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Agent-based modelling for assessing hybrid and electric cars deployment policies in Luxembourg and Lorraine

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ABSTRACT

Electric mobility is often presented as a way to tackle the environmental issues associated with individual mobility, provided that electric vehicles are adopted by drivers on a mass scale. In this paper, we propose an agent-based model (ABM) aiming at modelling the deployment of these vehicles. ABM is particularly indicated when modelling complex systems whose final results are the combination of the interactions between individuals and their environment and when the agents have partial information to take their decisions. We selected Luxembourg and its French neighbouring region, Lorraine, as the case study for our model, to test Luxembourg's ambitious objective of deploying 40,000 electric vehicles by the year 2020. Model results show that the number of battery powered electric vehicles in Luxembourg (including vehicles from Lorraine's commuters crossing the border every day) could be between 2000 and 21,000. A high number of commercial vehicles in Luxembourg, as well as an unlikely deployment in the neighbouring Belgium and Germany would therefore be required to meet the deployment objective. However, the deployment of plug-in hybrid vehicles could reach 60,000 cars by the end of 2020. To achieve this number, the deployment of charging points seems to be the more effective policy, along with actions aiming at increasing public awareness and acceptance of electric vehicles. The interest in using the ABM also lies in the identification of the main individuals' characteristics affecting the deployment of electric vehicles (household size, commuting distances, etc.), which further support the setting of public policies.

1. Introduction

1.1. Context

In Europe, road transport is a major contributor to air pollution. For instance it accounts for 33% of nitrogen oxides, 27% of carbon monoxide and 15% of volatile organic compounds emissions (EEA, 2013a). It is also the source of 19% of greenhouse gas emissions (EEA, 2013b) and it consumed 271 Mt of crude oil in 2011 (Eurostat), being one of the main sectors responsible for Europe's dependence on fossil fuels. Therefore, electric mobility is often presented as a way to decrease these burdens as well as a market opportunity for car manufacturers in a depressed European market.

Car electrification is a broad concept that can cover very different types of vehicles. It encompasses passenger as well as goods transportation, individual and collective mobility and can be more or less developed on the vehicle: from mild hybrid

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with stop and start systems to full hybrid, plug-in hybrid electric vehicles (PHEVs) and full battery-powered electric vehicles (BEVs). In this article, for the sake of simplicity and because of the case study further analysed, we will only consider passenger cars that use electricity from the grid, i.e. BEVs and PHEVs.

The potential environmental improvements associated with electric cars can only be visible if these mobility solutions are adopted on a mass scale. However, in 2012, 13,970 BEVs were sold in Europe, representing only 0.1% of the total passenger cars (12,000,000) sold that year (EEA, 2013c). At the Luxembourg's scale, out of the 50,000 vehicles sold in 2012, only 34 were BEVs (STATEC, 2013). Nonetheless, the Luxembourgish State has set an ambitious objective of 40,000 BEVs circulating in the country in 2020 (Gouvernement du Grand-Duché du Luxembourg, 2012a). Moreover, Luxembourg is a small country with peculiar characteristics inside the European Union. First, it is heavily dependent on its three neighbouring regions (Lorraine in France, Wallonia in Belgium and Saarland/Rhineland-Palatinate in Germany), with 160,000 commuters (half of them from France) crossing the border (CBCs, cross-border commuters) every day while only 203,000 workers are Luxembourgian residents (STATEC, 2013). As a result, Luxembourg cannot be completely isolated from its neighbouring regions when studying mobility issues. Secondly, Luxembourg has the highest rate of car possession in Europe (739 cars per 1000 inhabitants compared to 580 in France, according to the World Bank (2010)). Finally, the Luxembourgish sales repartition between private cars (PCs) and private/company mixed cars (PCMCs, i.e. cars that are leased or owned by a company but whose employees can benefit for private purpose) is heavily distorted towards PCMCs (18,000 PCMCs were sold in 2012 compared with 23,000 PCs, according to STATEC) compared with other EU countries (e.g. in Lorraine, 19,000 PCMCs were sold in 2012, compared with 40,000 PCs, Statistiques de la Grande Région).

1.2. Aim and scope

Given these disparities and the ambitious policy objective, the goal of the HELCAR project is to assess the potential environmental benefits, using a Life Cycle Assessment (LCA) approach (ISO, 2006a, 2006b), of the policies aiming at the penetration of BEVs and PHEVs in the Luxembourgish fleet by the year 2020. The present paper focuses on the first part of the research, i.e. modelling this penetration, by developing and validating a model including the economic, social and technical aspect that would lead to the deployment of these alternative vehicles. The development of an operational methodology to assess the environmental impacts associated with the deployment of electric vehicles will be presented in a companion paper. However, the granularity of the model described here, as well as its expected results, are driven by the data needed to perform the LCA (*Cf.* section 2).

The adoption of BEVs and PHEVs by Luxembourgish drivers is a complex system, as it involves mutually interacting entities and their environment at a mesoscopic scale (Bar-Yam, 2003). It is determined by the interactions between economic, political, technical, environmental and societal factors. Besides, the adoption of BEVs and PHEVs also influences the development speed of technologies, as well as their perception by drivers. Because of Luxembourg's strong dependence on its neighbouring countries, we will also study Lorraine, the largest neighbouring region in terms of number of cross-border commuters. The region is also selected because of the strong incentive framework currently in place in France. The approach retained is agent-based modelling (ABM), where a synthetic population of drivers uses the vehicles according to a defined set of rules and take the decision to buy new cars (possibly electric cars) depending on other rules interpreting the surrounding context. Indeed, different studies have already been conducted, using ABM to assess the penetration of alternative vehicles in the fleet (Eppstein et al., 2011; Mueller et al., 2009; Shafiei et al., 2012; Zhang et al., 2011) with conclusive results that are described in the section 1.3. The ABM developed here is presented in section 2.

1.3. State of the art

Fostered by the progress of computing power, ABM is more and more used in scientific research. In the literature, research on ABM has been conducted for activity agenda design and vehicle choice modelling. We therefore follow this line of research to assess electric vehicles deployment.

Activity agendas, especially concerning urban mobility, are often studied to identify mobility patterns, in order to improve urban planning. While some authors tend to reduce human mobility to a mere Brownian movement (Song et al., 2010), others have shown that it is in fact quite a predictable and highly repetitive process (Gonzalez et al., 2008). For instance, Newsome et al. (1998) proposed the first conceptual spatiotemporal model for urban activities prediction. Kuppam and Pendyala (2001) put into equations commuter activities and travels, based on socio-demographical data. Arentze and Timmermans (2000), Arentze et al. (2000) proposed the ALBATROSS model, establishing the first reference in ABM for activity-agenda forecasting. De Witte et al. (2013) have published a thorough review of the existing literature on modal choice modelling. All these models need statistical and geographical data, in our case those from the CERTU methodology used for French cities (CERTU, 1998) or, for cross-border commuting in Luxembourg, data from Schmitz et al. (2012).

In order to model the choice of new vehicles, Bhat et al. (2009) proposed a model characterising the impacts of demographics, built environment attributes, vehicle characteristics and gasoline prices on the choice. The latter is, however, adapted to the U.S. market and requires too many data to be used for our case. Eluru et al. (2010) proposed an econometric model for vehicle choice, also fitted to the U.S. conditions. At the Swiss level, Peters et al. (2011) showed that the choice of a car with lower fuel consumption is dependent on three hypotheses: personal attitude, ecological perception and social norm, and economical motivations. Mueller and de Haan (2009) studied the effect of incentives on the decision process of