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THE BASE FOR A EUROPEAN ENGAGEMENT MODEL – AN OPEN SOURCE ELECTRICITY MODEL OF SEVEN COUNTRIES AROUND THE BALTIC SEA

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ABSTRACT

This paper presents a long-term open source energy planning model for Denmark, Estonia, Finland, Latvia, Lithuania, Poland, and Sweden, as part of the preparation of a Pan-European model within the Horizon 2020 REEEM project. The model is built using the Open Source Energy Modelling System (OSeMOSYS) and is conceived as a stakeholder engagement model, comprehensive but accessible. It aims to lower the threshold to join and contribute to a model-based discussion about the optimal decarbonisation pathways for the energy supply of the region.

The lowest net present value for the modelled system and period (2015-2050) is calculated by using linear optimization. Existing and planned trans-border transmission capacity between the included countries is considered in the model. New projects are also allowed as far as economically optimal. The electricity exchange to countries not covered by the model are not modelled as of yet. Ten fuels are used by the technologies defined in the model, namely biomass, coal, geothermal, heavy fuel oil, hydro, natural gas, nuclear, wind and waste. In addition to technology parameters like investment cost, fuel cost, and fixed and variable operation and maintenance cost, an increasing emission penalty for carbon dioxide is defined, which represents the cost related to the emission of greenhouse gases (similar to the European emission trading system).

The model provides insights on how the cross-border electricity exchange might develop in the modelled period while decarbonizing the energy sector and considering the unequal distribution of (renewable) resources. But most importantly, the model builds the base for the first fully open source energy model for Europe, including the used data. It shall be conceived as a comprehensive modular tool for engagement in the field of European energy planning, especially for learning in academia, but also by the integration into an open engagement game for decision makers and stakeholders.

Keywords: open-source, long-term, energy planning, trans-border electricity transmission, OSeMOSYS

1. INTRODUCTION

The European energy system is complex. Low cost energy improves economic competitiveness. However, established and long used options - such as coal and oil – are subject to geo-political and environmental concerns. Their price may be volatile and (low cost) suppliers are limited. Other energy forms such as renewables, nuclear and transmission systems, that are needed to support them, are subject to variable levels of social acceptance and can require complex configurations [1].

To analyse possible options and to foster public understanding there is a need for models which could provide transparent and open insight. These are needed to evaluate pathways and help communicate difficult compromises, as for example the choice of energy carriers or the route of transmission lines. Preferably these modelling tools should allow for flexible design to account for new solutions, e.g. new market designs, market integration, new technologies, the appearance of prosumers, and they should be inexpensive to allow easy access to larger groups of analysts.

Yet there are no freely available optimizing energy models of the whole energy system available for all European countries. Models that focus on electricity sector only exist, but they do

not include other energy sectors [2]. Models for all energy carriers exist for all countries, but they are not free [3].

We are presenting an effort to change the current situation regarding modelling tools. Using the Open Source energy Modelling System (OSeMOSYS) [4] model generator we generate an electricity system model of seven EU member countries. Using a clear and simple structure, the model is scalable and flexible. Scalable so that other countries could be added in a modular manner using the same generic structure. Flexible as while we focus on a limited set of fuels, more could be added, depending on the scope of the conducted analysis. We call the model, OSeMBE, which is short for the Open Source energy Model Base for the European Union.

2. METHODOLOGY

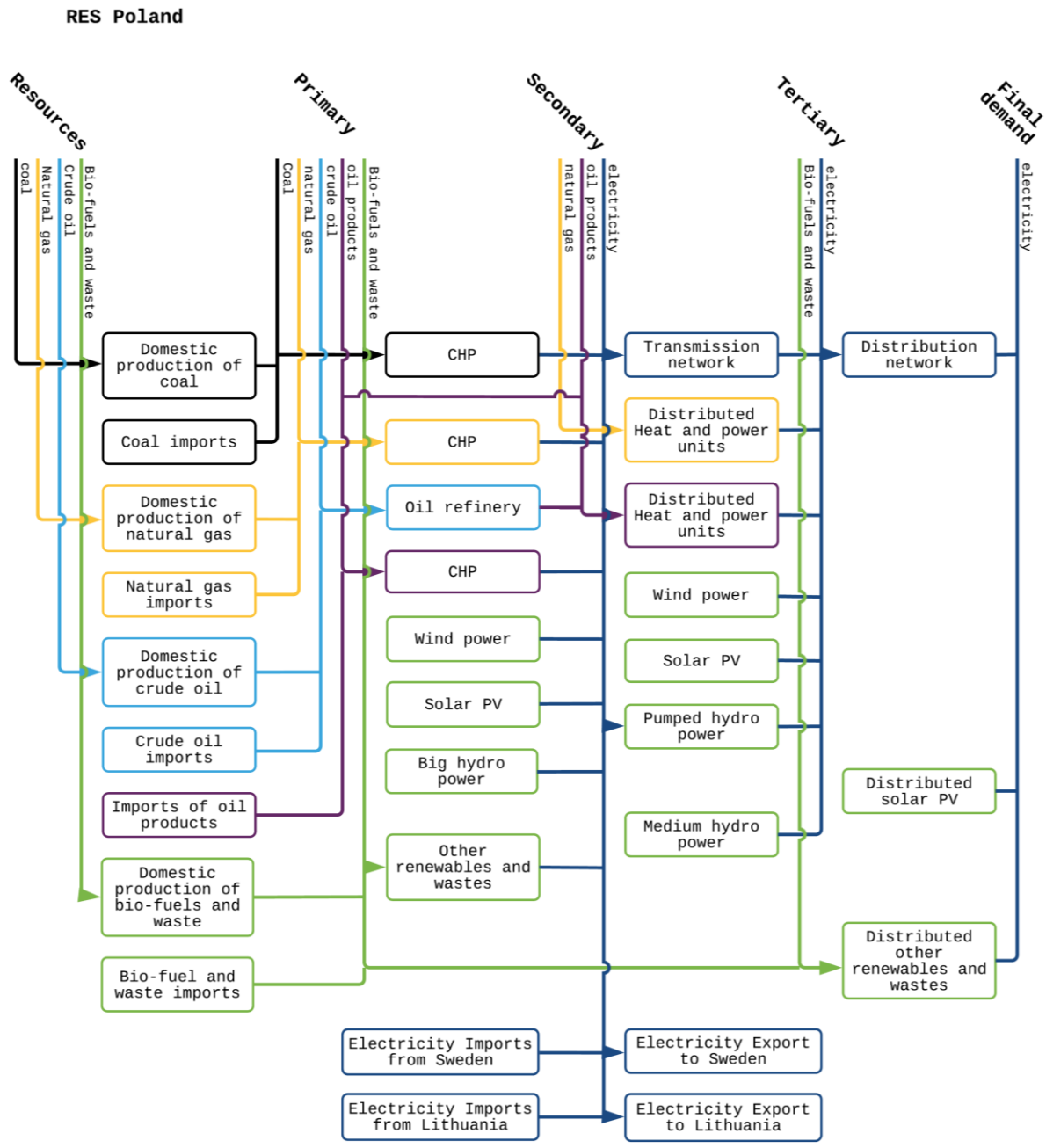
The work presented in this paper is the outcome of Master‘s thesis of the main author of this paper [5]. The co-authors contributed to the paper by supervising the thesis, reviewing the paper and providing the introduction to the paper. In the following sub-sections of this chapter the methodology used to develop OSeMBE, a model of the European electricity system is described. It describes the modelling system used, the model structure and the key assumptions made. The work done is open source and model source code, data and software used are freely accessible to ensure repeatability and access (www.osemosys.org).

2.1. OSeMOSYS

To develop the OSeMBE model described in this paper, the OSeMOSYS modelling system was applied [6]. OSeMOSYS is a dynamic, bottom-up, multi-year energy system model generator. The optimal investment strategy, production patterns of technologies, and fuels required to satisfy exogenously defined demand(s) are determined by linear optimization [7]. To use exogenously defined demand(s) implies that the model does not consider demand side management or energy efficiency measures. However, changes in demand and their effect on the development of the energy system can be pictured by creating scenarios with different demand assumptions. The analysis of how the system reacts to the changes in the demand is one aspect out of the field of technical, economic and environmental implications that can be analysed in the results. In OSeMBE the analytical focus lies on the system behaviour with increasing shares of (variable) renewable energies.

2.2. Model structure

The current stage of development of OSeMBE includes electricity only and covers the following countries: Denmark, Estonia, Finland, Latvia, Lithuania, Poland, and Sweden. The total electricity demand is specified per country. Demand projections were retrieved from the [8]. An energy chain to satisfy the electricity demand can consist of up to four technologies in the current version of OSeMBE, compare Fig. 1. The final electricity demand, shown on the right hand side of the Reference Energy System (RES) in Fig. 1, can be satisfied either directly by distributed technologies like solar PV or by electricity from the distribution grid (technology “Distribution network”). The distribution grid can receive electricity either from medium sized power plants like small wind parks, or from the transmission network. The transmission network is fed with electricity from centralised power plants, which in turn receive their required fuels from import or extraction technologies, if necessary.



Sources: http://www.iea.org/statistics/statisticssearch/report/?country=POLAND&product=renewablesandwaste&year=2015

Fig. 1. Reference energy system of Poland

2.2.1. Fuels and generation technologies

In total there are eight fuels (biomass, coal, heavy fuel oil, natural gas, crude oil, uranium, and waste) and thirteen technologies available (combined cycle power plants (PPs), combined heat and power plants, distributed and utility solar PV, hydropower dams, fuel cells, gas cycle PPs, internal combustion engines with heat recovery, offshore and onshore wind power, steam cycle PPs, and wave power plants). The main source for the techno-economic data of the power plants is [9]. Gaps in [9] where compensated by using [10]–[12]. Some of these power plant types are available in

different versions, differentiated by the fuel they require, e.g. steam cycle PP for biomass and steam cycle plants consuming coal. Additional to the domestic transmission and distribution of electricity OSeMBE considers trans-border transmission capacities to neighbouring countries. Due to their line specific techno-economic characteristics transmission technologies are modelled in a simplified way. For the domestic transmission and distribution does this mean that there are no costs related to it, but only a loss of five percent of electricity [13]. The transborder transmission considers existing and upcoming capacities, but the model cannot implement additional new capacities as it can for generation capacities. Anyhow, by creating scenarios with changed transborder transmission lines, congestions and the effect of enhanced trade options could be analysed. Especially in context of the different wind and sun resource quality and availability, this aspect is of high interest for the European power system with currently increasing capacities of wind and solar power [14], [15].

2.2.2. Time definition

OSeMOSYS is designed for long-term energy planning [6], therefore OSeMBE has a time horizon of 46 years, from 2015 to 2060. However, in the results analysis only the time period 2015 to 2050 is considered to avoid the effects of the end of the modelling period on the selection of technologies. The end of the modelling period might affect the results in the way that technologies with a short lifetime are preferred over technologies with a long lifetime since the later might not payback [5]. The year 2015 serves as the base year in OSeMBE and statistical information used was, when possible, taken for this year. Since OSeMBE is still under development the model was calibrated only to a limited extend, e.g. adjustment of the emission penalty and the price for biomass.

In the version of OSeMBE presented here, each of the modelled years is splitted into twelve seasons or rather the twelve months of the year. Each month is considered by one typical day. These typical days are then divided into day, peak, and night, adjusted to the average demand curve of the season. This results in 36 time slices per year.

2.2.3. Resource availability

To be able to capture the variable availability of wind and sun OSeMOSYS provides two ways of indicating the availability of a technology. Firstly there is the “AvailabilityFactor”, by using the AvailabilityFactor it can be indicated for how much time of the year a technology is available. The second option to indicate the availability is the “CapacityFactor”. The CapacityFactor is defined per TimeSlice, i.e. the change in availability per time slice can be considered, for example for solar PV the capacity factor during the night time is 0 and during the day e.g. 0.2 [16]. In this first version of OSeMBE the capacity factors for wind and solar power are national average values calculated based on data from renewables.ninja (renewables.ninja). The data from renewables.ninja is based on “NASA’s Modern-Era Retrospective Analysis for Research and Applications” (MERRA) and was corrected using measured data sets [14], [15].

2.2.4. Reserve Margin

The reserve margin (RM) in OSeMOSYS is defined as the minimum margin of a tagged commodity that a set of tagged technologies needs to be able to provide additional to the peak demand of the tagged commodity. Will say if the RM is set to 1.2 the technologies that are tagged as reserve margin tag technologies need to have enough capacity to generate 20% more than the annual peak demand of the commodity [17]. With the current version of OSeMBE a sensitivity analysis was conducted on how the results vary with a changing RM, the conducted analysis is described in more detail in subsection 2.4 Scenarios and section 3. Results and discussion.

2.3. Key assumptions

There are a certain number of fundamental assumptions made in OSeMBE that are not changed between the scenarios. These key assumptions are summarised in the bullet points below:

- The real discount rate applied is 5%
- The monetary unit is 2015 US$
- The reporting horizon of this study spans from 2015 to 2050. Simulations are undertaken for every year of the entire modelling period.
- As mentioned above, the year is represented by 36 characteristic time slices (12 seasons with day, peak, and night distinction) per year.
- OSeMOSYS assumes a perfect market with perfect competition and foresight [6]

2.4. Scenarios

Due to the development status of OSeMBE the scenarios analysed in this work serve the purpose of validating the results of the model. With the three scenarios created for this paper the change of behaviour of the model with different RM (of 1.15, 1.2, and 1.25) for the final electricity demand was analysed.

3. RESULTS AND DISCUSSION

This section provides some insights into the results OSeMBE is producing. However, it is important to consider that the model presented here is not yet fully fledged. Therefore, some of the results presented here are explicitly not realistic, e.g. trade patterns. In the first three subsections results for the scenario with a RM of 1.2 are presented and discussed.

3.1. Generation capacity

Below in Fig. 2 the development of the installed capacities in Finland and Sweden are shown. In the base year 2015 the installed capacities consist of statistical data on the installed capacities. Considering the expected lifetimes, the residual capacity is reduced year by year and new capacities need to be installed by the model. It is well visible in the two graphs how the availability of resources (mainly referring to hydro and wind) is affecting the capacity mix. The availability of both resources mentioned is lower in Finland in comparison to Sweden. Especially the linear development of installed wind power capacity in Finland indicates that the implemented limit is reached whereas the limit in Sweden is not reached. The different development of the installed capacity of nuclear can be seen in context of the different resource availability as well. While Sweden is almost phasing out of nuclear, Finland increases its capacity. The start is done by the nuclear power plants currently under construction, which are considered in this work due to their high importance for the Finnish electricity system.

In Fig. 2 in the lower sections of the graphs it can be seen that the model phases out power plants using biomass. This is an issue that needs to be addressed in the future work on the model since it is unlikely that power plants running on biomass are going to disappear from the power generation mix in the Nordic countries. It is rather likely that the assumptions made when calculating average prices of biomass were misleading.

The results for the capacity development in the other five modelled countries can be found in Appendix A. Capacity mix results.

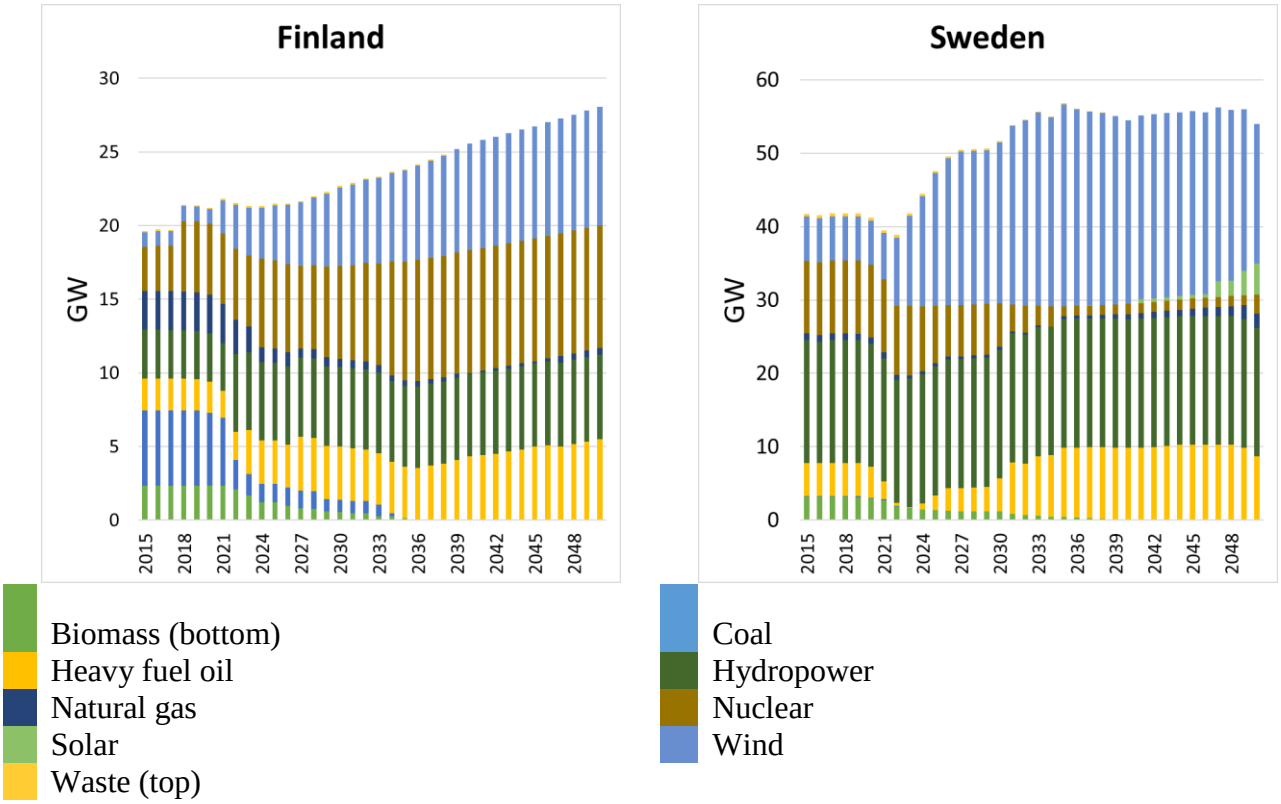


Fig. 2. Installed capacities in Finland and Sweden with RM 1.2

3.2. Electricity generation mix

Fig. 3 below, shows the annual production of Finland and Sweden throughout the modelling period. A red line in the upper half of the graphs indicates the actual electricity demand. Since imports and exports are not shown in the graphs, it can be seen in the graphs if the country is a net importer or a net exporter depending on if the upper edge of the production is below or above the demand curve. Is the upper edge below the demand curve the country is importing, is the edge above the demand curve the country is exporting. Considering this, the results indicate that Finland turns from a net importer to a net exporter. In 2019 a sudden peak in production is shown for Finland, it is caused by the newly added nuclear capacities. The phase out of nuclear in Sweden is compensated by wind power generation. Towards the end of the modelling period a small share of solar appears in the Swedish power mix. Due to its more northerly location this is not happening in Finland.

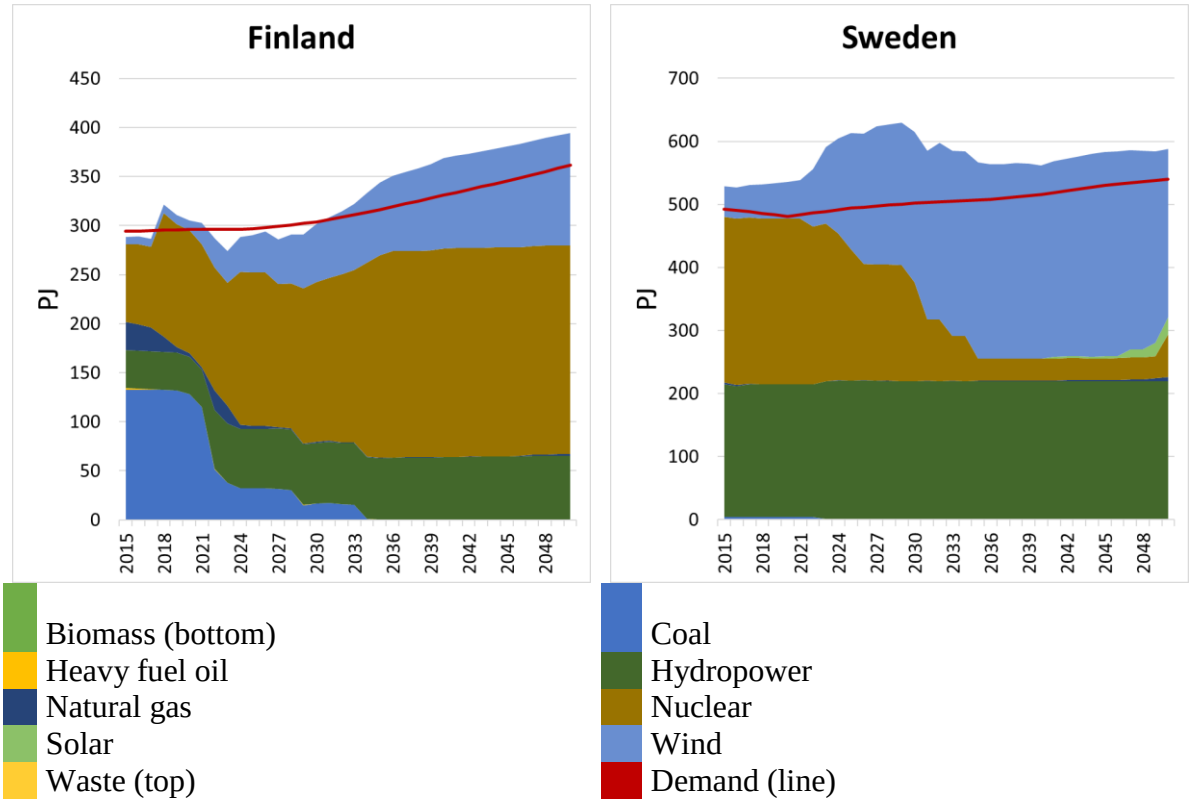


Fig. 3. Annual Production for Finland and Sweden with RM 1.2

The annual production pattern of the other five modelled countries can be found in Appendix B. Generation mix results

3.3. Cross-border electricity trade

Considering that OSeMBE is still under development, two aspects are interesting to contemplate in context of the transborder electricity trade. On the one hand there is the comparison between the modelled 2015 transborder flows and the real 2015 electricity exchange. On the other hand the development of the transborder transmission can be analysed.

Fig. 4, below, shows in the upper graphic the actual transborder electricity flows in the seven modelled countries. The figure at the bottom shows the transborder flows in the presented version of OSeMBE. Fundamental relationships like the export from Sweden to Finland or from Finland to Estonia are captured. However, the in reality almost balanced exchange between Denmark and Sweden shifted to only Denmark exporting in the model. Overall it is important to consider that the exchange with the not modelled/to be modelled countries is not considered so far, this explains e.g. the change in the relationship Poland-Sweden. It needs to be seen how the results will change when the model is extended and the exchange with 3rd countries, for example Russia, is considered.

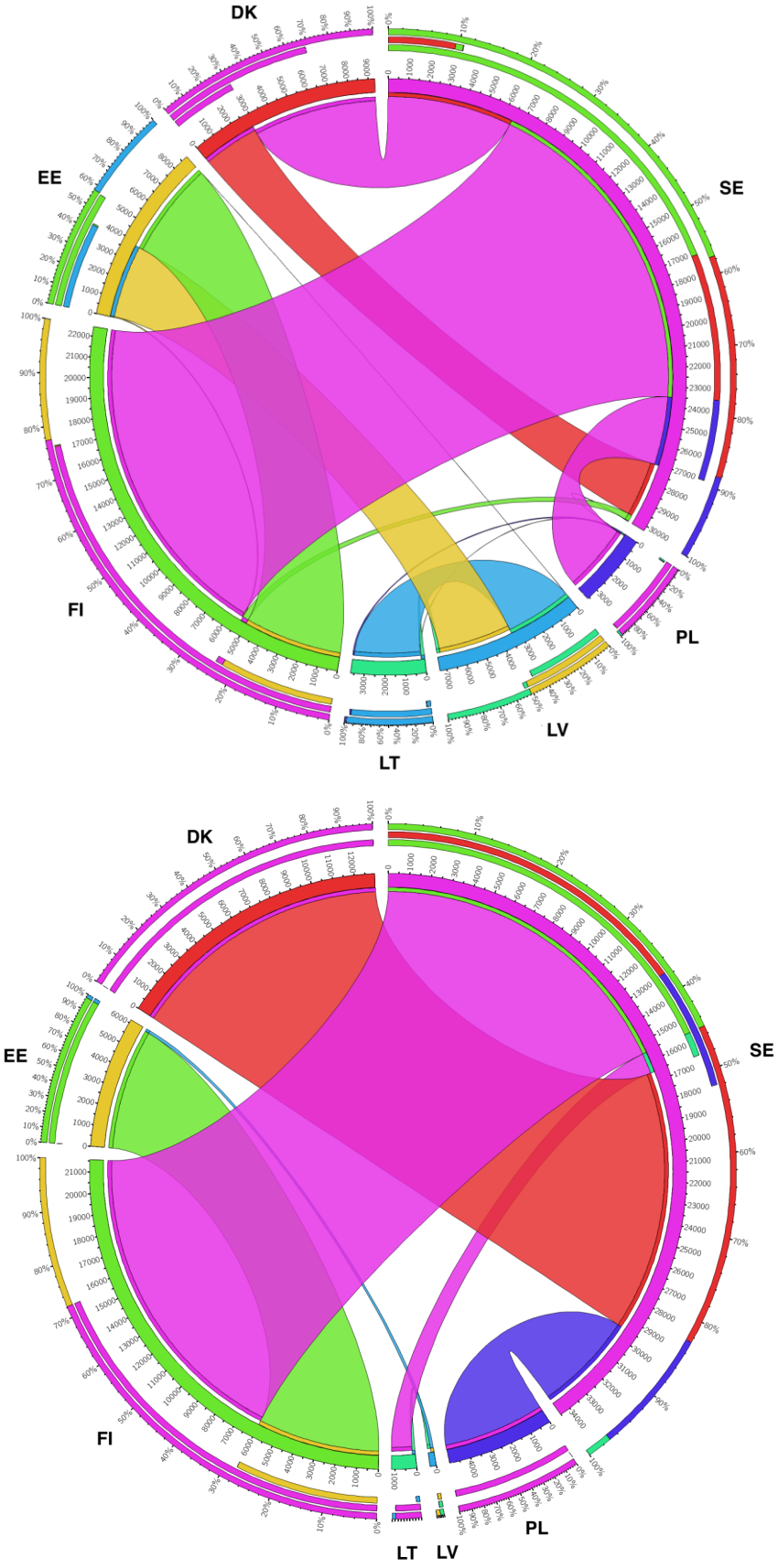


Fig. 4. Comparison of the 2015 real trans-border flows (top) and the trans-border flows in the base case (bottom) in GWh

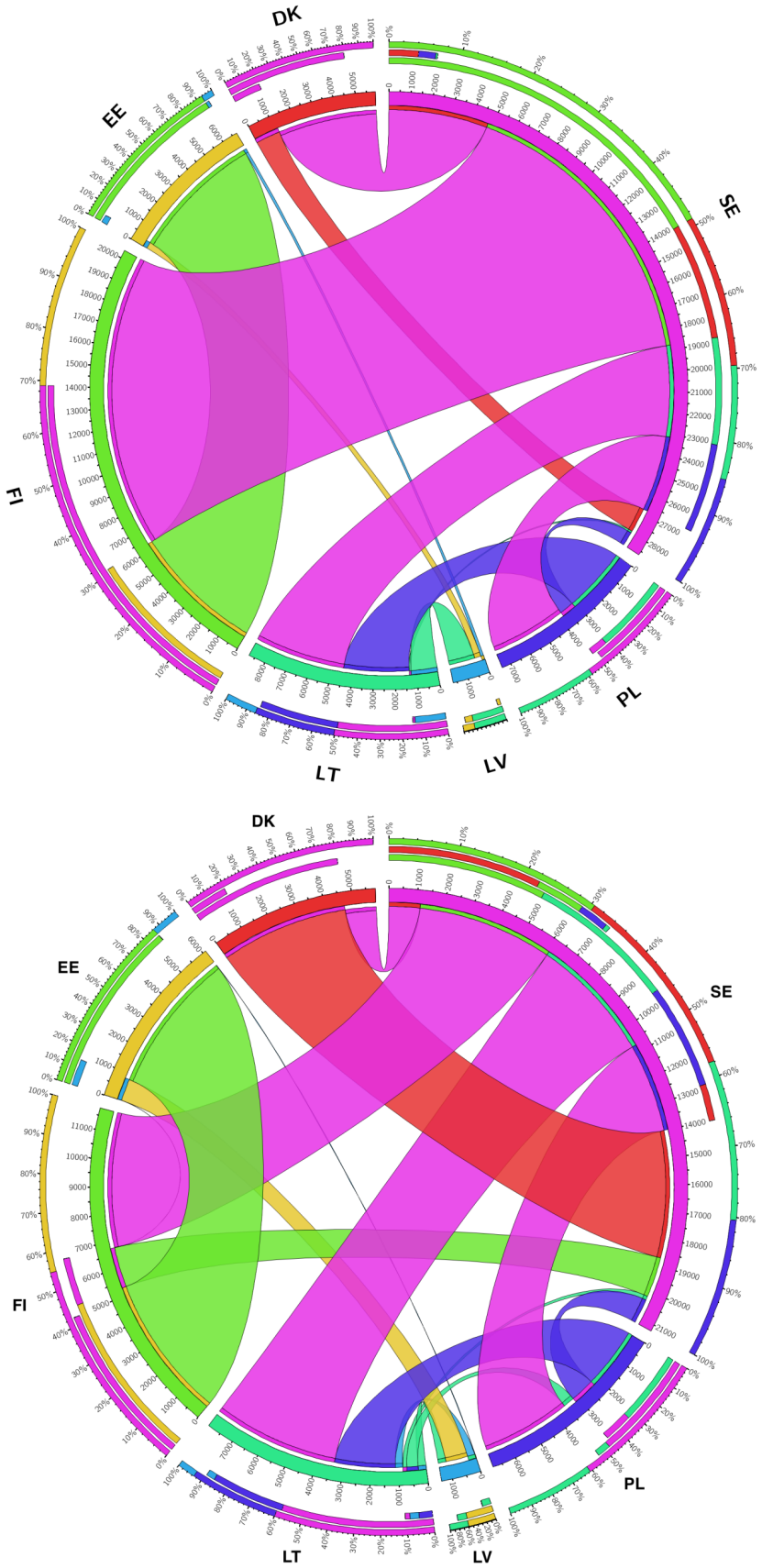


Fig. 5. Transborder flows in the base case scenario in 2030 (top) and 2050 (bottom) in GWh

When analysing the transborder flows in 2030 and 2050, shown in Fig. 5, two aspects can be highlighted: Firstly it is notable that the electricity trade seems to become more bidirectional over the modelling period than shown in Fig. 4 in 2015, where the flow between two countries was either in one or the other direction. The second aspect that can be seen is a decrease in the overall trade volume. The model indicates a trade volume of approximately 34 000 GWh in 2015 for Sweden which decreases to approximately 21 000 GWh in 2050. The change of one directional trade patterns to bidirectional be related to increased shares of variable renewables in the electricity production and their varying availability from country to country. The decrease in the trade volume might happen in cases of currently strong trade dependencies. However, it could also indicate that the chosen time resolution is coarse. This aspect will need to be further investigated in further research.

4. CONCLUSION

This first version of OSeMBE provides the base of an engagement model and tool, which is currently further developed in the REEEM project, funded by the Horizon 2020 EU framework programme. OSeMBE is structured in a simple but comprehensive manner which eases the use in academia and other learning environments like workshops on the energy nexus. Since the open source modelling systems OSeMOSYS was used to create the model and all data used is publicly available it shall also provide the possibility for further in-depth work by other users.
The above and in the appendices shown results indicate that fundamental dynamics of the modelled energy system are pictured, but also that the consideration of neighbouring countries is (modelled or not) and the definition of time slices will be crucial for the generating reasonable results with the enhanced and extended version of the model.

4.1. Future work

The next step in the development of OSeMBE, which is currently conducted, is the extension of the model to the entire European Union. This will allow analysis of electricity flows throughout the Union with the background of increasing shares of variable renewables and their varying availability in the region. As indicated earlier in the section on the generation mix a differentiation of biomass and biofuels will be done to better capture especially power plants using biomass as a fuel.

In the midterm there are five larger aspects that are possibly going to be addressed. These are namely: the integration of storage options like pumped hydro power and batteries, the implementation of heating demands, as already indicated in the RES, a better resource representation of solar and wind, and potentially the integration of the transport sector.

REFERENCES

[1] D. Scholten and R. Bosman, “The geopolitics of renewables; exploring the political implications of renewable energy systems,” *Technol. Forecast. Soc. Change*, vol. 103, pp. 273–283, Feb. 2016.

[2] RLI - Reiner Lemoine Institut, “oemof,” *open energy modeling framework*. [Online]. Available: https://oemof.org/. [Accessed: 23-Feb-2018].

[3] B. Fais, M. Blesl, U. Fahl, and A. Voß, “Analysing the interaction between emission trading and renewable electricity support in TIMES,” *Clim. Policy*, vol. 15, no. 3, pp. 355–373, May 2015.

[4] KTH - dESA, “OSeMOSYS,” *Open Source Energy Modelling System*. [Online]. Available: http://www.osemosys.org/. [Accessed: 23-Feb-2018].

[5] H. Henke, “The Open Source Energy Model Base for the European Union (OSEMBE),” KTH Roayl Institute of Technology, Stockholm, Sweden, Master thesis, 2017.

[6] M. Howells *et al.*, “OSeMOSYS: The Open Source Energy Modeling System,” *Energy Policy*, vol. 39, no. 10, pp. 5850–5870, Oct. 2011.

[7] C. Taliotis *et al.*, “An indicative analysis of investment opportunities in the African electricity supply sector — Using TEMBA (The Electricity Model Base for Africa),” *Energy Sustain. Dev.*, vol. 31, pp. 50–66, Apr. 2016.

[8] EC, *EU energy, transport and GHG emissions: trends to 2050 : reference scenario 2013*. Luxembourg: European Commission (EC), 2014.

[9] EC, *Energy Technology Reference Indicator (ETRI) projections for 2010-2050*. Luxembourg: European Commission (EC), 2014.

[10] IEA, “World Energy Outlook 2014 - Power Generation Investment Assumptions.” International Energy Agency (IEA), 2014.

[11] IEA ETSAP, “IEA ETSAP - Technology Brief E03.” IEA Energy Technology Systems Analysis Programme (ETSAP), Apr-2010.

[12] K. Darrow, R. Tidball, J. Wang, and A. Hampson, “Catalog of CHP Technologies.” U.S. Environmental Protection Agency Combined Heat and Power Partnership, Mar-2015.

[13] EIA, “How much electricity is lost in transmission and distribution in the United States? - FAQ - U.S. Energy Information Administration (EIA),” *U.S. Energy Information Administration*, 29-Jan-2018. [Online]. Available: https://www.eia.gov/tools/faqs/faq.php?id=105&t=3. [Accessed: 13-Apr-2018].

[14] I. Staffell and S. Pfenninger, “Using bias-corrected reanalysis to simulate current and future wind power output,” *Energy*, vol. 114, pp. 1224–1239, Nov. 2016.

[15] S. Pfenninger and I. Staffell, “Long-term patterns of European PV output using 30 years of validated hourly reanalysis and satellite data,” *Energy*, vol. 114, pp. 1251–1265, Nov. 2016.

[16] N. Mosknes *et al.*, “2015 OSeMOSYS User Manual.” KTH Royal Institute of Technology, Nov-2015.

[17] KTH - dESA, “OSeMOSYS documentation.” [Online]. Available: http://osemosys.readthedocs.io/en/latest/. [Accessed: 19-Feb-2018].

APPENDIX A. CAPACITY MIX RESULTS

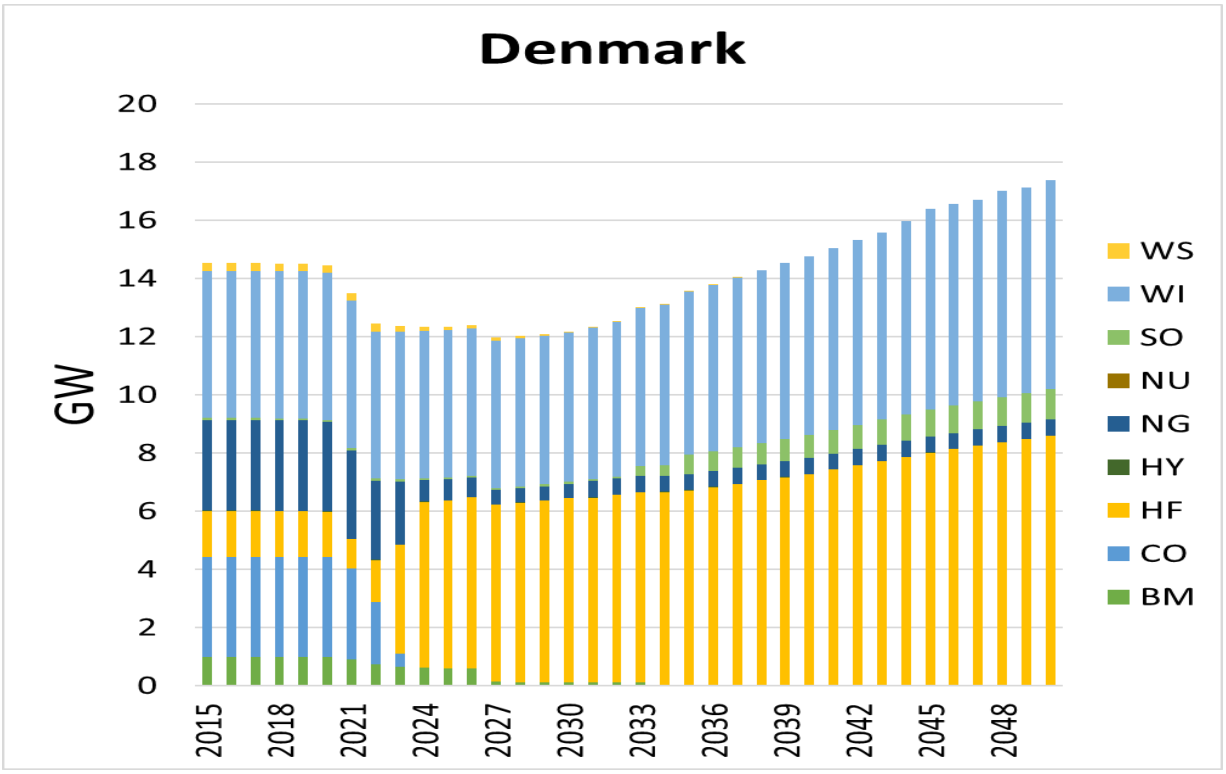


Fig. 6. Installed capacities in Denmark with RM 1.2

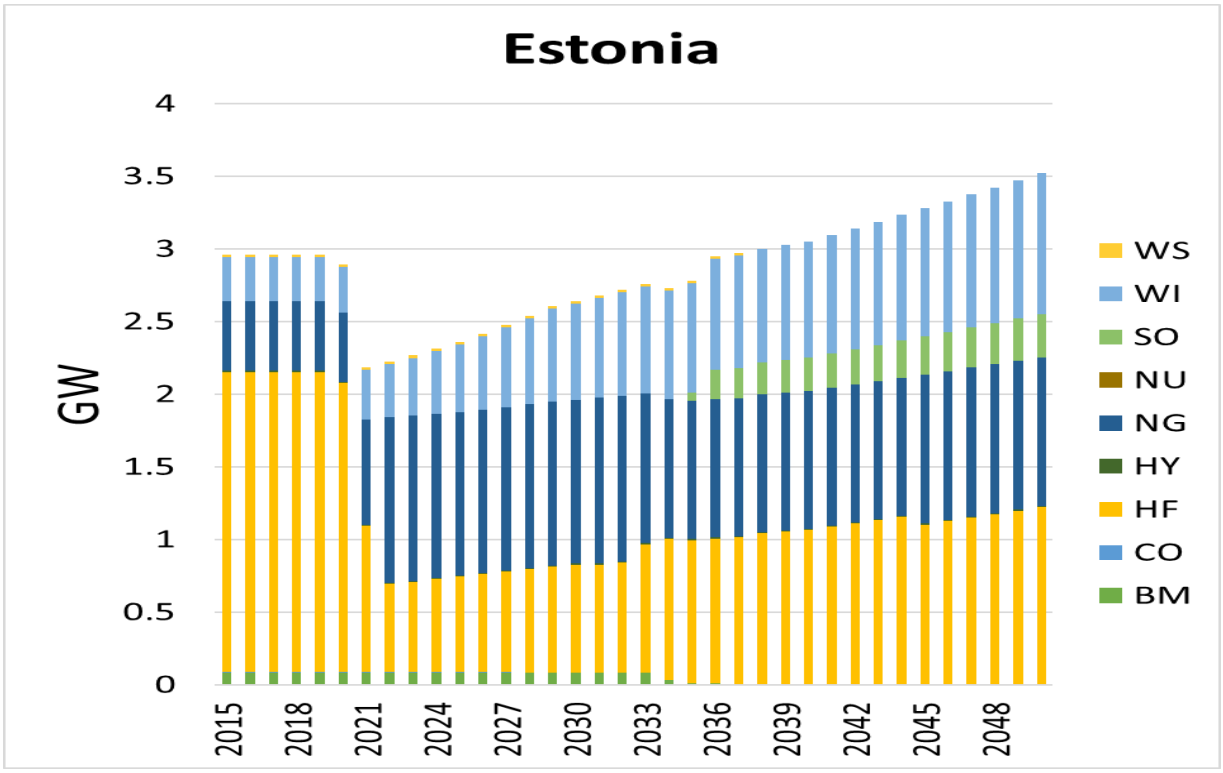


Fig. 7. Installed capacities in Estonia with RM 1.2

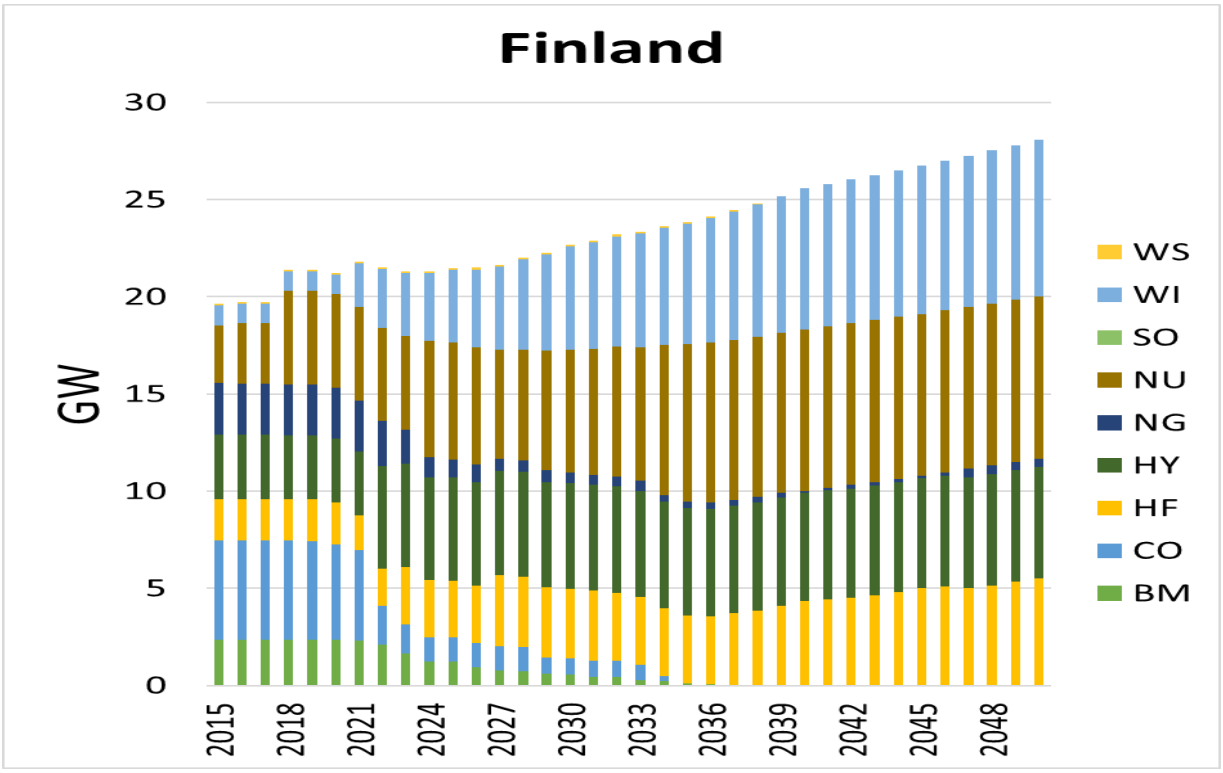


Fig. 8. Installed capacities in Finland with RM 1.2

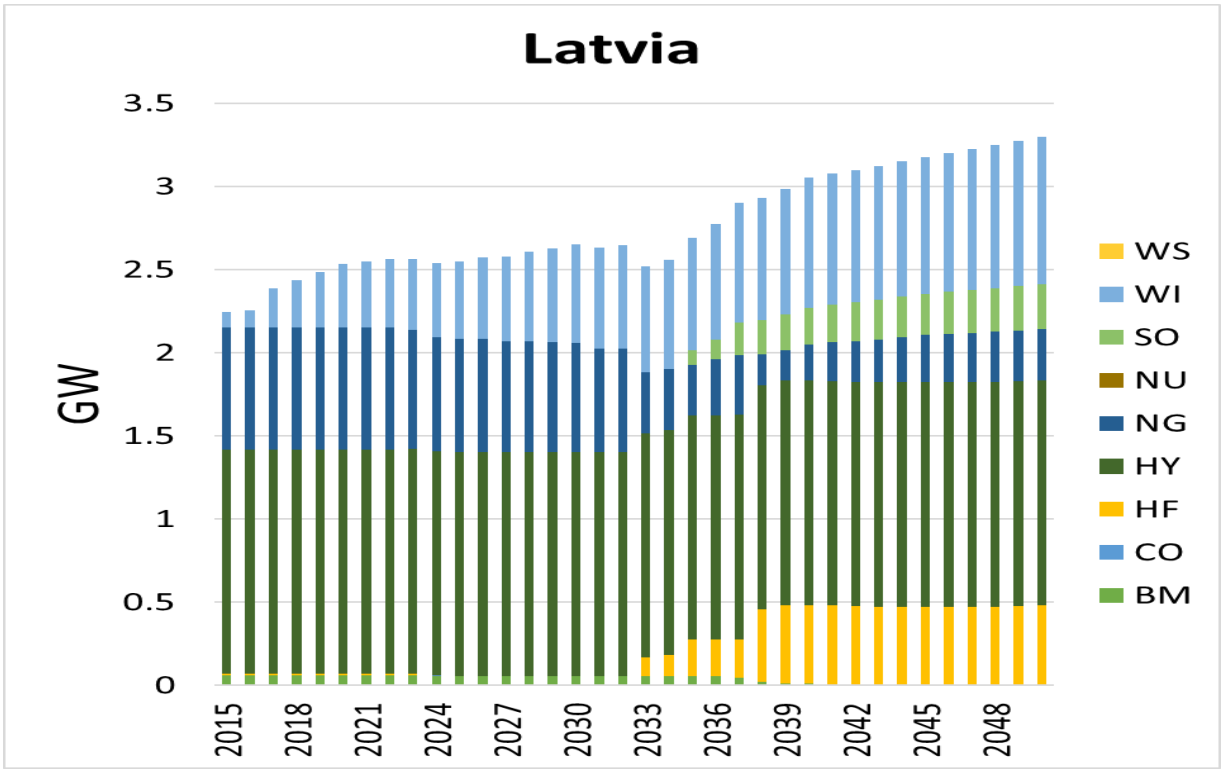


Fig. 9. Installed capacities in Latvia with RM 1.2

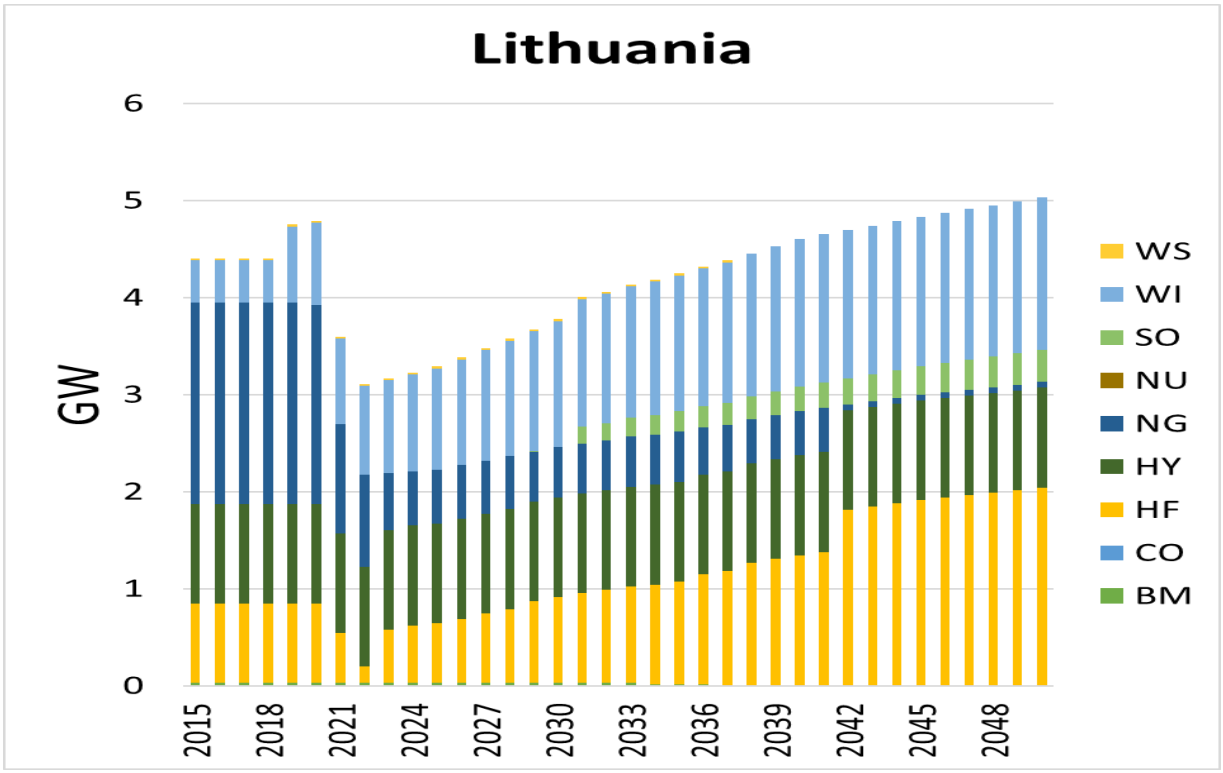


Fig. 10. Installed capacities in Lithuania with RM 1.2

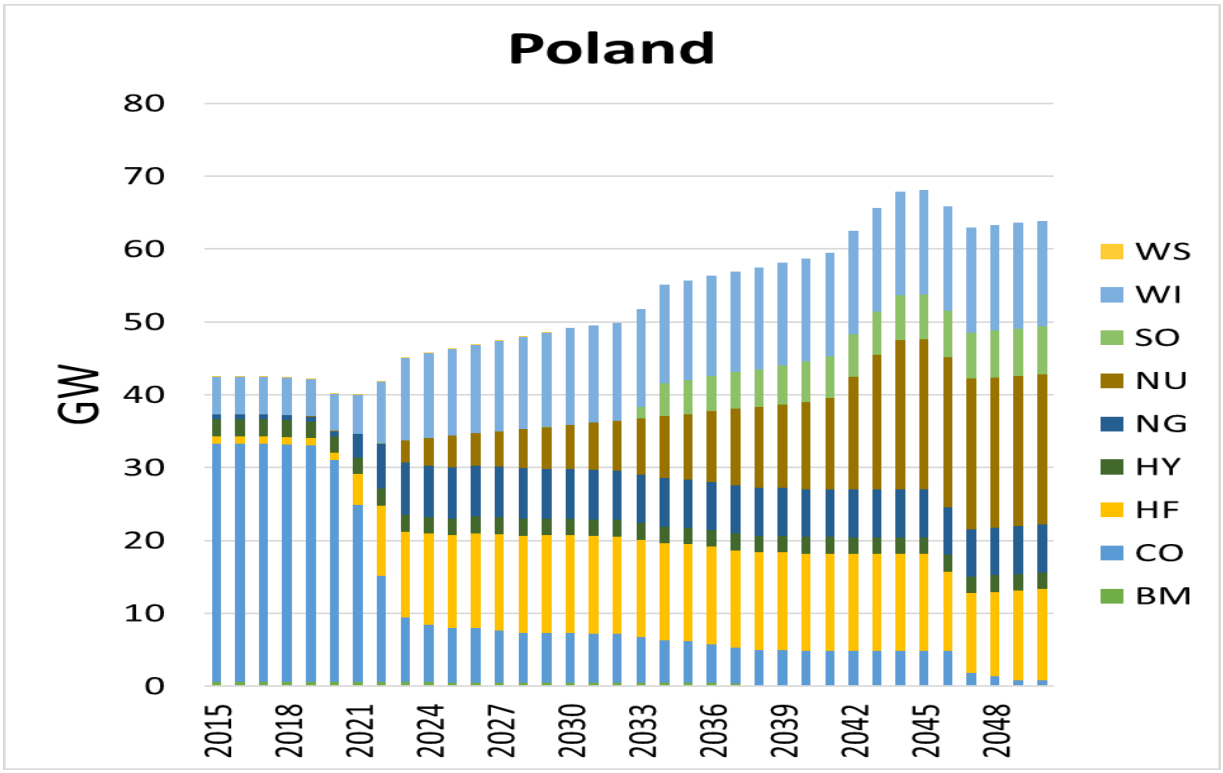


Fig. 11. Installed capacities in Poland with RM 1.2

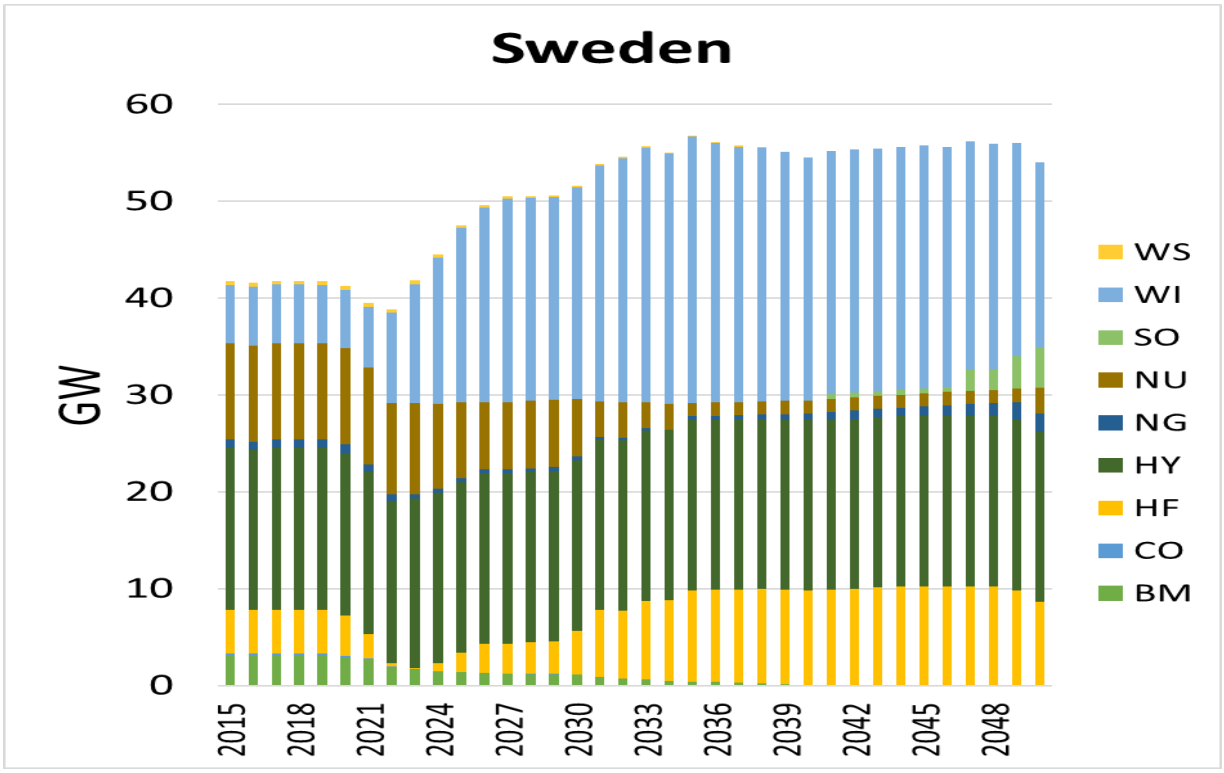


Fig. 12. Installed capacities in Sweden with RM 1.2

APPENDIX B. GENERATION MIX RESULTS

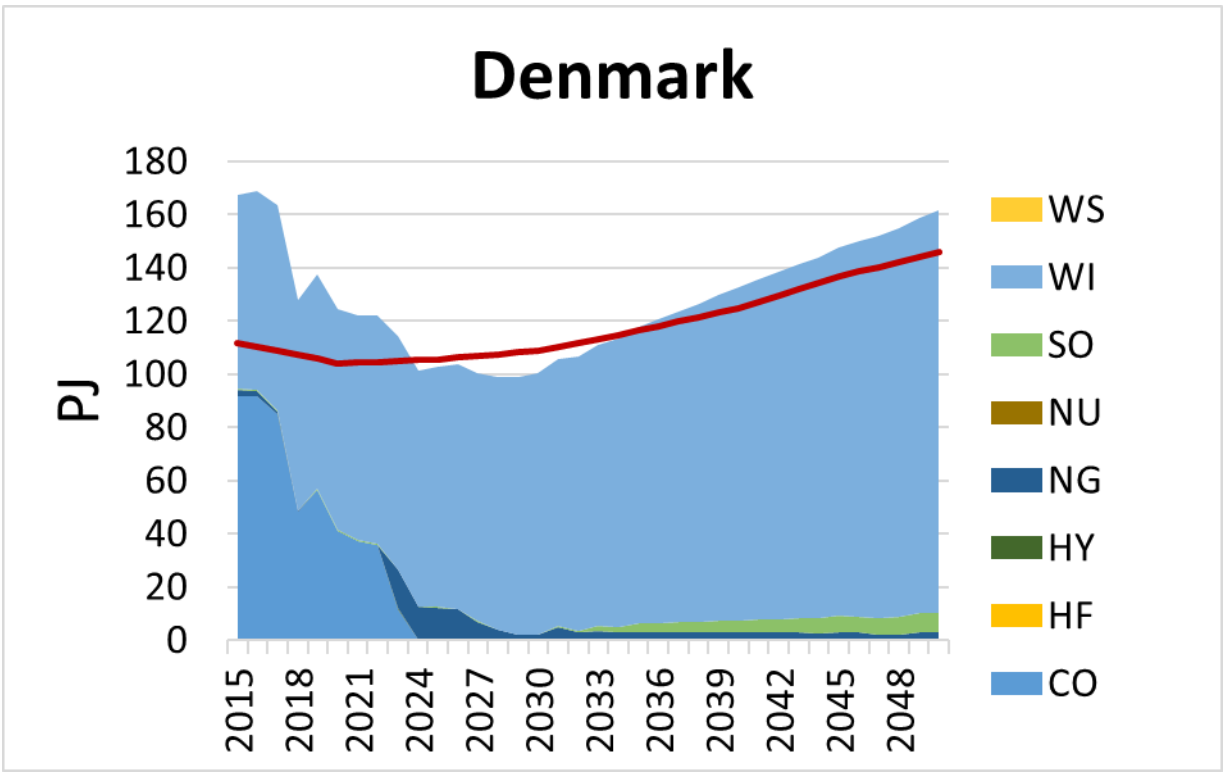


Fig. 13. Annual Production for Denmark with RM 1.2

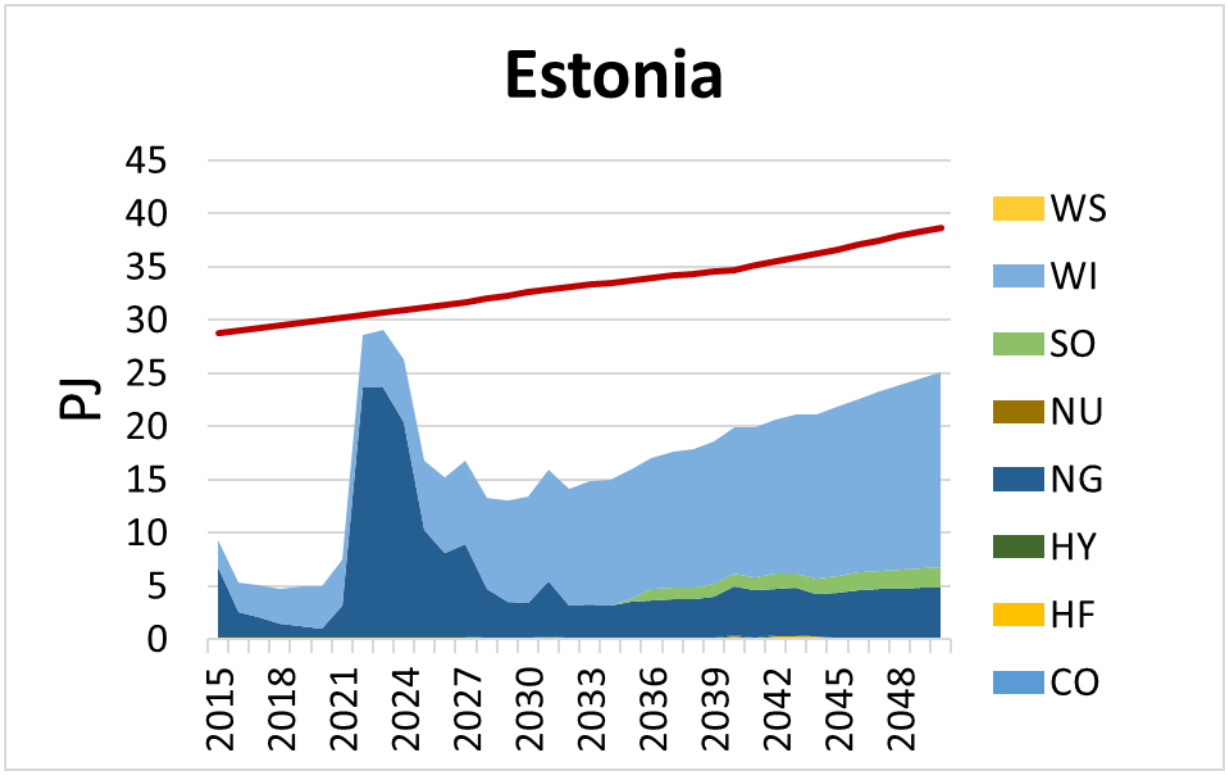


Fig. 14. Annual Production for Estonia with RM 1.2

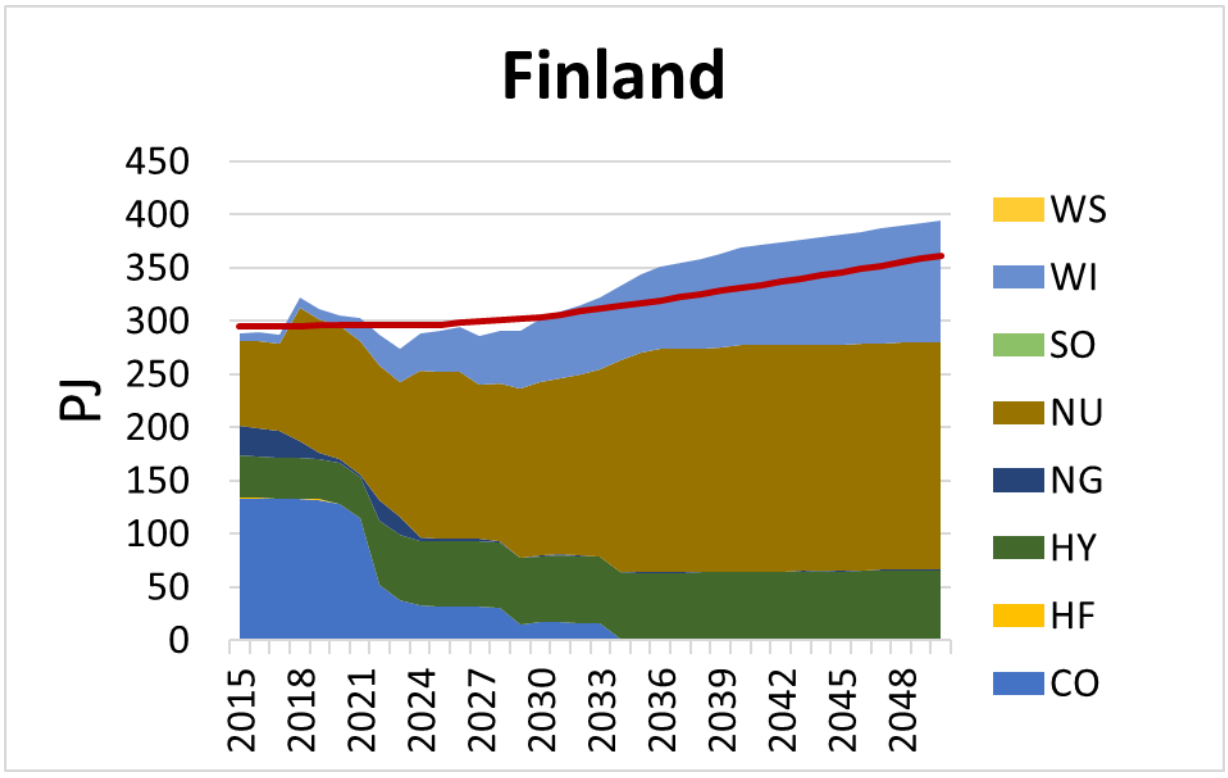


Fig. 15. Annual Production for Estonia with RM 1.2

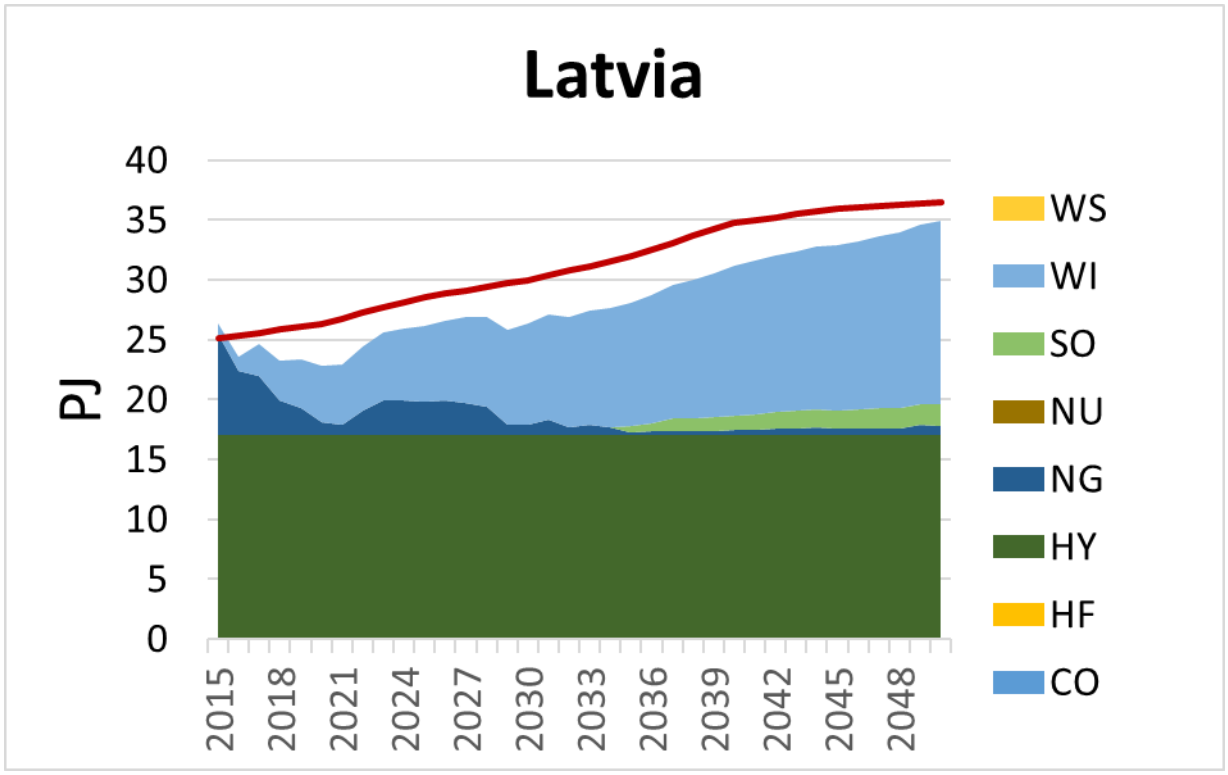


Fig. 16. Annual Production for Latvia with RM 1.2

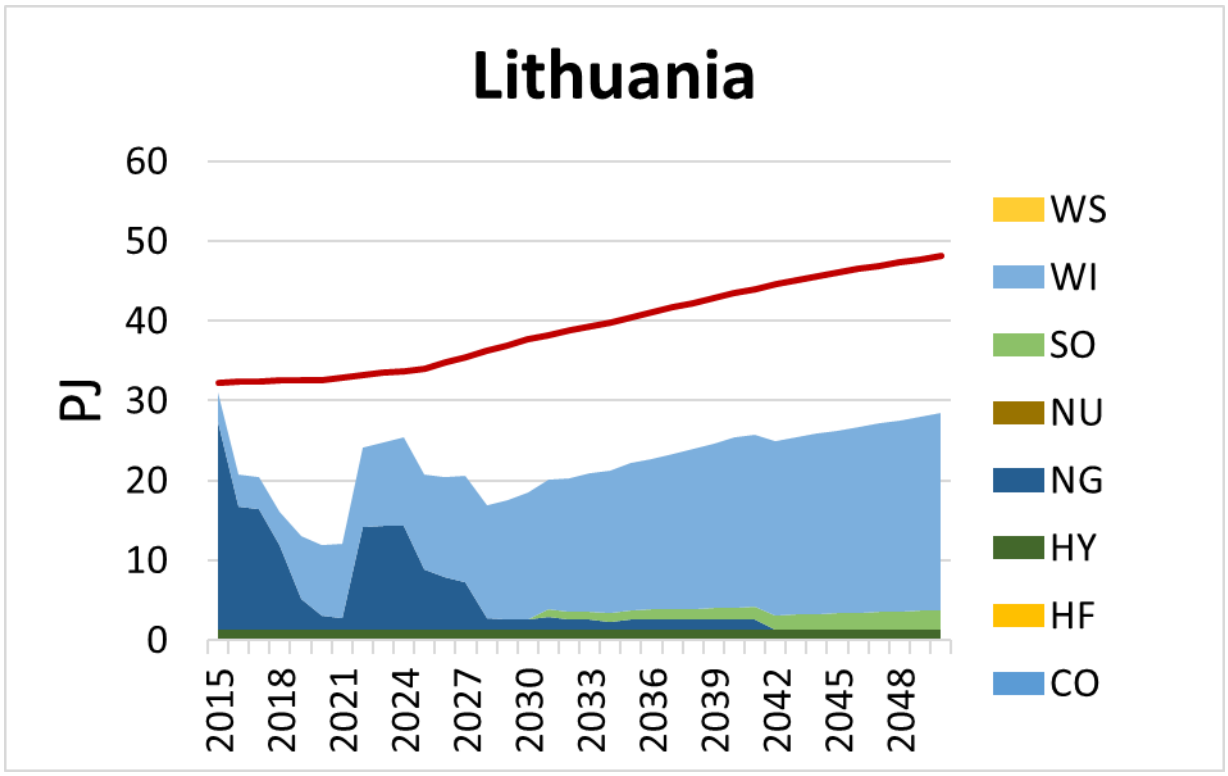


Fig. 17. Annual Production for Lithuania with RM 1.2

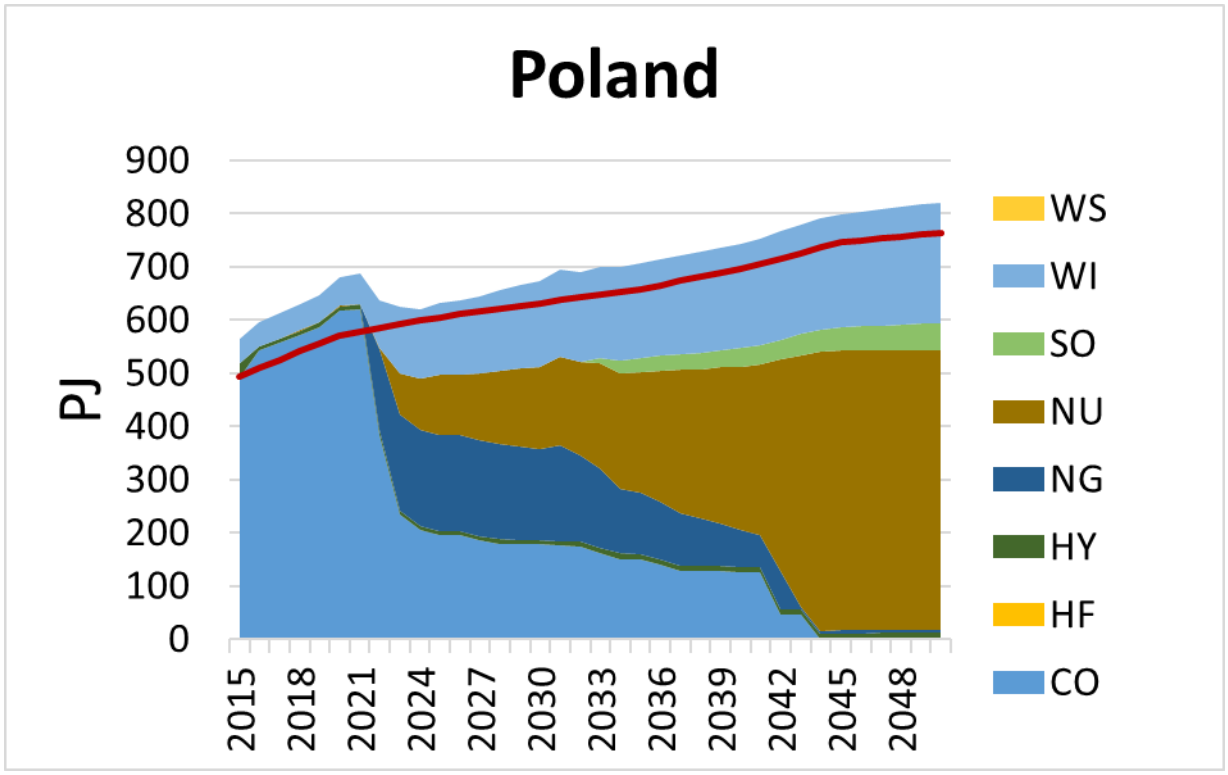


Fig. 18. Annual Production for Poland with RM 1.2

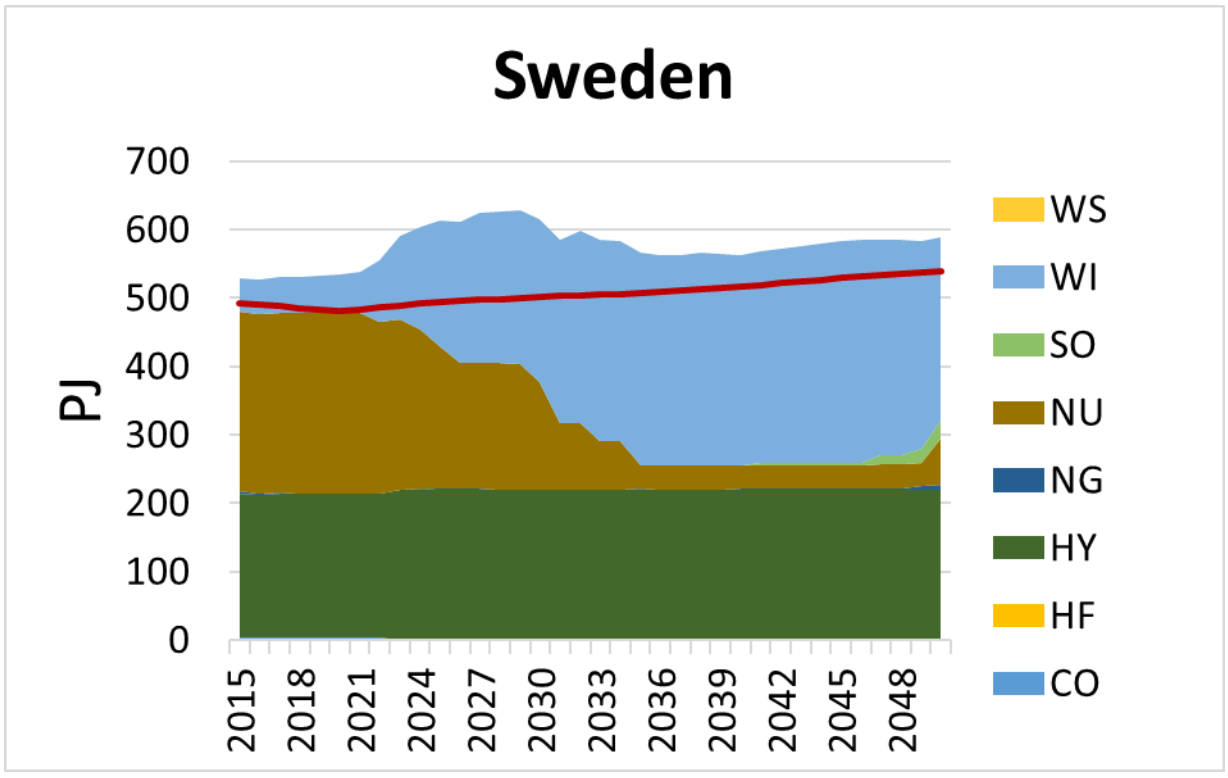


Fig. 19. Annual Production for Sweden with RM 1.2

APPENDIX C. CROSS-BORDER ELECTRICITY TRADE

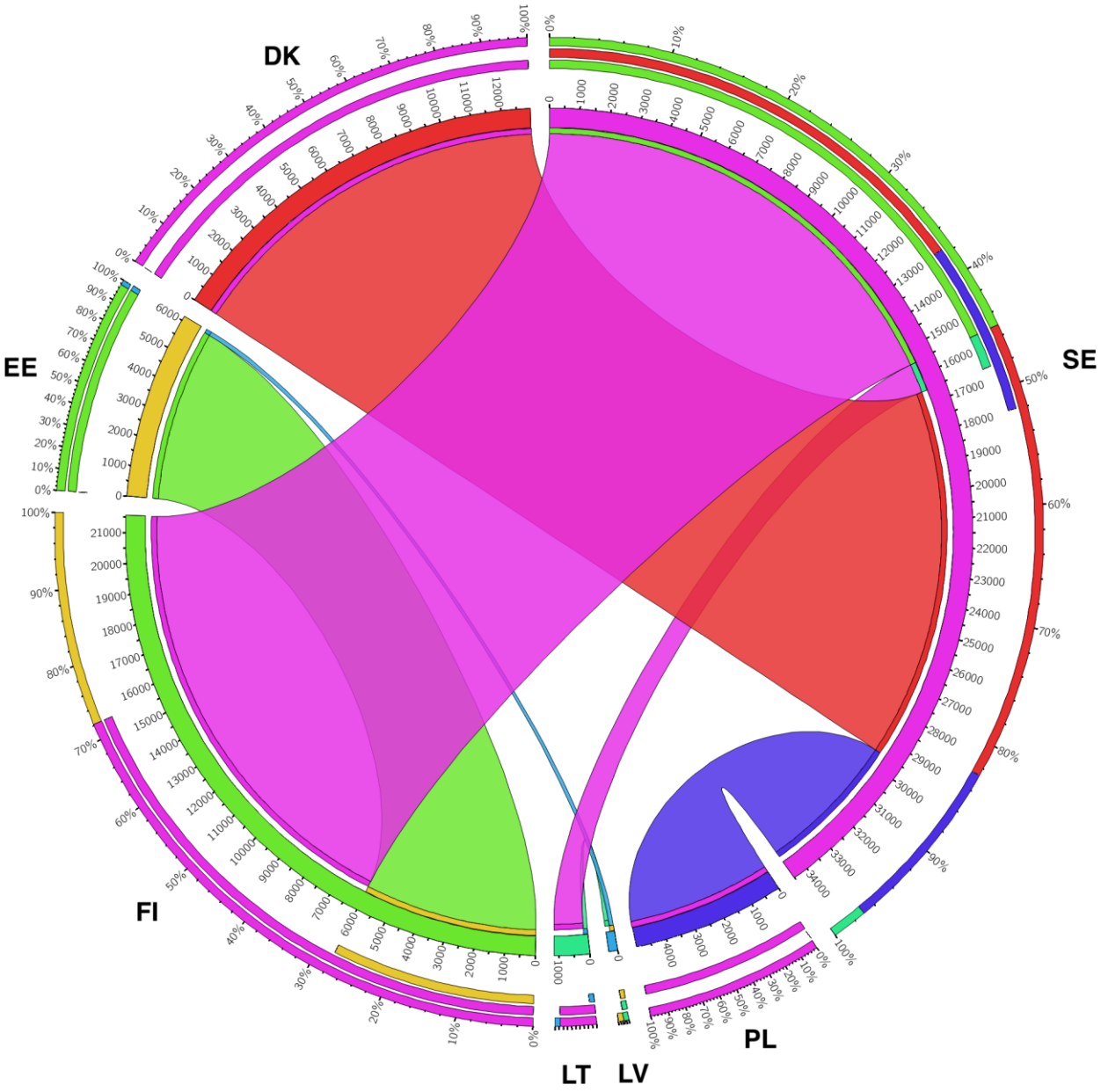


Fig. 20. Transborder electricity flows in the base case scenario in 2015 in GWh

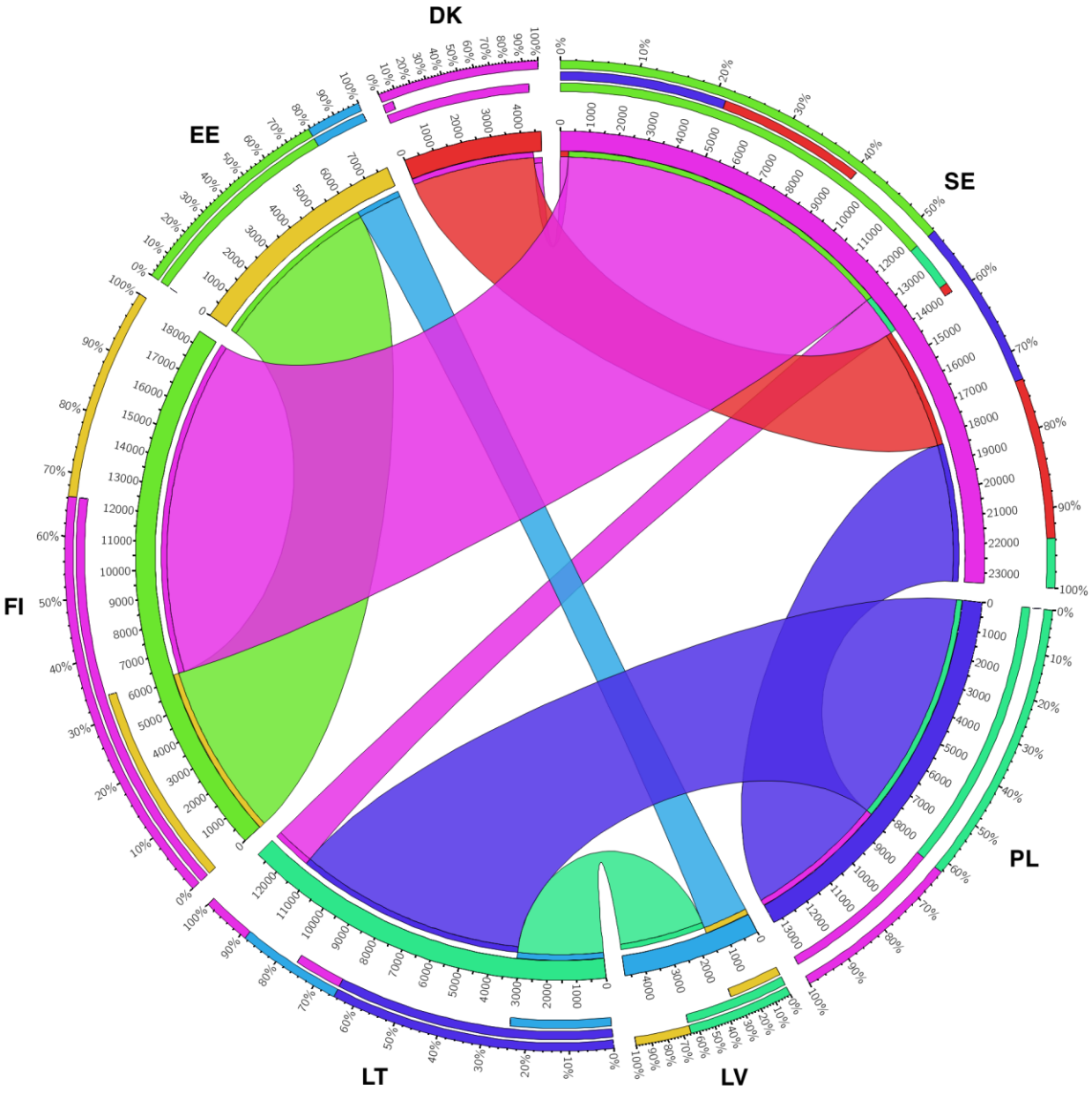


Fig. 21. Transborder electricity flows in the base case scenario in 2020 in GWh

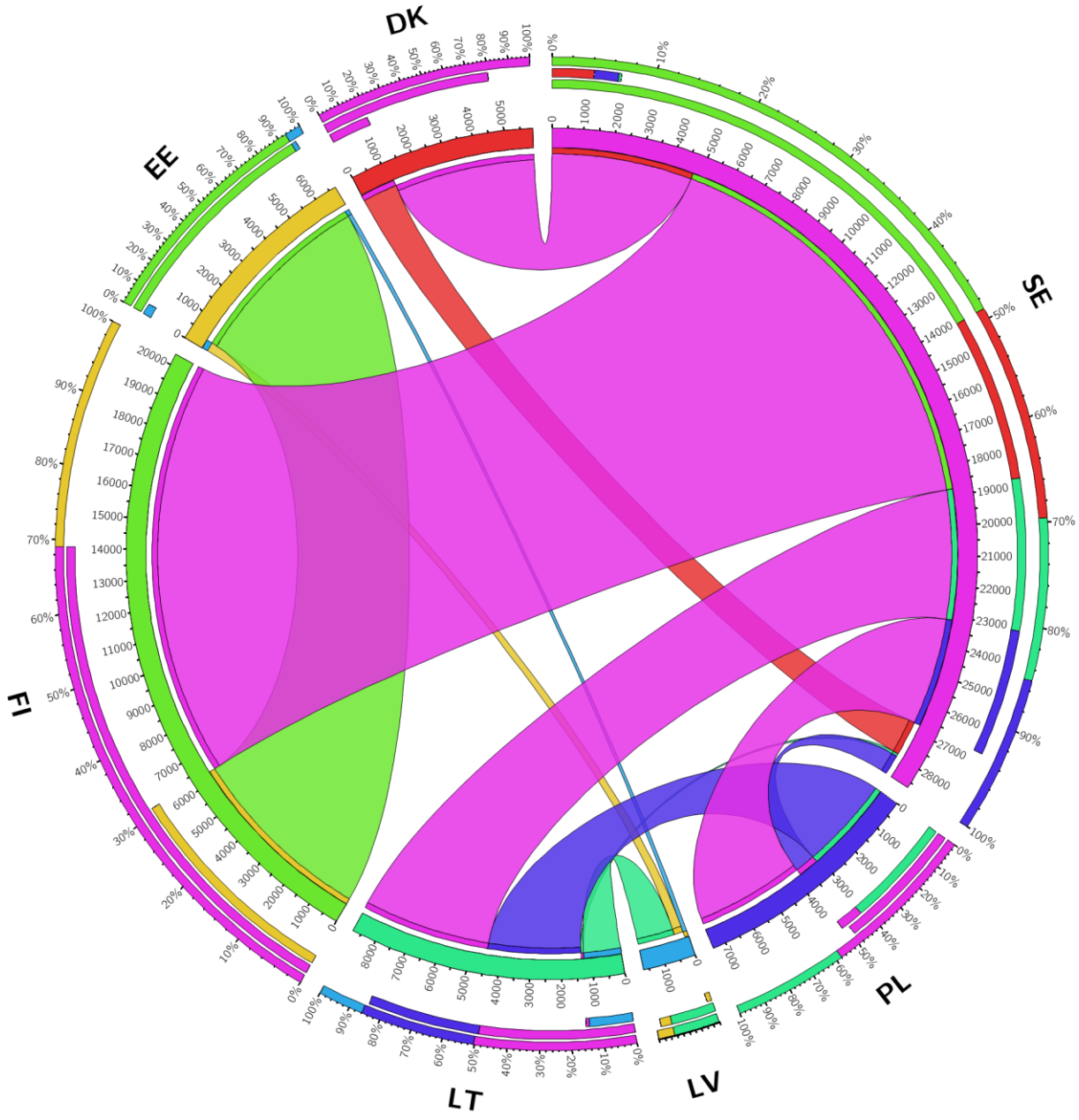


Fig. 22. Transborder electricity flows in the base case scenario in 2030 in GWh

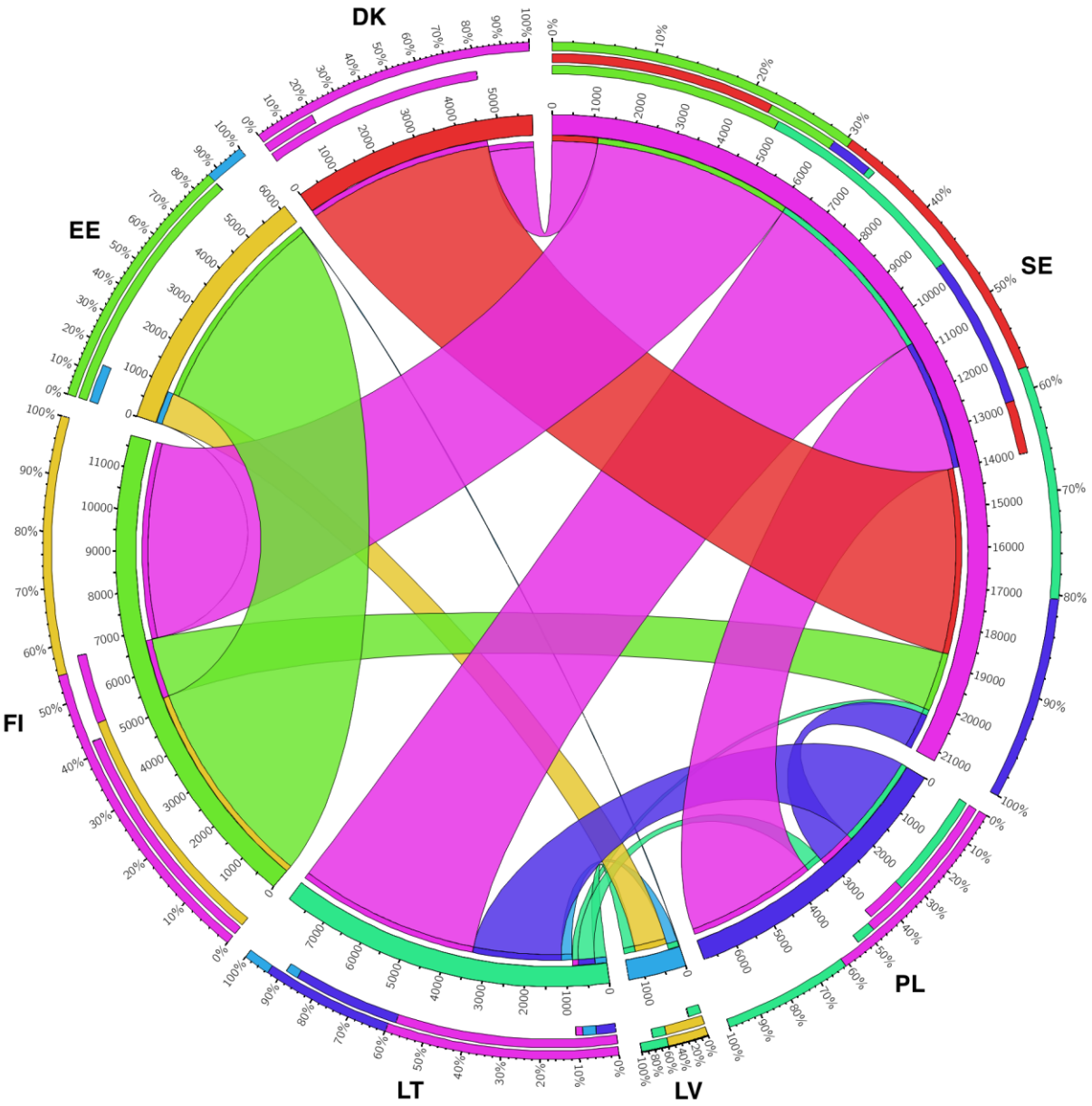


Fig. 23. Transborder electricity flows in the base case scenario in 2050 in GWh