DEFINE – POLICY BRIEF

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The CO_2 emission impact of introducing electric vehicles (EV) strongly depends on the power plant fleet and the EV charging mode. Our analyses illustrate that additional renewable capacities compared to current expansion scenarios are needed to fully exploit the emission reduction potential of EV; without such generation adjustments, the introduction of electromobility might increase CO_2 emissions compared to a reference case without EVs, irrespective of the charging mode.

Two scenarios of electric vehicle (EV) deployment in Germany up to 2030 are developed: a business as usual (BAU) and an electromobility$^+$ (EM^+) scenario that includes policy measures to support EV market introduction (a feebate system, adjusted energy taxation and ambitious CO_2 emission targets). Plug-in hybrid and range extended electric vehicles constitute the largest part of the EV fleets in both scenarios (around 5 million EV in 2030 in EM^+). Using a unit-commitment dispatch model, we analyze the integration of these EV fleets into the German power system. The overall energy demand of the modeled EV fleets is low compared to the power system at large. Yet, hourly charging loads can become very high. User-driven charging largely occurs during daytime and in the evening with respective consequences for the peak load of the system. In contrast, cost-driven charging is shifted to night-time. Accordingly, cost-driven EV charging strongly increases the utilization of hard coal and lignite plants, while additional power generation predominantly comes from natural gas and hard coal in the user-driven mode. Overall, specific CO_2 emissions related to the additional power demand of EV are substantially larger than specific emissions of the overall power system in most scenarios as improvements in renewable integration are over-compensated by increases in the utilization of hard coal and lignite. Only if the introduction of electromobility is linked to a respective deployment of additional renewable generation capacity (RE^+), electric vehicles become largely CO_2-neutral. Additional analyses on the net CO_2 balance of both the power and the transportation sector show that additional power-related CO_2 emissions over-compensate emission mitigation in the transport sector in BAU; in EM^+, this effect reverses.

Based on our findings we suggest the following policy conclusions. First, policy makers should be aware that EV increase the power demand and thus also fossil power plant utilization. If the introduction of electromobility is intended to be linked to the use of renewable energy and zero emissions, it has to be made sure that a corresponding amount of additional renewables is added to the system. Second, because of generation adequacy concerns, purely user-driven charging may have to be restricted with increasing EV fleets. Third, cost-driven charging – or market-driven charging, respectively – will only lead to emission-optimal outcomes if emission externalities are correctly priced. Last, but not least, we want to highlight that the introduction of electromobility should not only be evaluated with respect to CO_2 emissions; EV may also bring about other benefits such as lower emissions of other air pollutants and noise, and a reduced dependence on oil in the transport sector.

Introduction

In the context of the project DEFINE, Oeko-Institut and DIW Berlin jointly analyzed possible future interactions of the introduction of electromobility with the German power system. We were particularly interested in the impacts of electric vehicles (EV) on the dispatch of power plants, the integration of fluctuating renewable energy, and resulting CO_2 emissions under different assumptions on the mode of vehicle charging.

To do so, Oeko-Institut has developed two market scenarios of electric vehicle deployment in Germany up to 2030: a business as usual (BAU) scenario as well as an electromobility$^+$ (EM^+) scenario. Empirical mobility data and a conjoint analysis have been used to derive the market and stock developments of EV in both scenarios. Building on mobility data, 28 hourly patterns of power consumption and maximum charging power for different EV types have been derived for both 2020 and 2030. These parameters served as inputs for a numerical model analysis carried out by DIW Berlin. Using DIW Berlin's unit-commitment dispatch model, we have analyzed the integration of these EV fleets into the German power system for various scenarios, drawing on different assumptions on the charging mode. CO_2 emission outcomes, in turn, were handed over to Oeko-Institut. These served as inputs for the Oeko-Institut's TEMPS model in order to determine the overall emission effects of EVs, while also considering the substitution of conventional vehicles in the transport sector.

Two scenarios of electromobility

Two market scenarios for EV in Germany up to 2030 have been developed as a part of DEFINE. The BAU scenario takes current policy into consideration. In contrast, policy measures such as higher energy taxation of fossil fuels, more ambitious EU CO_2 emission standards for new passenger cars and a feebate system are considered in the EM^+ scenario. Representative mobility data for Germany has been used to account for mileage and usability restrictions of EV. The purchase decision between cars of different propulsion system has been modeled with a conjoint analysis that consists of data from 1,500 interviewees.

Major restrictions for EV usage and EV purchase are the charging infrastructure requirements and long trips that exceed the maximum mileage of battery electric vehicles. Roughly 50 % of car owners in German city centers do not own a parking spot at their property and are completely dependent on charging infrastructure in (semi-)public environment when using electric vehicles. This number decreases to less than 30 % in the outskirts of urban areas and in rural areas. Long trips are a severe restriction for battery electric vehicles and the probability that cars will be used for trips above their maximum mileage at least 4 times per year is higher than 70 %.

The conjoint analyses shows high acceptance for electromobility under the given assumptions of both scenarios. The potential market share of EV is around 50 % in the BAU scenario and increases up to roughly 60 % in the EM^+ scenario. Generally, the acceptance of plug-in hybrid vehicles is higher compared to battery electric vehicles. We also consider restrictions to the market diffusion of EV in the analysis, such as production capacity restrictions and a lack of EV model variety.

The share of newly registered EV is 5–6 % in 2020 and rises to 20 – 25 % in 2030. Higher market shares are achieved for plug-in hybrid (PHEV) and range extended vehicles (REEV). This new car registration data has been used as an input for vehicle stock modeling. For 2020, an EV fleet of roughly 400,000 (BAU) to 500,000 (EM^+) cars has been derived. The EV fleet increases to 3,900,000 cars in 2030 in the BAU scenario and to 5,100,000 cars in the EM^+ scenario, in which around 13 % of all cars are EV (Figure 1).

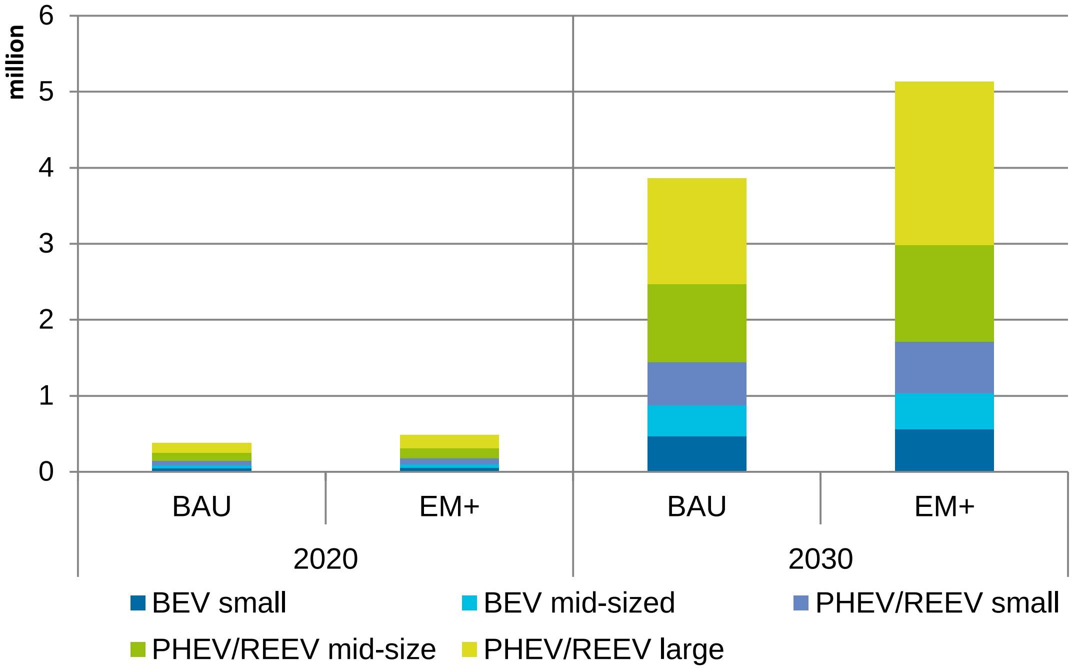

Figure 1: Electric vehicle stock in BAU and EM⁺ scenario

Power system impacts of electric vehicles in Germany

We use a numerical cost minimization model that simultaneously optimizes power plant dispatch and charging of electric vehicles. The model determines the cost-minimal dispatch of power plants, taking into account the thermal power plant portfolio, fluctuating renewables, pumped hydro storage, as well as grid-connected electric vehicles. Interactions with neighboring countries are not considered here. The model has an hourly resolution and is solved for a full year. It includes realistic inter-temporal constraints on thermal power plants, for example minimum load restrictions, minimum down-time, and start-up costs. The model draws on a range of exogenous input parameters, including thermal and renewable generation capacities, fluctuating availability factors of wind and solar power, generation costs and other techno-economic parameters, and the demand for electricity. We largely draw on semi-governmental data as well as on DIW Berlin's own database.

We apply the dispatch model to the BAU scenarios and the EM^+ scenarios of both 2020 and 2030. With respect to installed generation capacities, we draw on the semi-governmental German Grid Development Plan, which foresees a substantial expansion of renewables according to the targets of the German government. In addition, we carry out six additional model runs for the 2030 EM^+ scenario with further increase renewable capacities (RE^+). These capacities are adjusted such that they supply exactly the yearly power demand required by EVs. We assume that the additional power either comes completely from onshore wind, or completely from PV, or fifty-fifty from onshore wind and PV. EV usage is considered by applying the aforementioned 28 EV profiles that are derived by the Oeko-Institut from representative German mobility data. Hourly data of electricity consumption and grid connectivity of EV serve as inputs to the model. We further distinguish two extreme modes of charging: fully user-driven or fully cost-driven. In user-driven charging, EV are charged as fast as possible after a connection to the grid has been established. In the cost-driven mode, EV charging is shifted – given the restrictions of the EV profiles – such that electricity generation costs are minimized.

Model results show that the overall energy demand of the modeled EV fleet is low compared to the power system at large. In 2020, the EV fleet accounts for only 0.1% to 0.2% of total power consumption, depending on the charging mode. By 2030, these share increase to around 1.3% (user-driven) and 1.6% (cost-driven), respectively. Yet the hourly charging loads can become very high, with according effects on the power system. Hourly charging levels vary significantly over time and differ strongly between the user-driven and the cost-driven modes. User-driven charging largely results in vehicle charging during daytime and in the evening (Figure 2). This may lead to substantial increases of the system peak load, which raises serious concerns about system security. In the user-driven scenarios of the year 2030 there are several hours both in BAU and EM^+ during which the available generation capacity is fully exhausted. In contrast, in the cost-driven mode, the evening peak of EV charging is shifted to night-time, which results in a much smaller increase of the system peak load. The average charging profile of the cost-driven mode is much flatter compared to the user-driven one.

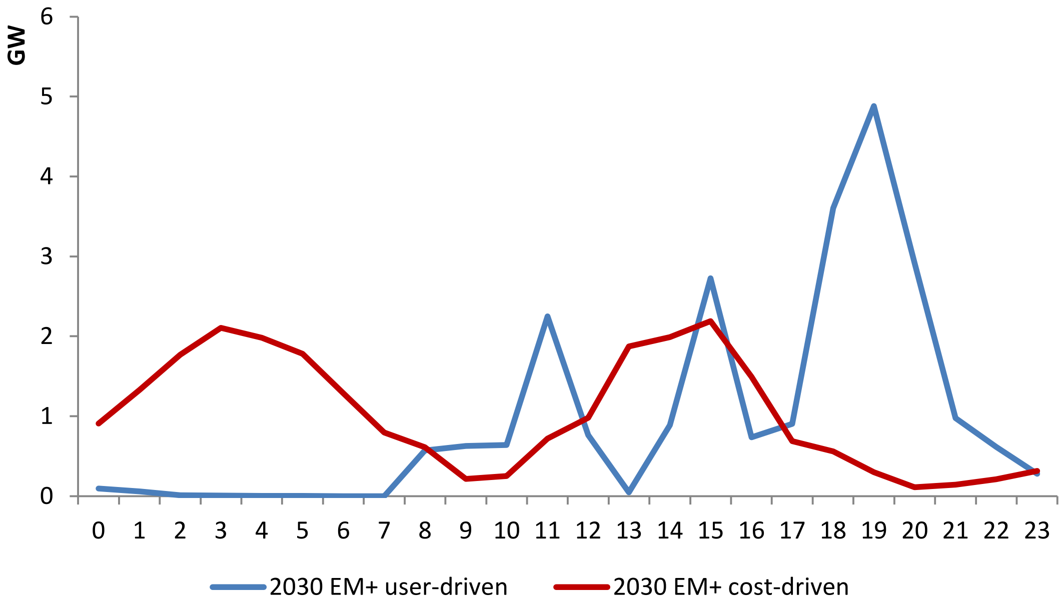

Figure 2: Average EV charging power over 24 hours

The different charging patterns go along with respective changes in the dispatch of the power plant fleet. In the 2030 EM^+ scenarios, cost-driven EV charging strongly increases the utilization of hard coal and lignite plants compared to a scenario without EVs. In the user-driven mode, in which charging often has to occur in periods when lignite plants are producing at full capacity, additional power generation predominantly comes from combined cycle natural gas plants, followed by hard coal and lignite (Figure 3).

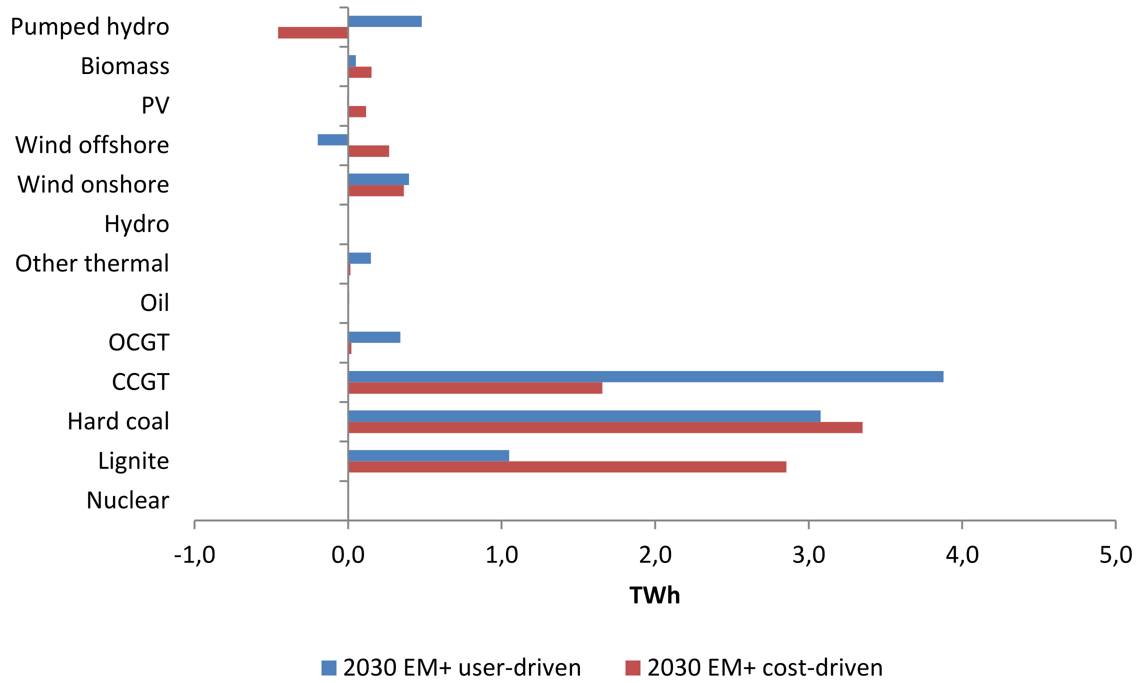

Figure 3: 2030 EM+: dispatch changes relative to scenario without EV

In additional model runs (RE+), we link the introduction of electromobility to an additional deployment of renewable power generators. Under user-driven charging, this leads, obviously, to increased power generation from renewables, but also to a slightly decreased utilization of lignite plants and increased power generation from natural gas, compared to a scenario without EVs and without additional renewable capacities. Under cost-driven charging, we find an opposite effect: generation from lignite increases while generation from natural gas decreases. This is due to the additional demand-side flexibility of the EV fleet.

As regards renewable integration, temporary curtailment of fluctuating generators is generally low in all scenarios, given the underlying assumptions on the power system. Having said that, model results show that the potential of EVs to reduce renewable curtailment is much higher in case of cost-driven charging compared to the user-driven mode**Fehler! Verweisquelle konnte nicht gefunden werden.**. In the 2030 EM+ scenario, cost-driven charging decreases the share of renewable curtailment from 0.65% in the case without EVs to 0.29%. In the RE+ scenarios, the one with 100% PV has the lowest curtailment levels whereas the one with 100% onshore wind has the highest ones. Accordingly, PV feed-in patterns may match the charging patterns of electric vehicles slightly better than onshore wind.

Specific CO_2 emissions of the additional electricity demand related to EV in the different scenarios depend on the underlying power plant fleet as well as on the mode of charging. EV may increase the utilization of both emission-intensive capacities such as lignite or hard coal, and fluctuating renewables. While the first tends to increase CO_2 emissions, the latter has an opposite effect. In the BAU and EM+ scenarios of 2020 and 2030, the first effect dominates the emission balance, in particular in the cost-driven charging mode. Specific emissions of the charging electricity are thus substantially larger than specific emissions of the overall power system, irrespective of the charging mode (

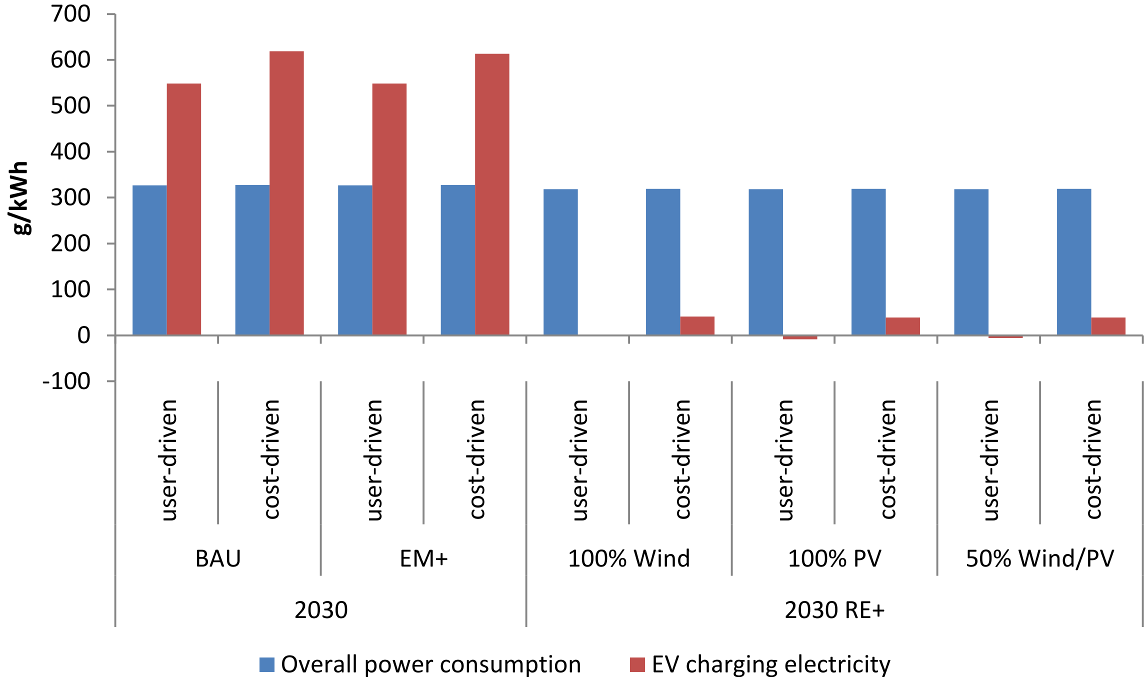

Figure 4). In contrast, introducing additional renewable capacities (RE+) pushes specific emissions of the charging electricity well below the system-wide average, and they even become negative in some cases. Importantly, these effects strongly depend on the power plant structure and on the extent of renewable curtailment in the system. In the future, the emission performance of cost-driven charging may improve substantially, if emission-intensive plants are removed from the system and if renewable curtailment gains importance.

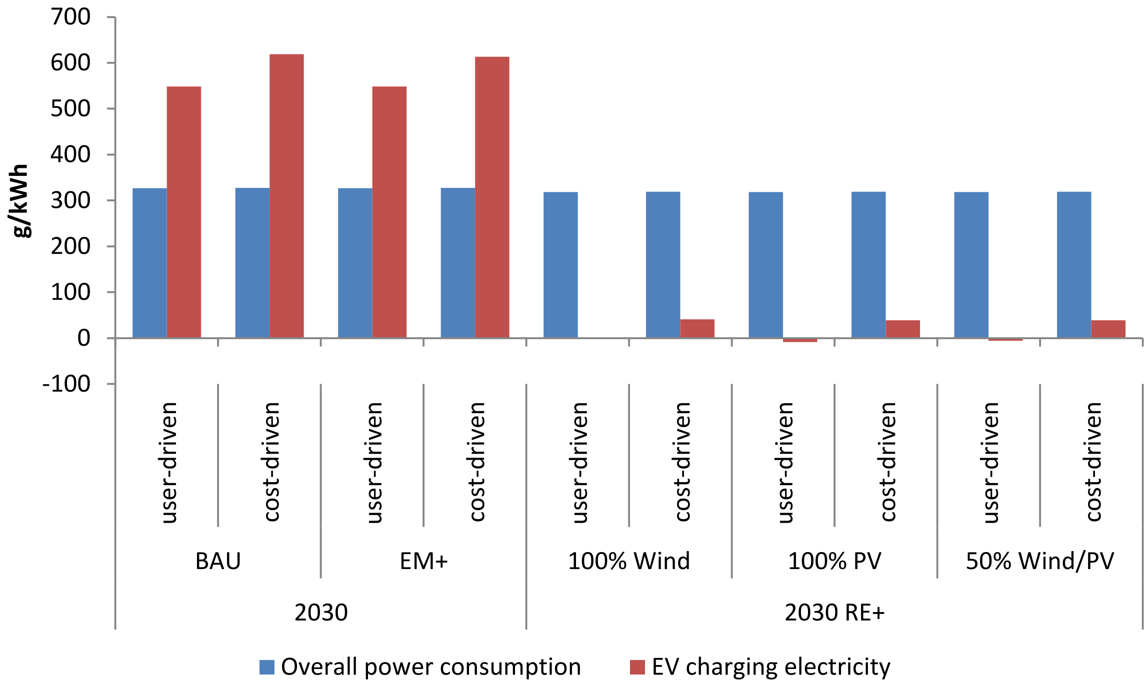

Figure 4: Specific CO_2 emissions of electricity generation in the 2030 scenarios

The net CO_2 balance of electromobility

Substituting cars with internal combustion engine (ICE) by EV reduces CO_2 emissions in the transport sector. In contrast, emissions of the electricity sector might increase due to additional power demand from EV (see above). Moreover, we assume decreasing specific CO_2 emissions of ICE cars in EM^+ in the context of the assumed policy measures. A combined net CO_2 balance of the transport and electricity sectors has been conducted to evaluate the total CO_2 impact of introducing electromobility. In 2030, the CO_2 mitigation of the transport sector is over-compensated by additional CO_2 emissions in the electricity sector in the BAU scenario, and net CO_2 emissions increase by 1.0 to 1.6 million tons CO_2 (compared to a scenario without EV), depending on the charging mode (Figure 5). A negative (decreasing) CO_2 balance is achieved in the EM^+ scenarios (-2.1 to --1.3 million tons CO_2), but this is caused by assumed lower emissions of ICE cars (more ambitious CO_2 emission standards compared to the BAU scenario). In both BAU and EM^+, specific CO_2 emissions of EV are still higher compared to ICE cars by 2030, as emission improvements in the power plant fleet are compensated by improvements of conventional cars. In the cases with additional renewable capacities (RE^+), EV become largely CO_2-neutral even when considering the power sector only, and the overall CO_2 balance becomes as low as -6.9 million tons CO_2. Thus, the potential for EV-related CO_2 mitigation is fully exploited only in the RE^+ scenarios.

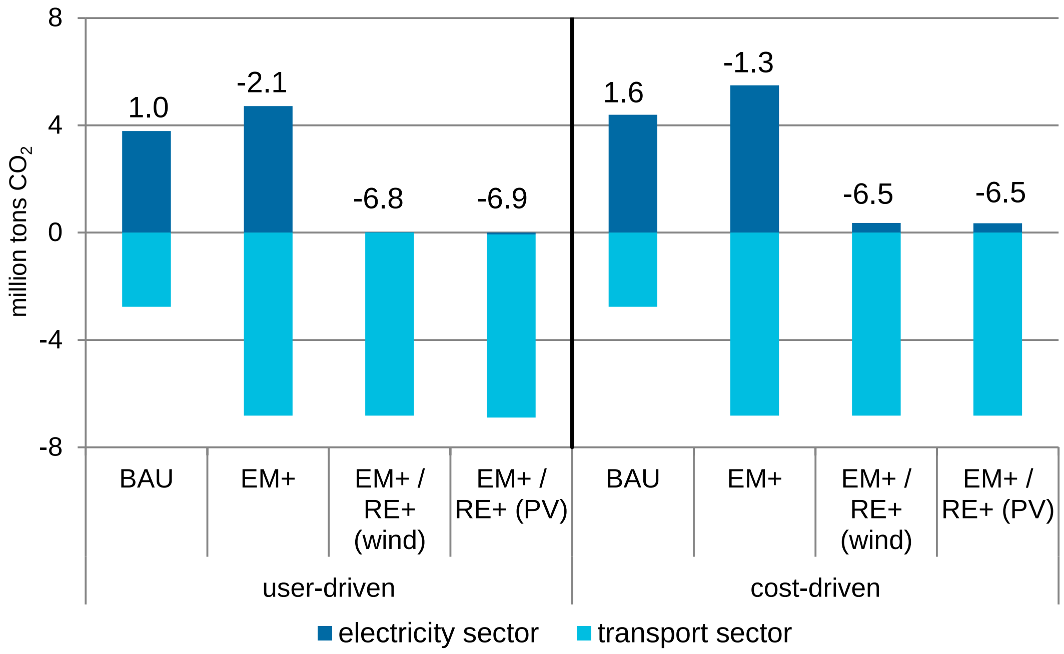

Figure 5: Net CO_2 balance of transport and electricity sectors in 2030 (in million tons CO_2, comparison to the scenario without EV and without additional renewables)

Policy conclusions

First, the overall energy requirements of electric vehicles should not be of concern to policy makers for the time being, whereas their peak charging power should be. With respect to charging peaks and system security, the cost-driven charging mode is clearly preferably to the user-driven mode. Because of generation adequacy concerns, purely user-driven charging may have to be restricted by a regulator in the future, at the latest if the vehicle fleet gets as large as in the 2030 scenarios.

Second, policy makers should be aware that cost-driven, i.e., optimized, charging not only increases the utilization of renewable energy, but also of hard coal and lignite plants. If the introduction of electromobility is linked to the use of renewable energy, as repeatedly stated by the German government, it has to be made sure that a corresponding amount of additional renewables is added to the system. With respect to CO_2 emissions, an additional expansion of renewables is particularly important as long as substantial – and increasingly under-utilized – capacities of emission-intensive generation technologies are still present in the system. Importantly, from a system perspective it does not matter if these additional renewable capacities are actually fully utilized by electric vehicles exactly during the respective hours of EV charging.

We suggest a third – and related – conclusion on CO_2 emissions of electric vehicles. Cost-driven charging, which resembles market-driven or profit-optimizing charging in a perfectly competitive market, can only lead to emission-optimal outcomes if emission externalities are correctly priced. Otherwise, cost-driven charging may lead to above-average specific emissions, and even to higher emissions compared to user-driven charging. Accordingly, policy makers should make sure that CO_2 emissions are adequately priced. Otherwise, some kind of emission-oriented charging strategy would have to be applied, which is possible in theory, but very unlikely to be implemented in practice.

Last, but not least, we want to highlight that the introduction of electromobility should not only be evaluated with respect to CO_2 emissions. EV may also bring about other benefits such as lower emissions of other air pollutants and noise, and a reduced dependence on oil in the transport sector. In particular, EV allow the utilization of domestic renewable energy in the transport sector without relying on biofuels.

References

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