Impact of Implementation of ERS on the German and Swedish Electricity System

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***Abstract*—The climate benefit from an introduction of Electric Road Systems (ERS) and an increase in the share of electromobility will be determined by the impact on the electricity generation which will be different between countries, depending on the characteristics of the electricity system such as the conditions for renewable electricity.**

An electrification of the transport sector through electric vehicles (EVs) with static charging and/or ERS introduces a new demand to the electricity system, and hence, will create new load profiles depending on the time of consumption and the amount of electricity used in EVs. Depending on electrification strategy, this new demand may introduce a potential for EVs to provide demand-side management to the power grid. The overall aim of this work is to apply two different electricity systems models to investigate how an electrification of the transport sector could impact the Swedish and German electricity system with respect to energy and power

Electric road systems, grid integration of e-mobility

I. INTRODUCTION AND METHOD (MODELS)

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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. Both Chalmers models have previously been used to study the transformation of the European electricity system to meet European policy targets on CO2 emissions (see Odenberger et al., 2009 and Unger et al., 2011, for a description of the original models and Göransson et al., 2014, Nyholm et al., 2016 and Taljegard 2017 for further developments of the model package). 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 with hourly time resolution. To include electrified transportation systems, the two electricity models are expanded with an add-on module to include also an electrified road transport sector in the form of static and dynamic charging of passenger vehicles, trucks and buses. Thus, a demand for electric transportation has been added to both the investment model and the dispatch model. The EV demand can potentially offer benefits for the electricity system in terms of system flexibility, e.g. demand response services in the form of strategic charging and possibly also discharge back to the grid (i.e. vehicle-to-grid; V2G) according to what is most optimal from an electricity system point of view.

Figure 1 shows a schematic picture of the modelling-package, including ELIN, EPOD and the transportation module.

The second model SCOPE has been developed at Fraunhofer IEE. The model, which is an investment and dispatch model, is used to evaluate interaction between the transport sector with the electricity supply and heat sector, in a European setting for an eligible year (see Fig. 2). SCOPE is a customizable linear programming model for multi-energy systems. The general model objective is the minimization of all investment and dispatch costs of all considered units from a social planners prospective. The optimization model has an hourly resolution and is solved for an entire year. Today's generation system and remaining run times are considered. New capacity will be installed according to the lowest LCOE.

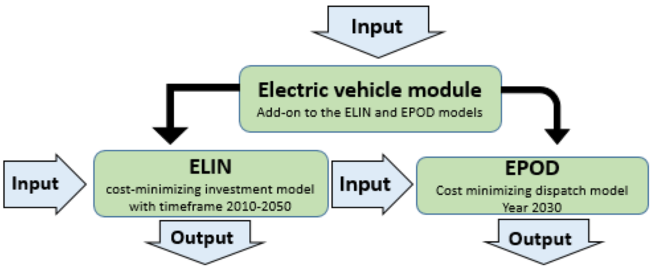

Figure 1. A schematic picture of the ELIN-EPOD modelling-package applied in the electricity modelling.

This study focuses on the modelling results for Sweden and Germany (although transmission to neighbouring countries are also included in the modelling). It should be stressed that Europe has an integrated electricity markets and, thus, in order to provide a meaningful analysis, it is important to model and analyse results not only for Sweden and Germany in isolation. A cap on CO2 corresponding to 99% emission reduction by 2050 relative 1990 emissions for the electricity sector is assumed. There are indeed different bottlenecks in electricity transfer regions throughout Europe (including transfer from and two Sweden and Germany) which is included in the modelling (as well as the model can invest in new transmission capacity).

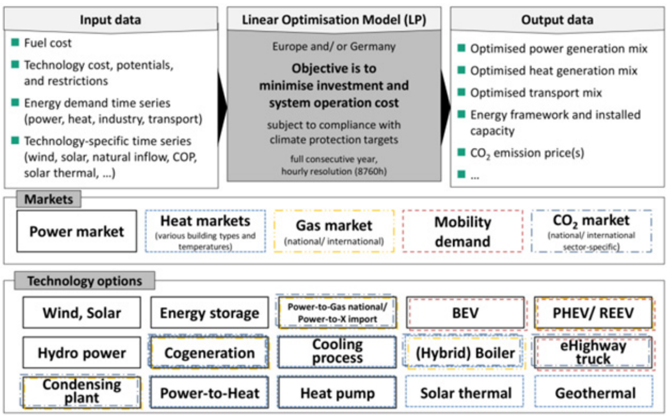

Figure 2. Overview of the SCOPE model for investment and dispatch optimization across energy sectors

II. SCENARIOS

The ELIN and EPOD models are run assuming three charging strategies for passenger EVs: (i) an optimisation of the charging time to minimise the cost of meeting the electricity demand (base-scenario); (ii) a direct charging of the electric vehicles according to their driving patterns (direct); (iii) optimised charging and a passenger vehicle-to-grid strategy including the possibility to discharge the EVs to the grid (V2G). To compare there is also one scenario without EV. All of the model runs includes electric road systems (ERS) as being the main option for trucks and buses. The ERS is used as a range extender for passenger EVs for those trips that cannot be completed using only electricity from the battery, due to the battery size and driving pattern (in the case without ERS, these trips are assumed to be covered by e.g. renting a combustion vehicle or taking the train). The -scenarios are named: Direct-ERS, Optimised-ERS (which is the base case scenario to compare with), V2G-ERS and a scenario without EV.

The model SCOPE uses a scenario where ERS is only used for heavy trucks, whereas passenger cars and light commercial vehicles use batteries that are charged stationary. The base scenario offers high flexibility and is compared to one scenario with reduced flexibility (reduced flex) and one scenario that permits V2G. It should be noted that this model does not include the possibility to use CCS, as this technology is assumed not to be an option in Germany due to lack of public acceptance for on-shore storage of CO2 (See also Böttger et al. 2018).

III. RESULTS

Figure 3 shows the total capacity installed in Sweden and Germany for 2050 for both investment models ELIN and SCOPE, while Figure 4 shows the difference of total installed capacity between different scenarios for the two countries as obtained from the ELIN model for year 2050. Figure 5 shows the difference in total capacity as obtained from the SCOPE model between the base scenario and the two EV-scenarios with reduced flexibility and optimized+ V2G for year 2050. Both models show that the installed capacity, due to electrification of the transport sector, differs between the two countries as can be seen from Figs 3 and 4. The SCOPE model yields significantly higher total capacity than the ELIN model. The main reason for this is due to the higher installation of solar and wind power that produce less energy per installed capacity. Further differences are that the SCOPE model does not take into account CCS which, as mentioned above, is due to that currently CCS applying on-shore storage of CO2 is in principle not foreseen in Germany. Also, there are differences in the cost for wind and solar PV between the models. The assumed costs for solar PV is lower in the SCOPE model compared to the ELIN model, where the SCOPE costs are lower since they were adjusted inspired by recent results from tenders for PV in Germany. On the load side the differences in assumptions between the models include that for SCOPE heat pumps and air conditioning are modelled as flexible consumers that could shift consumption in time. 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 3 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%. Thus, biomass need to be co-fired in the CCS plants in order to obtain electricity generation without net emissions to the atmosphere. Due to that CCS power plants (ELIN and EPOD model) have significantly higher full load hours than wind and solar which dominate the SCOPE results, the overall installed capacity is much higher in the SCOPE results as seen in Figure 3. However, 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.

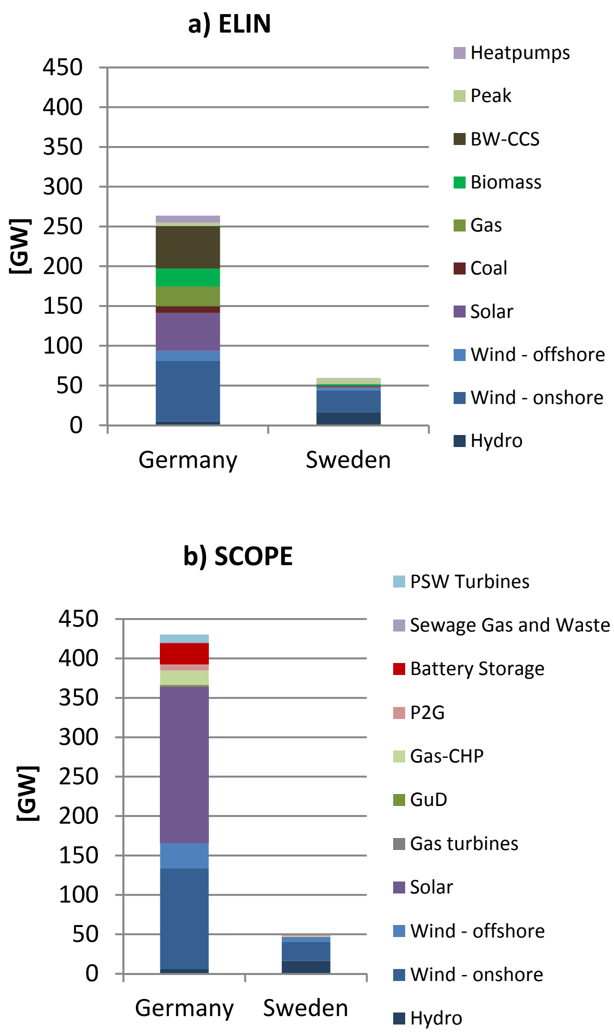

Figure 3 Total capacity in 2050 in a scenario with electric vehicles and optimized charging. BW-CCS= bio co-fired lignite with carbon capture and storage; a) ELIN Model; b) SCOPE Model.

For the ELIN results for Sweden, an additional demand from static charging of EVs and ERS is mainly met by additional investments in wind power. Electricity from wind power in Sweden increases with 7-30% in the EV scenarios compared to the scenario without EV, which is slightly more (few percent) than the increase in demand from EVs. The curtailment of wind power is reduced by 20-45% compared to a scenario without EVs. In Germany, a large part of the new EV demand is met by investments in thermal power, rather than variable renewable power, mainly due to lack of good sites for wind power (the wind power potential is limited to 10% of the land area) in relation to the increase of the demand. Storage in the EV batteries for periods longer than a day is needed in order for the EV batteries to help push in more wind power in the system. The value of investing in solar power is reduced in Germany with EVs due the fact that in Northern Europe, with poor conditions for solar power, solar power is mainly used to meet daytime peak load. Under the conditions in Germany, solar power competes with EVs to provide variation management and the modelling shows that it is less expensive to meet the peak power demand with charging and discharging EVs than by using solar power. In the scenario including V2G, the EV batteries can substantially help to reduce the need for peak power capacity in the system (a reduction of more than 90%) by discharging back to the grid, as seen in Fig. 4.

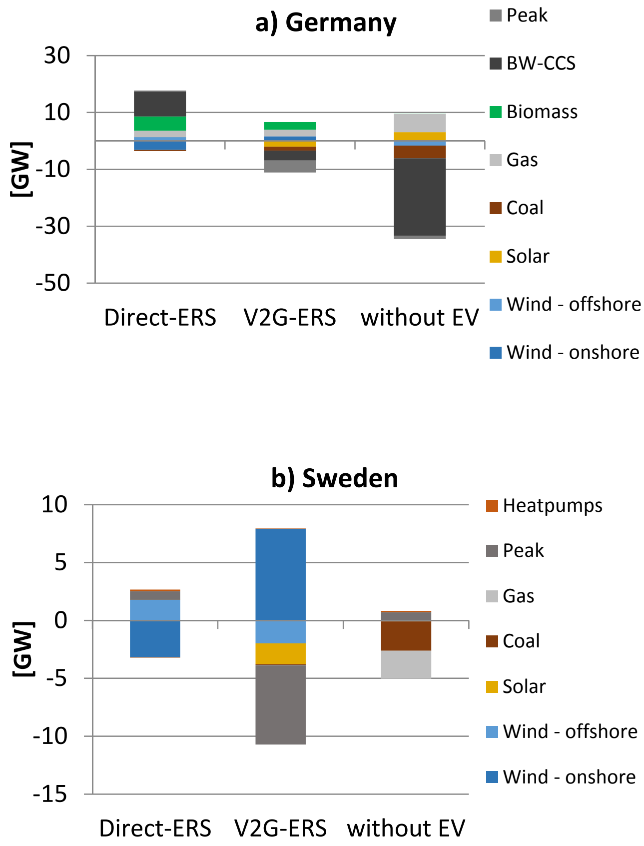

Figure 4. The difference in total capacity year 2050 as obtained from the ELIN model between a scenario with optimized charging of EVs and the threescenarios with direct charging, optimized charging+V2G and without EV for (a) Germany, and (b) Sweden. Opt= optimization of the EV charging to minimize system cost; BW-CCS=bio co-fired lignite with carbon capture and storage; V2G=vehicle-to-grid; ERS=electric road system.

ERS for heavy vehicles increases the peak power demand compared to the scenario without EVs, if no optimisation of the passenger vehicle charging. However, if all trucks and buses use dynamic power transfer and V2G is applied for the passenger vehicles, both the total investment and the investments in peak power will decrease to a larger extent than when only optimising the charging as seen in Fig 4.

The SCOPE modelling results in Fig. 3 show higher installed capacity for PV, around 200 GW (and onshore and offshore wind of some 150 GW). Stationary battery storage accounts for 27.3 GW (for the most part more than 4 h battery capacity). The modelling also shows that German

Power-to-Gas (PtG) systems have an economic potential of 7.3 GW for assumed Power-to-X import prices at which they compete (primarily based on relevant shares of "surplus electricity"). Fig. 5 also shows that the use of V2G can significantly reduce the needed capacity of stationary battery storages while more PV is installed. In the scenario with reduced flexibility (“reduced Flex) there is a higher demand of PV capacity and Battery storage. Smaller deviations between the scenarios can be seen in power plants, wind onshore or PtG.

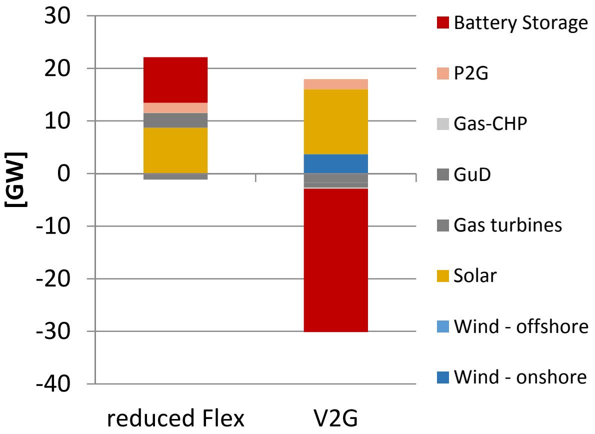

Figure 5. The difference in total capacity as obtained from the SCOPE model between the base scenario (with EVs and optimized charging) and two EV-scenarios with reduced flexibility and optimized+ V2G investigated for Germany V2G=vehicle-to-grid;

Figure 6 shows an example of the net load (i.e. load minus wind and solar generation) as obtained from the EPOD model. The net load includes the load from V2G and ERS, and the charging and discharging back to the electricity grid for one week in February in Scandinavia (i.e. Denmark, Norway and Sweden). The reason for including these three countries is that they are interconnected with import/export between the countries (including connections to Germany although not included in the plot). As seen in Fig. 4, the passenger EVs are discharged to the grid when the net load is high, which reduces investments need in peak power capacity. The amount of discharging ranges from 31 to 48 TWh in Year 2030 for the Scandinavian countries and Germany. This number is small compared to the total generation of approximately 900 TWh per year, although it gives a flexibility to the system which is important for reducing peak power demand and curtailment of wind power. For example, passenger EVs will 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 V2G is applied. With the optimized charging strategy (and no V2G), the peak net load will instead be reduced with 2 GW. ERS will on the other hand, as seen in Fig. 4, increase the current net load assuming the current traveling patterns. If no V2G is applied, the ERS would then increase peak in the net load curve with 25 GW in Scandinavia and Germany.

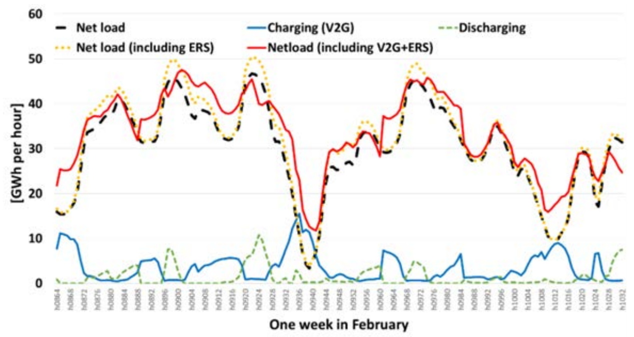

Figure 6. Net load (i.e., load minus wind and solar generation), including electric road systems (ERS) for trucks and buses, and the load from charging the EVs and the discharging back to the grid for one week in February in Scandinavia as obtained from the EPOD model.

Figures 6 and 7 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 respectively Germany. The black dashed curve in Figure 7 shows the net load, which is the load (w/o EV) minus generation from wind and solar PV. This does include neither other generation like thermal or hydro nor trading with neighboring countries. As can be seen, there are many occasions when there is a surplus of power (negative net load values). With a controlled charging algorithm (blue line) this surplus can be used to charge the EVs, i.e. similar to what is seen from the EPOD results in Figure 6. Differences between the models are also seen when comparing the actual timelines. SCOPE results show a negative net load when EV is not included while EPOD net load stays positive. For both models the connection of net load and charging power are obvious. A highly negative net load leads to charging power until 80 GW for SCOPE modelling. On the other hand Positive net loads lead to charging power of less than 20 GW. This means a higher flexibility than for the EPOD result but it should be considered while comparing Fig. 6 and Fig. 7 that for this evaluation different countries are chosen.

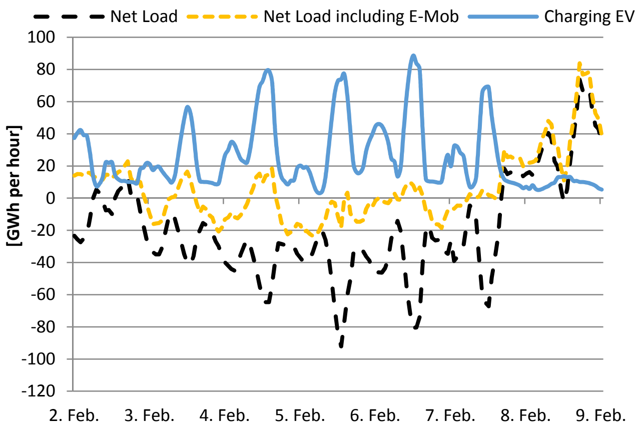

Figure 7: Modified net load (i.e., load minus wind and PV generation) without EV, net load including demand for EV (trucks and cars) and the load from charging EV for one week in February in Germany for the model SCOPE

IV. DISCUSSION

What are efficient charging and discharging strategies for passenger EVs are heavily influenced by the load curve from other sectors. This has been confirmed by means of two different modelling frameworks; the ELIN-EPOD modelling and the SCOPE model. Thus, this is a general finding in spite of differences in assumptions and scenarios between the two modelling frameworks. In addition, both modelling frameworks show that the increase of the net load from ERS could be handled by discharging EV batteries to avoid an increase in peak power investments. A major part of the static charging occurs during night time to avoid correlation with the net load. The main difference between the results of the two modelling frameworks originates from the difference in assumption regarding the CCS technology. However, the models show that an electricity system without CO2 emissions to the atmosphere can be reached both with (ELIN/EPOD) and without (SCOPE) CCS at the same time as powering an electrified transportation sector. A general conclusion from the modelling work is that models can be a powerful tool to understand the interaction between an electrified transportation system and the electricity supply system. Yet, differences in methodologies, assumptions and scenario formulations should be examined in more detail in order to draw more detailed conclusions from the modelling. All models have different limitations and such comparison can pinpoint the strength and weaknesses of the different models and what each model is best suited for.

In the future, autonomous driving and modal systems might change part of the transporting of goods to night time, which will smoothen the load curve from trucks and buses. Other factors that might impact the way we transport goods and persons are urbanization (including new car ownership structure such as car-sharing), globalization, working hours, etc. which might have an impact on the charging profile and thereby also on the possibility to use V2G to reduce the need for peak power and handle more vRE in the electricity system.

REFERENCES

Göransson, L., Goop, J., Unger, T., Odenberger, M., Johnsson, F., (2014), Linkages between demand-side management and congestion in the European electricity transmission system, Energy 69, pp. 860-872.

Odenberger, M., Unger, T., Johnsson, F. Pathways for the North European electricity supply (2009) Energy Policy, 37 (5), pp. 1660-1677.

Unger T, Odenberger M. Dispatch modelling of the European electricity supply: the EPOD model. Methods and models used in the project pathways to sustainable european energy systems, Mölndal. 2011:97-101 (2011)

Nyholm E, Goop J, Odenberger M, Johnsson F. Solar photovoltaic-battery systems in Swedish households–Self-consumption and self-sufficiency. Applied Energy. 183:148-159 (2016).

Taljegard M. The impact of an Electrification of Road Transportation on the Electricity system in Scandinavia. Licentiate Thesis, Department of Space-, Geo and Environmental Science, Chalmers University of Technology (2017).

Kjärstad J, Johnsson F. The European power plant infrastructure—presentation of the Chalmers energy infrastructure database with applications. Energy Policy. 35(7):3643-3664 (2007).

Böttger, D.; Jentsch, M.; Trost, T.; Bonin, M. v.; Gerhadt, N.; Eschmann, J. (2018): Cost-Optimal Market Share of Electric Mobility Within the Energy System in a Decarbonisation Scenario. 15th International Conference on the European Energy Market (EEM). Lodz.