Transformation of the German Energy and Transport Sector – a National Analysis

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Abstract— **The transition of the transport sector is still at its beginning. In the near future, an increase in the amount of battery electric vehicles (BEV) in Germany is expected, leading to a rise of electricity demand. At the same time, the German energy system is shifting from conventional power plants towards renewable power plants like PV and wind.**

Systemic research at the Reiner Lemoine Institut (RLI) shows how a future energy system should be designed in order to provide emission free electricity for the transport sector. We have modelled and compared several scenarios for the German transport sector with an electricity supply consisting of 50 % renewable energy. Our scenarios have a market penetration of 10 % and 20 % BEV in individual mobility and several charging flexibility options, such as vehicle-to-grid (V2G) and time-flexible charging.

Our analyses show that large-scale storage capacities can be significantly reduced if V2G is available; at the same time, the additional energy demand for mobility slightly increases. V2G also induces a technology shift from off-shore wind to less expensive photovoltaics.

Keywords- Energy transition, emission free mobility, battery electric vehicles, German energy system, topology optimization

I. Introduction

There is a vast public debate about the future of mobility. Politicians from all countries are pushing forward with regard to climate protection and have set themselves the ambitious 1.5-degree goal in Paris. As one important measure to reduce greenhouse gas emissions, the German Energiewende [1] sets the goal of covering more than half of the national electricity demand using renewable energy by 2035. At the same time, the number of battery electric vehicles (BEV) in the personal transport sector is targeted to 6 million, or roughly 15 %, by 2030.

The desired reduction in emissions can only be reached if the required electricity is generated by renewables. In this paper, we focus on e-mobility and its influence on the German electricity system. Following the goals of the German Energiewende, we cost-optimize several energy system scenarios. Based on an energy system with 50 % renewables, the effects of 10 % and 20 % BEV market penetration are examined. Furthermore three charging flexibilities of BEV are considered.

II. Method

The national analysis examines the effects of an increased share of BEVs in individual traffic with special regard to the expansion requirements for renewable energy sources and storage technologies for a power supply based half on renewable energy and half on conventional power plants. A combined analysis of the electricity and transport sectors of Germany with the scope of one year and a time increment of one hour is conducted. The expansion and usage of generation and storage facilities are optimized for different scenarios varying the charging flexibility of BEVs as well as the market penetration of BEVs (see Table 1) to the lowest overall economic costs. For this, we use the linear invest and dispatch optimization of the open energy modeling framework oemof [2].

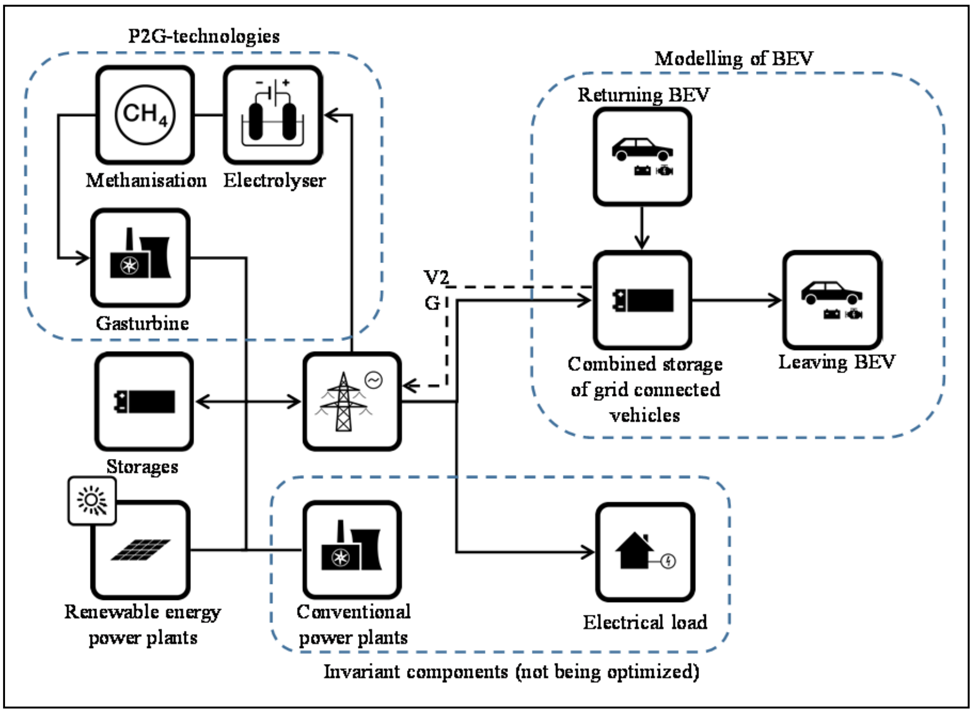

Fig. 1: National analysis model

oemof, short for the Open Energy Modeling Framework, is a tool created by RLI in collaboration with the Center for Sustainable Energy Systems (ZNES – University and University of Applied Sciences Flensburg) and Magdeburg University. It is an open-source software composed of flexible modules and can thus be compiled according to different specific needs. This makes it very useful for inter-sector studies. We use an open tool, because we are convinced that all researchers benefit from using open research tools, that research results become more trustworthy by making them transparent and that therefore, the process of the energy transition is promoted and sped-up. For this analysis, we have chosen oemof, because its structure allows different modeling approaches to coexist within one software framework. So far, we have mainly used the SOLPH Library which makes it possible to describe energy systems with linear problems as well as with mixed-integer linear problems (MILP). Many examples that demonstrate how SOLPH works already exist in oemof. For this analysis, we have developed a particular application based on oemof that can be used to model mobility options based on renewable energy. oemof is implemented in Python and builds upon different libraries. As our approach has generally been collaborative from the very beginning and relies on flexible modules, the concept offers maximum freedom for users concerning which functions they wish to employ.

Figure 1 shows the basic model components of the oemof application used in the analysis presented here. The calculation includes photovoltaic, wind, run of river, geothermal, and biomass power plants, battery and pumped storage, as well as power-to-gas technologies. Feed-in time series for wind and photovoltaics are generated using the oemof feedinlib [3] and weather data from 2011 from the coastdat2 dataset [4]. Fifty per cent of the energy system (without mobility) is powered by conventional fuels; all additional electricity necessary for mobility is generated by renewable energy. The expansion of renewable energy power plants as well as pumped storages is also generally limited by their technical potential.

In our model, restrictions of the electricity grid are not taken into account. It is further assumed that the current electricity demand without sector coupling does not change. The load profile of the BEVs is projected from current-day mobility studies. BEV load profiles are calculated based on assumptions for annual average kilometers traveled, charging options, travelling purpose, and related driving time, speed, and distance, etc. from the MiD 2008 report [5]. The modeling of the vehicles is shown in Figure 1. For the sake of computation we represent all grid-connected vehicles in the form of one combined storage unit. Returning vehicles add to the storage capacity and state of charge, while departing vehicles reduce the storage capacity and state of charge. While the flexibility with which a vehicle can be charged during the time it is connected to the grid is a scenario variable, it is a requirement that departing vehicles need to be fully charged. Depending on the travelling purpose, the state of charge of the returning vehicle is estimated and added to the state of charge of the combined storage. Charging of the combined storage is restricted by the number of vehicles connected to the grid at that time and the charging power that is as well a scenario variable (see scenario table). In some scenarios, the possibility of so called vehicle-to-grid (V2G) options is examined. In that case, feed-in into the grid from the combined BEV storage with a power equal to the combined charging power is allowed.

For the scenario definition, two aspects of current developments in the transport sector are taken into account: the possibility of flexible charging and vehicle-to-grid as well as different market penetrations of BEV. As for the charging power, BEV are charged with 3.7 kW at home and work and with 50 kW at public places, such as charging stations.

Regarding the temporal flexibility of the charging process, a fixed (“No Flex”) and a semi-flexible charging process (“Mid Flex”), allowing to not charge the vehicle during the first four hours, as long as the vehicle is fully charged at the end of the charging period, is considered. Furthermore, a completely flexible charging of the vehicles with V2G technology (“V2G”) is examined. In the case of fully flexible charging, any delay of charging is allowed, as long as the vehicle is fully charged when departing. An overview of all scenarios is given in Table 1.

Table 1: Overview of the analyzed scenarios

Scenario name	Share of BEV	BEV charging flexibility
Base	0 %	-
No flex 10	10 %	0 h
Mid flex 10	10 %	4 h
V2G 10	10 %	Full + V2G
No flex 20	20 %	0 h
Mid flex 20	20 %	4 h
V2G 20	20 %	Full + V2G

III. Results

A 10 % BEV market share of the transport sector results in an additional energy demand of about 10 TWh per year. When comparing the influence of charging flexibility, we observe that higher flexibility leads to a reduction of required storage capacities, especially if V2G is available (see Figure 2). V2G also induces a technology shift from offshore wind to less expensive Photovoltaics. This can be explained by the BEV load adjusting to times of high renewable energy production and feeding back energy to the grid in times of low PV power. Thus, V2G decreases the dependence on continuous energy production and is more robust against fluctuating energy production. This technology shift results in a significant increase in installed rated power of renewable energy power plants, since more installed rated PV power is required to produce the same amount of energy as off-shore wind turbines.

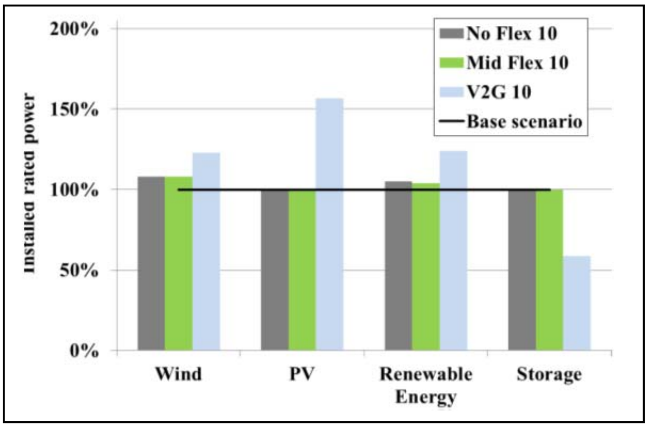

Fig. 2: Comparison of installed power of renewables and storage for different charging flexibilities and a BEV market penetration of 10 %

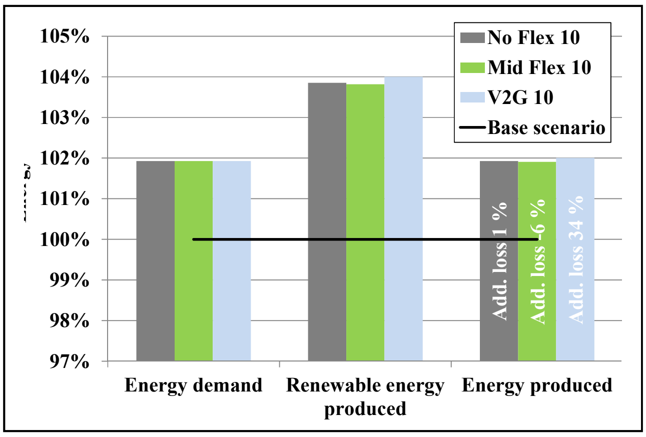

Fig. 3: Comparison of produced renewable energy for different charging flexibilities and a BEV market penetration of 10 %, additional losses compared to the base scenario are displayed on the bars

However, the surplus of installed power of renewables increases the actual produced electricity only slightly (see figure 3). Compared to the base scenario, the energy losses for no charging flexibility increase by 1 %, for mid flexibility it decreases by 6 % and for V2G it increases by 34 %. The decrease of losses with mid flexibility shows that the increase in flexibility allows a better use of volatile renewables. The increase in losses for the V2G scenario can be explained by the V2G charging and discharging efficiencies; the losses are compensated by the prevention of adding extra storage.

The results for a market penetration of 10 % BEV show that different charging flexibilities have a significant effect on the renewable technologies used and the storage power of the energy system. The actual energy produced varies only slightly among the charging flexibilities. V2G requires slightly more energy to be provided due to charging and discharging efficiency. This trend is also observed when looking at a market penetration of BEV of 20 %. Accordingly, Figure 4 and Figure 5 show installed power and energy usage. The most significant change in the 20 % BEV scenario is the significant rise in storage demand for the scenario without charging flexibility.

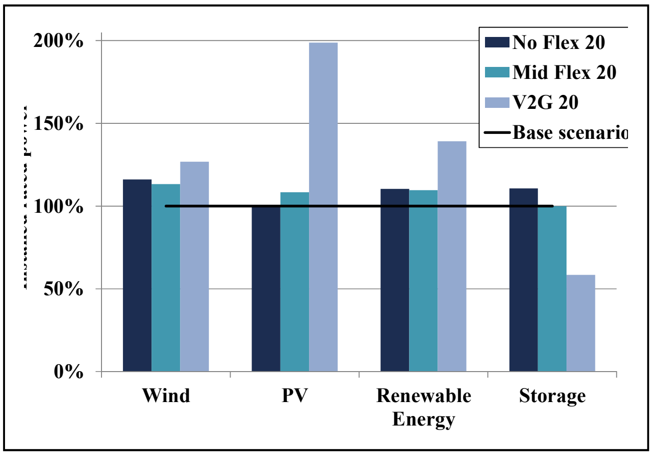

Fig. 4: Comparison of installed power of renewables and storage for different charging flexibilities and a BEV market penetration of 20 %

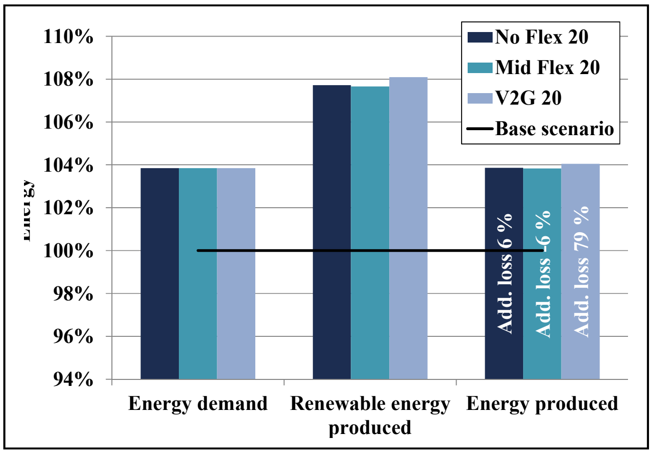

Fig. 5: Comparison of produced renewable energy for different charging flexibilities and a BEV market penetration of 20 %, additional losses compared to the base scenario are displayed on the bars

IV. Conclusion and Outlook

The German climate protection targets include an increase of renewable energy as well as a shift from conventional cars towards carbon free car technologies like BEV. This study conducted by the Reiner Lemoine Institute analyses possible scenarios of a German electricity system around the year 2030 with increasing shares of e-mobility in the private transport sector, aligned with the German Energiewende [1]. Based on an energy system with a 50%-share of renewables, the impact of market penetrations of BEV of 10 % and 20 % have been analyzed as well as different charging flexibilities, including the V2G technology.

One result is that flexibility options in general have a strong influence on storage demand. An energy system consisting to a large extent of renewable energy requires high flexibility due to the fluctuating energy production of the most dominant energy sources wind and solar energy. This flexibility can be introduced to the system by either storage units or flexible demand. Our analyses have shown that the storage demand can be reduced with growing flexibility of BEVs. Furthermore, a fully flexible BEV demand with V2G allows a technology shift from an expensive but steadier energy production from off-shore wind power plants to a cheaper but highly fluctuating energy production from photovoltaic systems. However, due to charging and discharging losses the total energy losses are increasing in the V2G scenarios. This means, that overall more electricity has to be produced to supply the energy system.

RLI work on these issues continues by integrating all energy sectors into the model. In the future, the heat sector must therefore be included. Also, for now we use a copper-plate assumption of the electricity system which certainly does not hold in reality and should be replaced by a capacity-based grid model in future studies. By using a higher temporal simulation resolution, the impact of vehicles' charging power on additional capacities could be further investigated.

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