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Developments of CO_2-emissions and costs for small electric and combustion engine vehicles in Germany

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ABSTRACT

Electric vehicles have the potential to lower emissions in the mobility sector, but especially high costs might hinder their market development. This paper aims to access environmental and economic impacts and potentials by comparing CO_2-emissions and costs of small vehicles. Considering actual data it is analysed, if and under which conditions electric vehicles are financially competitive for private consumers and under which conditions emissions can be saved. For this, a multiple-stage approach is focusing on (1) emissions during production and operation, (2) private costs and (3) external costs of emissions. A model of total cost of ownership is applied for the analysis of private and external costs.

Results show that emissions of electric vehicles exceed emissions of combustion engine vehicles in the production phase, but electric vehicles cause fewer emissions during operation. Total emissions can be saved by electric vehicles even with low annual driving distances (2500–5500 km/a today). Results highly depend on the form of electricity production.

Today, private costs of electric vehicles exceed the costs of combustion engine vehicles. Due to cost decreases electric vehicles can gain financial advantages in the future. External costs are high, especially for combustion engine vehicles (up to 15% of private costs), but in none of the considered cases high enough to give electric vehicles a financial advantage today. This picture will change in the future.

Introduction and motivation

Private transportation displays an elementary function of today's economic and private life. But while facing global major challenges like climate change, overall interconnections between social and economic systems have to be transformed towards environmentally friendly systems. The mobility sector in Germany is still responsible for 16% of overall greenhouse gas emissions (Umweltbundesamt, 2013) without high decreases in the past, even though significant gains in energy-efficiency of passenger cars are feasible at acceptable costs.

Electric vehicles have the potential to lower emissions and to contribute to the transformation of the mobility sector. Driving with electricity does not cause local emissions, greenhouse gas emissions are dependent on the form of electricity production. With renewable energies emissions can significantly be reduced. Anyhow, environmental potentials of electric vehicles still remain questionable because of higher emissions in production and the dependence on the form of electricity production. In addition, possible advantages of electric vehicles can only be realised, if the technology evolves in the market.

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For this, financial competitiveness of electric and conventional driven vehicles is a necessary condition, as costs display one of the most important criteria for the purchase decision (Sommer, 2011).

This situation leads to the research questions: Under which conditions can electric vehicles save emissions during the lifetime? Under which conditions are electric vehicles financially competitive for private consumers? What impact do external costs of emissions have to the total costs of vehicles? In-deep analyses of emissions and costs of electric vehicles in relation to conventional reference vehicles are needed to verify and quantify advantages of electric vehicles.

This study compares CO_2-emissions and private costs of small electric and combustion engine vehicles in Germany in three car classes. Additionally, this paper focusses on external costs resulting from the emissions of vehicles. Section 'Materials and methods' describes the methods and objects of the observation, Section 'Calculation of vehicle emissions' calculates emissions and Section 'Calculation of vehicles costs' costs of vehicles. Section 'Results' presents the results of emissions, private costs and external costs of vehicles. The final sections discuss the outcomes and conclude.

Materials and methods

Classification of the topic

The transformation towards an environmentally friendly mobility sector demands the reduction of emissions. This paper considers the environmental impact of small passenger cars by the investigation of greenhouse gas emissions as one factor of sustainable mobility (Prillwitz and Barr, 2011). The model in this paper focusses on CO_2-emissions. Furthermore, the financial competitiveness of electric vehicles determines their market success. This is influenced by private costs for the consumer, but from an environmental perspective also by external costs resulting from emissions during the lifetime. Only a combination of perspectives can ensure an environmentally friendly integration of electric vehicles in the mobility sector.

The research of this paper (especially the analysis of costs) refers to the work within the NET-ELAN project (Bickert, 2014; Linssen et al., 2012) and presents an update and major extension of the existing cost model by the investigation of emissions, the consideration of actual data and the integration of external costs into the model.

Besides to the NET-ELAN project, various studies analyse private plus external costs, emissions and the environmental impact of electric vehicles in comparison to other mobility concepts in Germany (Blesl et al., 2009; Dudenhöffer, 2010; Erdmann, 2009; Richter and Lindenberger, 2010; Rodt et al., 2010) and also in an European and international context (CONCAWE and EUCAR, 2007; Granovskii et al., 2006; van Vliet et al., 2011). The results in all of these studies point out that the form of electricity production highly influences the amount of emissions and thereby the environmental impact of electric vehicles. Private costs of electric vehicles exceed the costs of conventional vehicles. However, electric vehicles can gain cost advantages in the future, dependent on the assumptions made. External costs depend on the considered emissions and assumed abatement costs. Althaus and Bauer (2011) summarise results of eight studies for Switzerland and highlight the need for analyses of further developments of vehicles. The study of Notter et al. (2010a, 2010b) appears with well elaborated environmental impacts of the production phase of vehicles. Their results provide the basis for the production emission analysis in this paper. Helms et al. (2011) present comprehensive analyses of different vehicles and phases within the life cycle, whereby only modelled vehicles are used. The study underlines the low environmental impact of the phase after operation. Emissions of this phase are excluded from this analysis.

The existing literature and present conditions highlight the need for revised analyses of costs and emissions of vehicles. Changing framework conditions (e.g. ongoing developments in technology, prices and political objectives) demand updated investigations to achieve up-to-date and valid results. Due to a lack of data most existing studies refer to virtual electric vehicles. But since there are more electric vehicles in the market today, analyses need to be extended and reconsidered with data of real existing vehicles. Therefore, this study combines inputs from established studies with data of real existing vehicles to achieve high relevance and data quality of the results. Future technological developments are focused and supported by the consideration of different years of acquisition and scenario analyses. Assumptions for the calculations were discussed and validated within the NET-ELAN project within the consortium and in project workshops with experts from industry and research centres including engineers, economic and social scientists. Calculation results of the updated cost-model and emissions were discussed in internal workshops with researchers from the Chair of Production Engineering of E-Mobility Components, RWTH Aachen University to review the plausibility of the results.

With this, the paper provides an updated and extended scientific contribution towards an environmentally friendly mobility sector, focusing on the conditions in Germany. To the authors' knowledge, a comprehensive analysis in this detail with real existing vehicle data has not been applied for the considered framework conditions before.

Objects of observation

Vehicles

Electric vehicles are compared to gasoline driven internal combustion engine vehicles (ICE) as reference vehicles in the compact class, subcompact class and micro car class. The smaller car classes are especially considered because an increase of electric vehicles especially in these classes is predicted. For electric vehicles in all classes exclusively battery electric vehicles (BEV) are considered. Those vehicles have an electric engine and a battery to store a relevant amount of energy