3rd Electric Road Systems Conference 2019
Frankfurt am Main, Germany, 7th to 8th of May 2019

The Impact of ERS on the electricity system – an energy system model comparison for Sweden and Germany

Johanna Olovsson[1], Maria Taljegård[1] and Filip Johnsson[1]

Michael von Bonin[2], Bernhard Ernst[2], Norman Gerhardt[2]

[1]johanna.olovsson@chalmers.se, Department of Space, Earth and Environment Chalmers University of Technology, 412 96 Gothenburg, Sweden

2michael.von.bonin@iee.fraunhofer.de,· Fraunhofer Institute for Energy Economics and Energy System Technology, Königtor 59, 34119 Kassel, Germany

Summary

This study analyses how an electrification of the transport sector, including static charging and electric road systems (ERS), could impact the Swedish and German electricity system. The study applies and compare the results from two different energy system models called ELIN-EPOD and SCOPE. The results show that since an electric road system increases the net load, there is a need for more investments in power and storage technologies. The model comparison shows that different assumptions and methodological choices impact what kind of investments are taken, such as in wind, solar and thermal power plants to cover an additional demand from the use of ERS.

1 Research Questions

The aim of this study is to apply two different optimisation models to investigate how an electrification of the transport sector, including static charging and electric road systems (ERS), could impact the Swedish and German electricity system with respect to energy and power, assuming the same sets of future scenarios for both models. The following research questions (RQ) are investigated:

RQ1. What investment in the future electricity system will be made to cover an additional demand from ERS for heavy transport and static charging of passenger cars? What are the important modelling factors and assumptions that effects the investment decisions?

RQ2. How is ERS impacting the dispatch of electricity system?

RQ3. Does ERS increase or decrease the net load (i.e., electricity demand minus wind and solar generation)?

2 Methodology

The integration of ERS in the Swedish and German electricity system is analysed using (i) a model-package consisting of an electricity system investment model (ELIN) and electricity system dispatch model (EPOD) and (ii) an energy system investment and dispatch model (SCOPE). The models are run for the same sets of scenarios and methodological differences and results will be compared with the purpose of identifying important variables and/or factors affecting the outcome as well as similarities and differences in how the electrification of the transport sector can be accomplished under ambitious CO_2 mitigation targets.

2.1 Description of ELIN-EPOD and SCOPE

The model developed at Chalmers includes a cost-optimisation investment model (**ELIN**) and an electricity dispatch model (**EPOD**) of the European electricity systems, including electricity demand from EVs [1,2]. The investment model has an hourly resolution with 20 representative days and an investment period from 2020-2050. The dispatch model EPOD is run for a full year (2030) with hourly time resolution. The models are based on current and historical data and information of the European electricity system, using the Chalmers power plant database to describe the current electricity generation system. The results from the ELIN model, i.e., the composition of the electricity supply system including transmission lines and fuel and CO_2 prices for the investigated year (2030) are used as input for the optimisation in the dispatch model (EPOD) to determine the least-costly hourly dispatch of the system.

The model, **SCOPE**, has been developed at Fraunhofer IEE [3,4]. The model is a cross-sectoral model designed to analyse and optimize the European energy system. The general model objective is to minimize the total system cost in the energy system for investigated specific year. Input data describing the energy system is used to find the least-cost hourly dispatch of the system for the investigated Year . For 2050 a green-field approach is taken, assuming an empty system as a starting point without any generation capacity in place, besides hydropower and waste. The model is run for a full year with an hourly time resolution.

2.2 Model comparison

Table 1 gives an overview of the ELIN and EPOD model package and the model SCOPE. The performed comparison of the models is based on different parameters, model assumption, technology options and limitations. Table 1 shows some of the characteristics being analysed.

Table 1. Model comparison between SCOPE and ELIN-EPOD

Parameter	ELIN-EPOD	SCOPE
Geographical Scope	Sweden, Germany (transmission to neighbouring countries are included in the optimisation)	EU 28 + Norway and Switzerland excluding Malta and Cyprus
System starting point	Historical data	Green-field (2050)
Sectors	Electricity and part of heating,	Electricity, heat and transport
Main inputs	Cost and properties for different fuels and technologies, hourly electricity and heat demand, CO_2 constraints, vehicle driving patterns	Fuel costs, technology cost, potentials and limitations, energy demand time series
Main outputs	Investments in power and storage technologies, marginal cost of electricity, total system cost, curtailment, production patterns, CO_2 emissions, electric vehicle charging profiles	Electricity generation mix, optimised transport mix, energy framework and capacity, CO_2 emission prices
Time resolution	ELIN is 2020-2050 with 480 timesteps, EPOD is 1 year, 8760h	1 year, 8760h
CO_2 mitigation approach	Budget	Budget
Vehicle-to-grid cost	10 EUR/MWh	10 EUR/MWh
Long-term storage technologies	EV batteries and stationary batteries and power-to-gas	EV batteries, stationary batteries and power-to-gas
Technology limitations	No new investment in nuclear and CCS	No new investment in nuclear and CCS
Vehicle categories	Passenger cars; light trucks; heavy trucks; bus	small passenger car, medium passenger car, large passenger car, light commercial vehicle, heavy commercial trucks
Number of EVs	EV penetration rate (20% by 2030 and 60% by 2050; 60% by 2030 and 100% by 2050); exogenously given	Number of EV is optimised in vehicle inventory model add-on
Traffic demand/implementation	Individually driving profiles	Aggregated vehicle fleet
ERS implementation	ERS for heavy trucks	ERS heavy trucks

2.3 Scenarios and sensitivity analysis

The two models will be run for a set of base cases (i) direct charging, (ii) 40% optimised charging, (iii) possibility to use V2G, as well as, varying different parameters such as (i) investment in CCS technology, (ii) varying investment costs for wind and solar power, (iii) different cost for vehicle-to-grid, (iv) ERS for all transport modes, for sensitivity analysis.

3 Results

The results presented in this section are from an earlier stage of the modelling applying somewhat different assumptions than listed in Table 1. An updated version of the results will be presented at the conference, i.e. applying assumptions in Table 1 and updated scenarios. This will allow a more detailed and comprehensive analysis and comparison of the model and their outputs.

3.1 Investments in the electricity system

Figure 1 shows the total capacity installed in Sweden and Germany for 2050 for both investment models ELIN and SCOPE. Both model result show that the installed capacity, due to electrification of the transport sector, differs between the two countries. The SCOPE model yields significantly higher total capacity than the ELIN model. The main reason for this difference is due to the higher installation of solar and wind power that produce less energy per installed capacity. The reason for the higher installation in solar and wind power in the SCOPE model is due to that CCS is not an option in this model (*cf.* Table 1). Also, there are differences in the cost for wind and solar PV between the models. The assumed costs for solar PV are lower in the SCOPE model compared to the ELIN model, where the SCOPE costs are lower since they were adjusted based on costs obtained from recent tenders for PV in Germany. Furthermore, different driving profiles are used for passenger cars. The ELIN model includes individual driving profiles, while the SCOPE-model uses an aggregated vehicle fleet. The ELIN and EPOD models consider ERS for both trucks and buses and passenger cars, while in the SCOPE model ERS is limited to trucks.

As a consequence, from the difference in assumptions, the main differences in the model results in Figure 1 is that the electricity generation portfolio obtained from the ELIN model includes CCS combined with biomass, whereas there is obviously no CCS in the SCOPE results. In addition, the ELIN results give a certain amount of biomass which is used to offset the fossil emissions which actually come from CCS since the capture rate of CCS is assumed to be limited to 90%. Yet, taken together the model results show that there are different ways to receive an electricity generation system with zero emissions which also provides electricity for the transportation sector while not emitting CO_2 to the atmosphere.

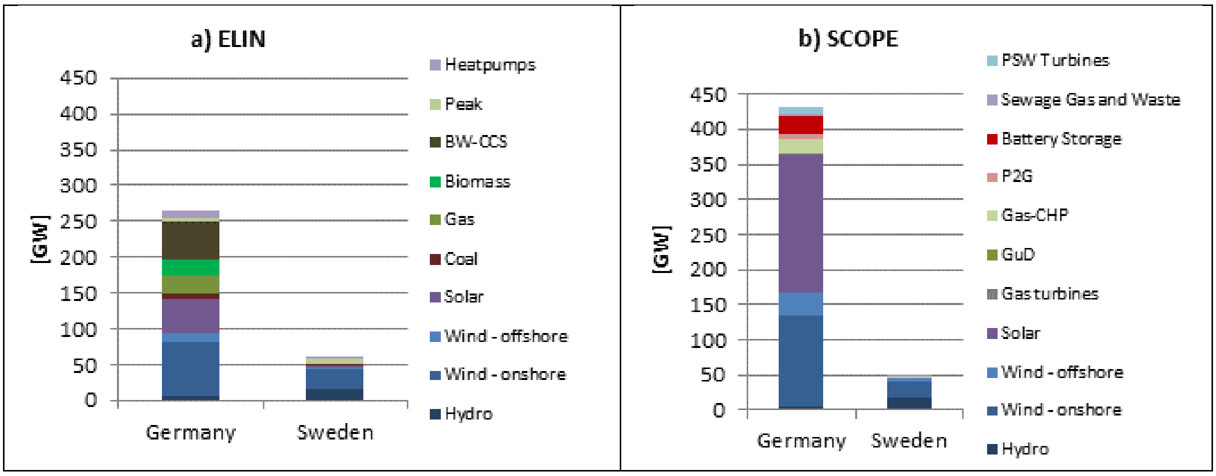

Figure 1. Total capacity in 2050 for Germany and Sweden with electric vehicles and optimized charging. BW-CCS= bio co-fired lignite with carbon capture and storage; a) ELIN Model; b) SCOPE Model**.**

3.2 Impact of ERS on the net load

Figures 2 and 3 show how a controlled charging of EV can help to smooth the generation of wind and solar PV based on an example week in February in Scandinavia from the EPOD-model and Germany from the SCOPE-model, respectively. As seen in Figure 2 and 3, ERS will increase the net load assuming current traveling patterns. However, from Figure 2 it can be concluded that passenger EVs will, if V2G is applied, smoothen the net load curve in the Scandinavian and German electricity system so that the hour with maximum net load is reduced with 9 GW (from 127 GW to 118 GW). If no V2G is applied, the ERS would then increase peak in the net load curve with 25 GW in Scandinavia and Germany.

Differences between the models are that the SCOPE model shows a negative net load when EV is not included while EPOD net load always stays positive. For both models the connection of net load and EV charging power are obvious. A negative net load, as seen in Figure 3, leads to charging power of about 80 GW. On the other hand, a positive net load, as seen in Figure 2, leads to charging power of less than 20 GW.

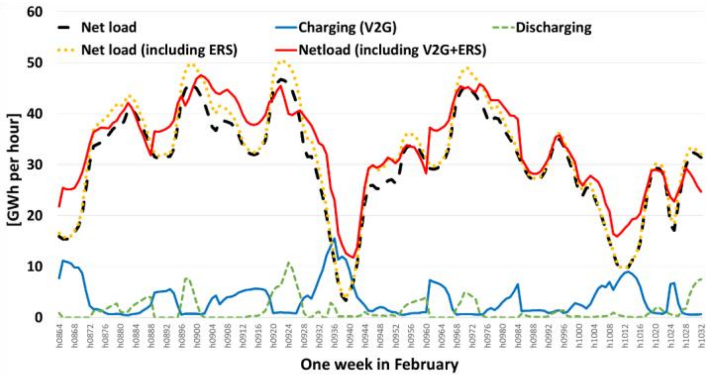

Figure 2. Net load (i.e., load minus wind and solar generation), including electric road systems (ERS) for trucks and buses, and the load from charging the EVs and the discharging back to the grid for one week in February in Scandinavia as obtained from the EPOD model.

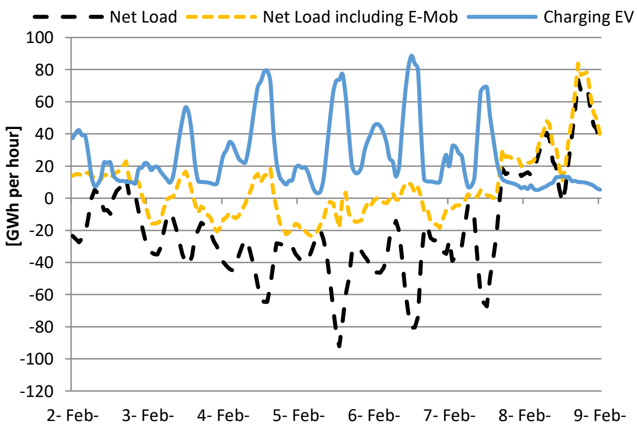

Figure 3: Modified net load (i.e., load minus wind and PV generation) without EV, net load including demand for EV (trucks and cars) and the load from charging EV for one week in February in Germany for the model SCOPE

The electricity system analysis performed with ELIN-EPOD models only includes the electricity sector with electricity for transportation exogenously given. Thus, it Is not known to how biomass will be prioritized between sectors, i.e. it may not be used for electricity or heat production in the future. None of the models include demand response (DR) but assumes a fixed demand. Application of DR may influence the results. The models have limited and predefined technology options which might exclude future possible combination and investments in new technologies that might ease the implementation of ERS in a future electricity system.

Acknowledgments

This study has been performed within the Swedish-German Research Collaboration on Electric Road Systems. We gratefully acknowledge the Norwegian Public Road Administration ("Norsk Vegvesen"),the Swedish Road Administration ("Trafikverket") and German Federal Ministry of Environment, Nature Conservation and Nuclear Safety for financial support.

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Authors

	**Johanna Olovsson, M.Sc.** Johanna Olovsson has a M.Sc in Energy and Environmental Systems and Technology and is employed as a project assistant at the Department of Space, Earth and Environment, Chalmers University of Technology. She is working with WP 2.4 within the Swedish-German esearch collaboration on electric road systems.
	**Maria Taljegard, M.Sc.** Maria Taljegard has a M.Sc. in Environmental Studies and is a PhD student at the Department of Space, Earth and Environment, Chalmers University of Technology. She is doing research on the integration of electric vehicles and renewable energy in the energy system by using energy system modelling and assessment. The research is part of the infrastructure project “Ferry-Free E39”.
	**Prof. Filip Johnsson** Prof. Johnsson is Professor at the Department of Space, Earth and Environment, Chalmers University of Technology. His research concerns the transformation of the European energy system. He is leading the research programs Pathways to Sustainable European Energy Systems and Mistra Carbon Exit. He is also the Swedish leader in WP 2.4 in the Swedish-German collaboration on electric road systems.
	**Michael von Bonin, M. Sc.** Has a M.Sc. in Renewable Energies and Energy Efficiency at the University of Kassel and is a scientist at Fraunhofer Institute of Energy Economics and Energy System Technology IEE. His work focuses on direct marketing of renewable energies and feedback effects of the mobility sector on the energy sector.
	**Dr. Bernhard Ernst** Dr. Bernhard Ernst is manager of the group Studies Grid Planning and Operation at Fraunhofer Institute for Energy Economics and Energy System Technology (IEE). Prior to this he was the director of the department Grid Integration at SMA Solar Technology AG, one of the world’s largest manufacturers of PV power converters. Before joining SMA he was manager of the Front Office System Planning at Amprion GmbH (formerly RWE TSO), one of the four German transmission system operators.
	**Norman Gerhardt, M. Sc.** Is manager of the group Energy Economics and Energy System Analysis at Fraunhofer Institute for Energy Economics and Energy System Technology (IEE).