Electric Vehicle Charging: Impacts on European Energy Systems and CO_2 Reduction

BY PHILIPP ANDREAS GUNKEL AND CLAIRE BERGAENTZLÉ

Philipp Andreas Gunkel, and Claire Bergaentzlé are with the Technical University of Denmark. Gunkel may be reached at phgu@dtu.dk

Context and Method

Electricity systems are undergoing deep transformations to reach full decarbonisation. Not only are changes in the means of production necessary to the integration of Variable Renewable Energies (VRE), but new challenges are also arising on the consumption side, due to the continuous growth of electricity demand. Especially, the market uptake of Electric Vehicles (EV) can result in important threats for the electricity system. In the meantime, EV also consists of a source of flexibility to balance VRE production, thereby accelerating the decarbonisation of electricity mix. With the upcoming growth of EV, existing electricity systems will face important risks due to the increasing load effects, which are difficult to predict in detail. A charging process that flexibly reacts to electricity price and network signals can, however, offset these risks. EV charging can then in turn support the integration of low-cost, competitive VRE technologies while acting for a more reliable system.

This paper investigates the effects of flexible charging schemes such as smart charging and vehicle-to-grid on energy system development in Northwest Europe from 2020-2050. It shows how EV affects the energy landscape in the electricity and heat sector and highlights how flexible charging can give rise to cross-border decarbonisation strategies.

Three main concepts for EV charging are available. Passive charging (PC) is the current state of the art. The EV battery charges at full charger capacity as soon as it is connected to a charger. It is expected that large numbers of vehicles will start charging during late afternoon when people return from work. Consequently, substantial loads are added to the already existing peak in electricity consumption, which can lead to congestion and cause severe issues for electricity supply. The alternative to PC is smart charging (SC). In the enrolment process of dynamic prices on household level, SC gets more and more applied. SC allows shifting the charging process to hours of low prices while ensuring to offer enough energy in the battery at all times. This charging scheme therefore supports cost savings at the household level, limits the need for backup capacities, while it simultaneously prevents network congestion. The third charging process is called Vehicle-to-Grid (V2G). While SC charges the vehicle in only one direction, V2G gives the option to discharge the battery and to provide services to the grid. This is done by a simple upgrade of the previously installed unidirectional charger to a bidirectional charger. V2G offers the opportunity to actively participate in several electricity markets and balancing of energy by buying, storing and selling electricity at appropriate times.

This paper investigates the impact of the three EV charging schemes on future European electricity and heat systems and greenhouse gas emissions. The fundamental areas and questions this paper aims to shed light on are:

- How increasing flexibility in EV charging affects electricity and heat mix and generation?
- What effects on CO_2 emission mitigation does each EV charging scheme have?

The energy system model Balmorel is applied to determine optimal investments into production and the operation of units in Northwest Europe in the annualized decades from 2020-2050 [1]. The model includes a progressive CO_2 tax and a net-zero emission goal in 2050 for the entire modelling region for a steady integration of VRE. Assumptions on policies and data are taken from the Flex4RES project[2]. The transmission system is expanded according to the ENTSO-E ten year network development plan until 2030 and capacities are fixed for the following decades. It is assumed that approximately half of the national vehicle fleets are electrified with battery electric vehicle (BEV) and plug-in hybrids (PHEV) in 2050 with a gradual increase [3]. It is focused on charging at home to simplify the problem of space. Three different scenarios are investigated. PC acts as a base case, which is used as a comparative scenario for SC and V2G. Finally, this study develops a methodology for EV availability and consumption patterned from the Danish National Transport Survey [4]. The model considers limited availability and state-of-charge targets of EV. Furthermore, the methodology includes a battery degradation model, which converts calendrical and cyclical aging of the battery into cost. The battery degradation model helps to not only prevent uneconomical charging but also allows for lifetime extension of the battery itself.

Results and discussion

The Northwest European electricity production is shown for PC in Figure 1. This provides the baseline against which the scenario with SC and V2G are compared in Figures 2 and 3.

In this baseline scenario, the main changes in the electricity mix are driven by the progressive CO_2 tax. The tax takes out of the mix the thermal power plants using fossil fuels, starting with coal that is entirely

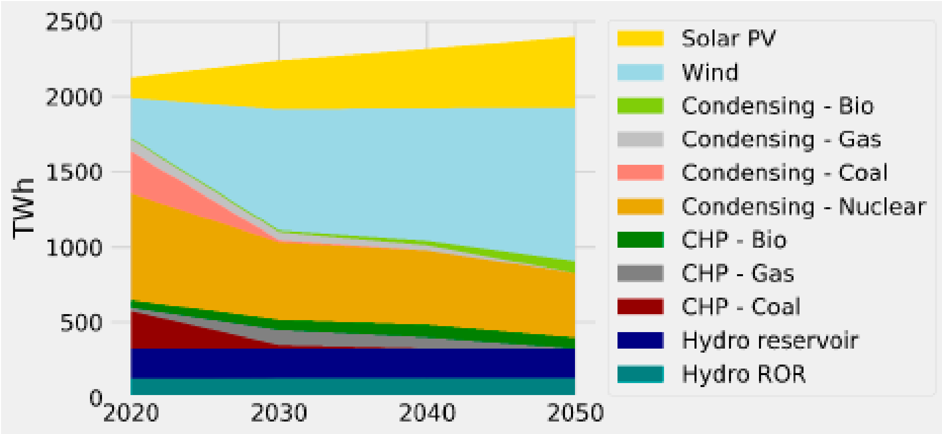

Figure 1 Electricity production in Northwest Europe by technology while integrating EV using PC charging scheme from 2020 until 2050 [3].

phased out in the 40's. CHP plants using natural gas increase their output until 2030 and produce approximately 75 TWh more than in 2020. In 2050, all the fossil fuels-based units are phased out in response to the applied zero emission cap. From the 30's, the largest share of electricity is produced by VRE technologies. Solar PV produces around 473 TWh of electricity, whereas wind power contributes most with 1019 TWh in 2050. In this set-up, the major flexibility provider is hydropower, especially coming from Norway and Sweden, and new capacities utilizing biomass in condensing power plants and CHP. Finally, baseload technologies (nuclear and run-of-river hydro) keep a relatively stable share of electricity production throughout the period, the oldest decommissioned piles being to some extent replaced by the new EPR reactors. Overall the results show, that passive charging vehicle are not a threat towards a carbon neutral electricity production and VRE produce the largest share.

Figure 2 presents the variations in electricity production induced by SC and V2G compared to the base scenario with PC

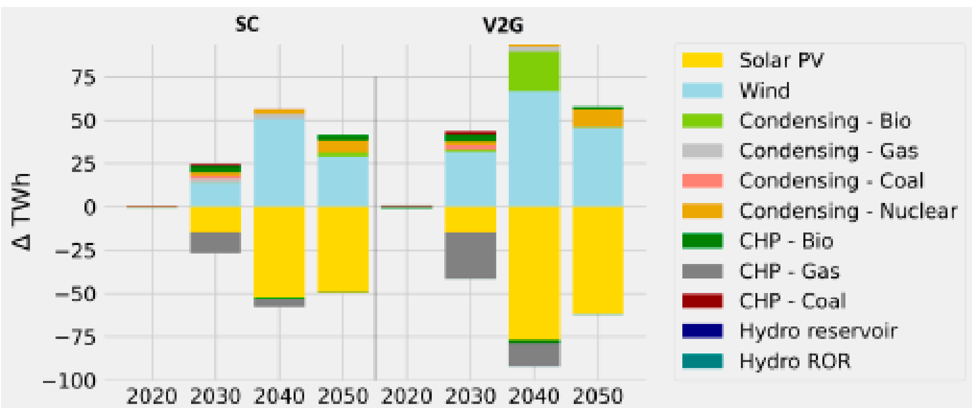

Figure 2 Difference in electricity production of SC and V2G compared to the base case PC from 2020 until 2050 [3].

Increasing the flexibility of EV charging results in three main impacts on the power mix. First, more flexibility generates a substitution of solar PV by wind. With PC, EV charge immediately when car users arrive at home with full charger capacity. Therefore, the major part of the load is situated in the late afternoon hours. In this time, solar PV produces more reliable electricity, compared to wind, which does not follow a comparable daily pattern. With more flexible charging schemes, charging hours are more spread in time. Solar PV is less invested in and contributes less to total production, especially in 2040 and 2050 with -50 TWh to -76 TWh (-10.5% and -13.1% compared to PC). The main part of this loss of production is substituted with wind power. Besides, flexible charging concentrates charging times to low residual load hours when electricity is cheap, further increasing the final use of wind energy output.

Second, SC and V2G, by definition, avoid charging during peak hours. This load shifting from peak to baseload hours directly reduces the participation of gas-based CHP power plants. In the 30's, when natural gas still participates substantially to the mix, passing from PC to V2G lowers by 26.6% gas plants production.

Third, the more flexibly EV are charging, the better can baseload technologies cover demand. EV charging shifts to baseload hours. This increases full load hours for large power plants such as nuclear, which increase their production by between 8-12 TWh, or up to 2.5% in 2050.

Our results also point out the impact of EV charging across sectors. We show that more flexibility in EV charging limits the electrification of the heat sector. The reduction of peak prices on the wholesale electricity market limits the business case for highly flexible gas-based CHPs as described earlier. Besides, due to this increased flexibility on the demand-side, average electricity prices increase and price fluctuations simultaneously decrease. As a consequence, the deployment and operation of power-to-heat equipment such as heat pumps and electric boilers are negatively affected. The overall electricity production is therefore lower in SC and in particular in V2G compared to PC, because the heating sector uses more biomass. Cross-sectoral competition effects can subsequently be expected in the future. This competition affects investment decisions not only from households, but also from utilities reacting on available flexibility sources on the consumer side.

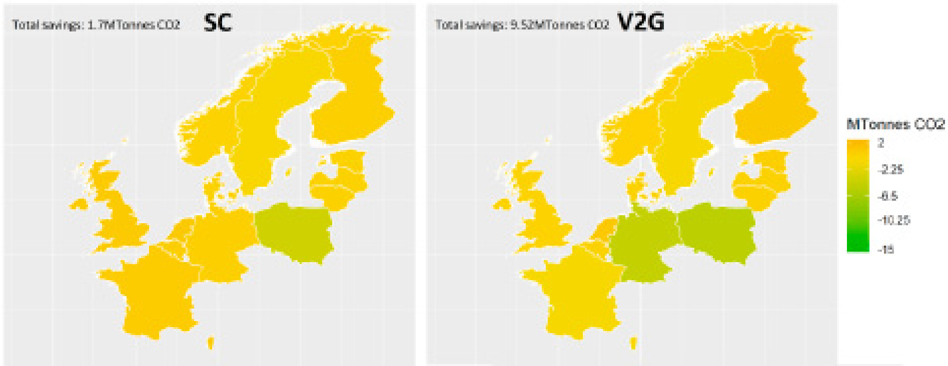

Figure 3 Cumulative reduction of CO_2 emissions in Northwest Europe compared to the base case PC from 2020 to 2050 [3].

Figure 3 summarizes the cumulative saving effects from EV charging schemes on CO_2 emissions compared to PC.

Distributional effects take place when improving the flexibility of EV. The overall emissions savings go up to 1.4%. The largest mitigation takes place in Central Europe. Mainly Poland and Germany achieve better results when EVs charge with V2G. The reduction of CO_2 emission are 5.23 mTonnes of CO_2 in Poland and 4.65 mTonnes CO_2 in Germany compared to the base case. At the same time, other countries pollute more than before, such as Netherlands and Denmark. They emit together approximately 1 mTonnes CO_2 more than in the PC scenario. The main reason for that are the overall positive effects when adjacent countries support the high emission energy systems of Poland and Germany. As both electricity sectors are strongly dependent on coal, the optimization suggests that surrounding countries such as Denmark produce more electricity using their high efficient CHP plants. Low efficient gas and coal condensing power plants in Germany and Poland are therefore substituted.

In addition, EVs with V2G contribute with their storage capacity to absorb the volatile wind production and discharge electricity when needed. This also allows utilization of existing transmission capacities more efficiently, because electricity from VRE is stored for several hours and injected as well as exported again when wind and solar production is low. Consequently, it is expected that flexible EV can not only support the integration of VRE locally, but also strengthen the utilization of interconnection and therefore serve European efforts for greenhouse gas mitigation. In particular in the case of a less progressive CO_2 pricing, it is expected that the overall emission reduction as well as distributional effects are stronger with flexible EV.

Conclusion

In a future where EV are passively charged and create substantial peak effects on electricity supply, decarbonised energy system get more balanced by the supply-side and more specifically by hydropower and biomass power condensing plants as well as CHPs. However, solar PV and wind power are still the largest contributors to electricity generation with EV using PC, whereas polluting power plants are phased out.

The energy system adapts with the introduction of SC and V2G. Wind energy is the main benefiter of the growing flexibility provided by SC and V2G charging schemes in Europe. This is both visible in terms of additional installed capacities and production and is attributable to a double dynamics. On the one hand flexible charging facilitates load shifting to the hours where large quantities of wind (and solar) energy is produced. It thereby releases the constraint on increasing the production of (carbon free) electricity during restricted periods of charging as it is the case with PC. On the other hand, in the case of V2G, extra flexibility services are provided to the system, not only to absorb production surpluses, but also to provide balancing services when VRE output drops.

Flexible EV charging also creates losers in either accelerating the downfall of some technologies or slowing down the uptake of others. Flexible plants with high marginal cost like gas power plants are among the first technologies who suffer from demand-side flexibility, as already well described in the literature. Flexible EV charging is no exception to the rule due to its direct impact on price variation. The other less scrutinized impact of flexible charging is on the heat sector and its substitution to power-to-heat technologies and subsequent thermal storage. This competing effect between flexible EV charging and heat electrification calls for a better appreciation of the links between both sectors in the design and implementation of suited integrated regulatory frameworks for flexibility and storage.

The mitigation of CO_2 emissions is greatly supported by flexible EV charging schemes. Distributional effects get furthermore visible. While countries such as Poland and Germany can significantly reduce their emissions, surrounding countries increase slightly their CO_2 emissions. The slight rise in some countries are however more than offset by countries with historically large shares of coal in their mix. This suggests that flexible EV not only supports local integration of VRE, but also strengthens cross-country trade, and subsequently the mitigation of European emissions. In order to strengthen the role of EVs in energy systems, policy barriers need to be addressed to facilitate flexibility and to pick low-hanging fruit. At the same time, distributional effects along several countries and regions may create conflicts. We therefore suggest further research on cross-border and cross-sectoral impacts of EV integration to support stakeholder and policy makers with data-driven and robust policy recommendations for optimal decision-making.

References

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[2] Flex4RES, "Flexible Nordic Energy Systems - Summary Report," 2019.

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measured, there was only one that had a significant and moderate negative effect on the likelihood of not purchasing another EV and that was the EV user experience with the time it takes for them to charge their EVs when on the road. The levels of dissatisfaction with availability of charging stations does not appear to be a significant barrier to their continued purchasing of an EV.

While investment in infrastructure is important to future EV adoption, the principal challenge that remains is the initial conversion of ICE drivers to EV owners. The evidence from our study seems to imply that once they have experienced driving an EV they are likely to realize that their range anxiety is unfounded and that the technology works. Continued financial incentives to assist in purchasing an EV would help lower the initial price of the vehicle but the cost of such incentive programs, and the political resistance to them, can be avoided if instead, government policy was designed to influence industry financing of EVs so that the monthly cost to the consumer, net of the fuel and maintenance costs, would be lower than if they drove an equivalent ICE vehicle. Once converted, our study suggests that federal government investment in EV charging infrastructure in urban areas will then be beneficial for a number of reasons. Firstly, the investment will assist in attracting the ICE driver, as it would provide a positive optic to help alleviate concerns about being able to charge their EV when and where needed. Second, increasing the availability of EV charging stations outside of the home or work would reduce user dissatisfaction and improve ease of use. Finally, the added investment in charging infrastructure would mitigate what appears to be a barrier to the continued use of EVs by improving charging times when the driver is away from home or the office. These findings confirm the need for continued policy support on the part of the Canadian government to encourage technology advances in EV charging in order to stimulate increased demand for EVs. They also suggest that additional study is required to better understand the electricity system demands associated with encouraging EV drivers to fast charge during peak hours instead of doing so off peak at home and overnight.

Footnotes

[1] https://toronto.citynews.ca/2019/05/01/federal-rebates-electric-car/ - Accessed on May 24, 2020

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