources, which can lead to issues such as overproduction and under-utilization of renewable energy.

As such, energy system optimization is imperative, with a key area in need of this being transport. To effectively address a transport problem, advanced energy system modeling tools are required. One tool capable of building energy models is the Calliope framework, which also provides spatial and temporal optimization (see Verrascina (2022)). However, while it is possible to use continuous power transmissions for modeling within the framework, it needs to be improved to handle more complex cases. One such case is the discrete transportation of energy carriers, within the maritime industry for example.

To effectively setup a test model within Calliope to apply these improvements to, a case study will be built focusing on Iceland. This country is a world leader in renewable energy, producing a majority of its total primary energy supply locally, which then gets exported in the form of aluminum. Potential trade-offs with other methods, such as power transmission, will also be investigated.

2 Literature Review

One prevalent approach to transportation modeling within energy systems is through the use of other linear programming (LP) techniques. These models are designed to optimize transportation routes and schedules, considering factors such as distance, fuel consumption, transportation time, and infrastructure constraints. By formulating transportation problems as LP optimization tasks, researchers can identify the most cost-effective solutions while satisfying system requirements and operational constraints. An example is the case study by Groppi et al. (2022) on a small island in which the Marginal Abatement Cost (MAC) curve was optimised. This is a heuristic approach.

An emerging trend in transportation modeling is the incorporation of uncertainty and risk analysis techniques. Stochastic optimization methods, scenario analysis, and robust optimization approaches are employed to account for uncertainties in factors such as fuel prices, demand forecasts, and infrastructure disruptions. By evaluating transportation strategies under different future scenarios, uncertainty-aware models help decision-makers identify robust and resilient solutions, thereby mitigating risks associated with energy transportation. In the paper by Işıklı et al. (2020) the Response Surface Methodology (RSM) is used for an in-depth analysis on fuel consumption within the maritime industry. This approach focuses on statistical experimentation.

The concept of Separable Mobile Energy Storage Systems (SMESS), where mobile energy storage and mobile energy carriers are scheduled and dispatched separately, offering enhanced flexibility for energy management, is very relevant when it comes to transporting discrete units with a time delay. This concept is particularly valuable for addressing issues related to the intermittency of renewable energy sources and the transport of energy in discrete units, according to Wang et al. (2022). The methodology uses a Mixed-Integer Linear Programming (MILP) model to schedule SMESS, Mobile Emergency Generators (MEGs), and Fuel Tankers—provides a robust framework for optimizing energy transport, outlined in Zhang et al. (2014). The ability to model the discrete transportation of energy carriers with variable fuel consumption and time constraints is directly applicable to the focus on using ships to transport aluminum between Iceland and the Netherlands. Moreover, the emphasis on resilience, which involves adapting to changes in supply and demand conditions by efficiently scheduling energy carriers, aligns with the goal of optimizing energy transport under complex conditions, such as variable fuel costs and renewable energy constraints. Furthermore, this paper also addresses the operational complexities of scheduling multiple energy carriers and vehicles in a dynamic environment, which is crucial for extending the capabilities of existing energy modeling frameworks like Calliope. By incorporating similar principles, you can better model the discrete transportation of energy resources, optimize fuel usage, and explore trade-offs between different transport and transmission methods in the maritime industry. The application of the separable scheduling approach will help in devising a more flexible and resilient energy system, specifically when integrating the transportation of aluminum and the renewable energy sources available in Iceland.

3 Methodology

The approach for this case study will follow a heuristic LP approach using the Calliope framework. The idea is to model a transport problem, applied to a specific case study. With Calliope a high spatial and temporal resolution can be achieved, meaning the behavior during transport between nodes can be analyzed in time and space. However, the idea is to model a more complex problem involving the transportation of an energy carrier with ships, which involves additional parameters and constraints based on the fact that the ships will move discretely, consume fuel and take more time than the power transmission technologies which Calliope is using.

For the case study Iceland will be used as a location. The island country produces a majority of its total primary energy supply locally and derived from renewable sources (e.g. geothermal energy) and produces about ten times as much electricity per resident compared to the European Union. The idea is to address this overproduction of renewable energy by exporting it. Currently, the export is mainly in the form of aluminum by using the excess electricity to refine ore and then shipping it. The Netherlands will be used as the second location as the main importer of Iceland's aluminum. After the modeling, the trade-off for choosing this export method will be investigated as opposed to, for example, using submarine power cables for direct eletricity transmission. The main research question to answer is the following:

- How can the Calliope framework be utilized to optimize the transport of renewable energy from Iceland to The Netherlands using ships and what are potential trade-offs compared to other methods?

To model the transport of aluminum with ships between Iceland and the Netherlands within the Calliope framework, you would typically set up the model with appropriate constraints, variables, and objective functions. However, this is not yet possible with the base mathematical formulations provided. Thus, custom mathematics will first need to be defined, which is possible as of Calliope version 0.7. To reach an answer for the research question, the following points need to be defined:

- A time delay to the transmission (of aluminium) between 2 nodes (Iceland and The Netherlands).
- The ability to track the transmission of discrete units (of ships) between 2 nodes, through time.

Finally, a solver will be used and the results analysed to answer the research question. The project will take 30 weeks to complete.

4 Results

5 Discussion

6 Conclusion

References

Groppi, D., Nastasi, B., and Prina, M. G. (2022). The eplanoptmac model to plan the decarbonisation of the maritime transport sector of a small island. *Energy*, 254:124342.

Işıklı, E., Aydın, N., Bilgili, L., and Toprak, A. (2020). Estimating fuel consumption in maritime transport. *Journal of Cleaner Production*, 275:124142.

Pickering, B., Lombardi, F., and Pfenninger, S. (2022). Diversity of options to eliminate fossil fuels and reach carbon neutrality across the entire european energy system. *Joule*, 6(6):1253–1276. Pickering, Bryn Lombardi, Francesco Pfenninger, Stefan eng 2022/07/06 Joule. 2022 Jun 15;6(6):1253-1276. doi: 10.1016/j.joule.2022.05.009.

Verrascina, M. (2022). Energy transition of the sardinia region.

Wang, W., Xiong, X., He, Y., Hu, J., and Chen, H. (2022). Scheduling of separable mobile energy storage systems with mobile generators and fuel tankers to boost distribution system resilience. *IEEE Transactions on Smart Grid*, 13(1):443–457.

Zhang, Q., Shah, N., Wassick, J., Helling, R., and van Egerschot, P. (2014). Sustainable supply chain optimisation: An industrial case study. *Computers Industrial Engineering*, 74:68–83.

A Appendix

To-do list:

- Create a 2-node system that has continuous supply of fuel and aluminium at ISL and continuous demand for aluminium in NLD, with a transmission line between the two that consumes fuel to transmit aluminium
- Shape up thesis draft and write the literature review and theory chapters
- Add in the math to add a time delay to the transmission of aluminium
- Add in the math to transform the transmission link into a ship, tracking the location of the ship through time
- Replace a constant fuel cost in ISL with the full, climate-neutral energy system representation, so it can decide how it will meet fuel requirements with the technologies available (and accounting for other demands for electricity/fuel in the system)
- Write down why the non-custom parts of the math are analogous with Calliope
- Visualise, interpret and discuss results (research question)