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Extended Abstract

Identification of the Optimal Passenger Car Vehicle Fleet Transition for Mitigating the Cumulative Life-Cycle Greenhouse Gas Emissions until 2050

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Abstract

We present an optimization model for the passenger car vehicle fleet transition—the time-dependent fleet composition—in Germany until 2050. The goal was to minimize the cumulative greenhouse gas (GHG) emissions of the vehicle fleet taking into account life-cycle assessment (LCA) data. LCAs provide information on the global warming potential (GWP) of different powertrain concepts. Meta-analyses of batteries, of different fuel types, and of the German energy sector are conducted to support the model. Furthermore, a sensitivity-analysis is performed on four key influence parameters: the battery production emissions trend, the German energy sector trend, the hydrogen production path trend, and the mobility sector trend. Overall, we draw the conclusion that—in any scenario—future vehicles should have a plug-in option, allowing their usage as fully or partly electrical vehicles. For short distance trips, battery electric vehicles (BEVs) with a small battery size are the most reasonable choice throughout the transition. Plug-in hybrid electric vehicles (PHEVs) powered by compressed natural gas (CNG) emerge as promising long-range capable solution. Starting in 2040, long-range capable BEVs and fuel cell plug-in hybrid electric vehicles (FCPHEVs) have similar life-cycle emissions as PHEV-CNG.

The world community concurred to the goal of limiting global temperature rise to ideally 1.5 °C compared with the pre-industrial age during the United Nations climate conference in Paris in 2015. According to this, the German government set the goals of reducing greenhouse gas (GHG) emissions by 40% in 2020 (compared to 1990). The climate protection report of 2018 states that these climate targets will be missed. In contrast to the two main contributors—the energy sector and the industry sector—that will achieve almost a 40% GHG emission reduction by 2020, the GHG emissions of the mobility sector have only been reduced by 5%. Consequently, in this sector there still is a lot of unlocked potential for climate protection.

This study addresses this issue focusing on the vehicle fleet transition and minimizing its GHG emissions. In contrast to this study, previous studies have made prognostics of the German vehicle fleet transition following different approaches without minimizing the GHG emissions. Supported by the Transport Emission Model (TREMOD), a project of the German Federal Environment Agency (UBA), Knörr et al. predict 7.5 and 44 million vehicles with plug-in option for the years 2020 and 2035 respectively. In 2035, this corresponds to roughly 90% of the fleet according to their calculations. This model has been developed over 20 years ago and since then been improved and expanded several times. Its main goal was to calculate the emissions of the German transport sector. The German Aerospace Center (DLR) has developed the simulation model VECTOR21. They predict that by 2040 only 35% of the fleet will have a plug-in option. The simulations are based on the customer perspective and reflect the limited acceptance these powertrain classes currently have. The model includes a total cost of ownership approach, which calculates the lifelong costs which have to be covered by the respective owners. VECTOR21 minimizes this cost and this way determines the future fleet composition. Interestingly, Harrison et al. conclude that even assuming high user acceptance, by 2050 only 50% of the fleet will have a plug-in option. Their model was specifically developed to gain insights in influences on the adoption rates of new technologies that can be applied in a policy context. Therefore, they modeled several agents of the automobile sector including their interactions. Plötz et al. determine the vehicle fleet transition with special focus on the resulting electricity demand. Similar to VECTOR21, their model relies on a total cost of ownership approach. They base the distribution of annual vehicle kilometers travelled over different vehicle classes on a large dataset of driving profiles from Germany. They predict that in 2050 approx. 60%—or 25 million vehicles—will have a plug-in option. Overall, the prognostics have very differing outcomes depending on who performed them and what their modelling approach was. When comparing different studies and prognostics regarding the German vehicle fleet, one finds that most of them predict a transition to more hybrid electric vehicles (HEVs) without plug-in option, plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), and fuel cell electric vehicles (FCEVs). However, as the outcomes of most studies predict, even in the next 20 to 30 years, these alternative powertrain classes will not replace conventional internal combustion engines vehicles (ICEVs) completely. In some

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studies, the purchasing behavior plays an important role. According to the studies, only a limited customer segment feels comfortable switching to PHEVs, BEVs, and FCEVs.

In the present paper, we focus on the minimum achievable GHG emission potential—hereinafter referred to as ecological potential—of passenger car vehicles in the vehicle fleet. For this purpose, we research available life-cycle assessment (LCA) data. An essential difficulty in LCAs of passenger car vehicles lies in the many varying factors that influence its GHG emissions. Especially for PHEVs the differing charging behavior of different users can lead to very different outcomes when looking at the GHG emissions. This uncertainty adds to the fact that the GHG emissions caused by the electrical consumption differ depending on the energy sector composition in every region.

A series of studies have performed LCAs on series production vehicles, which is a common approach to assess the life-cycle GHG emissions of current state-of-the-art powertrain technologies. However, when explicitly comparing the ecological potential of different powertrain concepts, the meaningfulness of these studies has to be questioned. This is because series production vehicles were not dedicatedly designed to minimize their GHG emissions and, therefore, will not represent the true ecological potential of their powertrain concept. Further, a powertrain concept can have different parametrizations, thus, the LCA of one specific series production vehicle does not allow generalized conclusions on the powertrain concept. In [9] an optimization framework was introduced, that allows to design the powertrain concepts so that the ecological potential is achieved. Using this approach, we ensure that no powertrain concepts are excluded from the fleet transitions due to non-optimal powertrain parametrizations.

Our team conducts comprehensive analyses of the production phase, the operational phase—taking into account the energy mix for electricity production—and the end-of-life (EoL) phase. We model the German fleet transition until 2050 and calculate the cumulative GHG emissions, including all life-cycle phases of all vehicles. The cumulative GHG emissions serve as objective value for an optimization problem, which enables us to determine the GHG-optimal fleet transition. This way, we are able to make a precise time-based assessment of the GHG emissions of different powertrain concepts taking into account the dynamic interaction of the vehicle fleet with the energy sector. Furthermore, the results serve as guideline as to which powertrain concepts should be introduced at which point in time in order to reduce the GHG emissions of the German vehicle fleet as a whole. Unlike other prognostics, this study is not intended to show the most likely transition of the German vehicle fleet. Instead, the GHG-optimal transition paths for different scenarios are identified and analyzed to gain comprehensive knowledge about similarities in different scenarios that can be used as a guideline for decision makers.

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