DEFINITION AND INFLUENCE OF FUNCTIONAL UNIT IN LCA OF ELECTRIC AND PLUG-IN HYBRID VEHICLES APPLIED TO IMPLANTATION SCENARIOS

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ABSTRACT

Life Cycle Assessment (LCA) studies of electric mobility are often limited to the comparison of few electric vehicles (EVs) with their internal combustion engine (ICE) counterparts, suffering from an unclear definition of the functional unit. This bias has potentially significant repercussion on the assessment of the environmental consequences of mobility policies and objectives fixed by European states. This paper aims at proposing a multi-agent model in order to assess the vehicle market of Luxembourg and how the ICE vehicles are going to be replaced by EVs. This model can thus help us to define the functional unit associated with electric mobility, whether it is applied to individual, company or shared cars and feed consequential LCA of policy and implementation strategies.

INTRODUCTION

Context

Electric (EVs) and plug-in hybrid (PHEVs) vehicles are often presented as a way to limit the impact of individual mobility on climate change, air pollution and oil depletion as well as an opportunity for carmakers in a mature European market. Accordingly, member states have started defining mobility policies involving ambitious targets, such as for example the Luxembourgish government which has set an objective of 40,000 electric vehicles in 2020, representing grossly 10% of the circulating fleet.

State of the art

Most of the literature LCA studies have been conducted to assess specific vehicle types and for comparative purposes at technological level, without addressing the overall environmental impacts of these mobility policies. For instance, Notter et al. (2010) have studied the environmental impact of a segment C (VW Golf, Renault Mégane, etc.) electric vehicle with its comparable internal combustion engine vehicle (ICEV). Hawkins et al. (2013) have compared a Nissan Leaf to a Mercedes A-Class. While providing interesting insights as well as proposing inventories for electric vehicles, none of these studies can directly answer the question of deployment policies. Indeed, Hawkins et al. (2012) have conducted a review of the available studies and showed that, depending on the hypotheses retained, the results could greatly vary. The role of the functional unit appears to be crucial (for instance compared cars, lifetime of the battery or lifetime of the car).

Objectives

The goal of this work is to assess the environmental consequences of EV deployment policies in Luxembourg and the Greater Region. For this purpose, a model has been developed to forecast EVs and PHEVs deployment in the circulating fleet, for individual vehicles as well as for company fleet cars and car-sharing. Since Luxembourg is strongly dependent on neighbouring regions (Belgium, France and Germany), Lorraine, a bordering French region, is also included here.

MATERIALS AND METHODS

NetLogo

To calculate the environmental impact of various EV deployment scenarios, a multi-agent (M-A) model has been designed. The model is based on NetLogo, a software tool enabling M-A programming of complex phenomena (Tisue & Wilensky, 2004). M-A modelling allows to simulate complex systems by giving a set of attributes and rules to individual agents that will react to external conditions and toward each other. Here, we use M-A modelling to represent the behaviour of Luxembourg and Lorraine inhabitants towards cars. The purpose of M-A modeling is twofold: it allows simultaneously assessing if an individual would change for an EV or a PHEV and it calculates the characteristics and mileage for every vehicles running.

Synthetic population

The first step to assess the effect of EV policies on the fleet is to build a synthetic population of agents owing a car. This is done by using macro statistics, mainly from STATEC[1], INSEE[2] and Eurostat[3]. The main data used are number of inhabitants, active population, retired population, household composition and car ownership. Considering the detailed composition of the fleet and car types sold in 2012, vehicles are distributed amongst the agents, distinguishing between main or secondary vehicles for households owing at least two cars. Each agent has a set of characters, defining, for instance: the distance between home and work, parking possibilities, attitude towards EV and PHEV or mobility needs. Once the synthetic population is defined, simulations are run, for a time step of one hour and over a given timeline (for instance 5 or 10 years). The agents can then react, considering external conditions and their own set of rules.

Activity chains

For each simulation day, each agent has its chain of activities describing, for each hour, if he will use its car and what distance he will drive for various activities such as commuting, shopping, picking children at school, etc. The activity modeling approach is based on daily-

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[1] http://www.statistiques.public.lu/fr/acteurs/statec/index.html
[2] http://www.insee.fr/fr/
[3] http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/

based activity agendas for mobility, such as defined by Arentze & Timermans (2009) and Becks et al. (2009). This daily agenda will thus determine, for each agent, how many kilometers will be driven during the day and, if applicable, when the EV or PHEV will be charged. Thus, the use of the car for one day is unique for each agent, considering its agenda and which type of car he uses (own, fleet or car-sharing).

Car changing process

For every month of the simulation, a car-changing process occurs when a car is old enough to be dismantled or when an agent wants to change its car. Different decision trees have been designed, for EV and PHEV buying and depending on the type of car which is bought (personal or company fleet). For instance, before buying an EV, an agent will ask himself, considering its own characteristics and external factors (such as the price of fuels and electricity, incentives, prices and technical characteristics of EVs...): can I park and charge an EV? Is the range sufficient for my mobility needs? Am I ready to change for a new technology? Is a car model available in the fleet of vehicles sold by the targeted car manufacturer, having the necessary performances (size, acceleration, type of body, etc.)? Is the cost of EV competitive enough? If all the answers are positive, the agent will then buy an EV and start to use it. If not, he will buy a new ICEV.

The combination of synthetic population, activity chains and monthly car-changing process can thus model the deployment of EVs and PHEVs for a given territory, with given policies (e.g. incentives or deployment of public charging infrastructures). It also defines the functional unit of EVs for different types of uses, since it allows knowing how the EVs and PHEVs are used and which car they actually replace.

RESULTS

EV and PHEV deployment

In figure 1 are presented the results of the deployment of EVs and PHEVs for Luxembourg and Lorraine residents (only private vehicles, i.e. company fleet cars are not included). The main differences between these two regions are: the incentive value (5,000€ in Luxembourg, 7,000€ in Lorraine), the distance travelled, the purchasing power and the car market. As a consequence, the penetration of EV and PHEV are not the same for the two regions. The deployment of EVs and PHEVs is higher in France and Lorraine, because of the value of the incentive, though at the beginning the deployment is faster in Luxembourg because of its higher renewing speed.

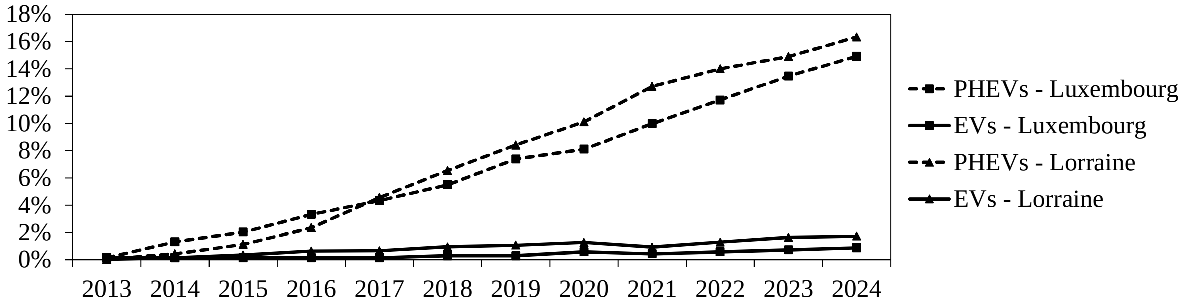

Figure 1. Share of EVs and PHEVs in the circulating fleet in Lorraine and Luxembourg

Functional unit

The functional unit for EVs and PHEVs is defined by the mileage per day, the total mileage and the replaced vehicles. For instance, Table 1 shows the average commuting distance per day for different types of vehicles at the end of the simulation (year 2024).

Region	ICEVs	PHEVs	EVs
Luxembourg	14 km / day	14 km / day	17 km / day
Lorraine	15 km / day	19 km / day	19 km / day

Table 1. Commuting distance for ICEVs, PHEVs and EVs in Luxembourg and Lorraine.

Though EVs are frequently seen as “urban” cars, it is shown here that they tend to replace the vehicles with longer commuting distances, since the main benefit of EVs is their cost / km. PHEVs can also be used for longer distance. However, the mileage of EVs per year is significantly higher for EVs than for ICEVs because 92% are used for commuting, while this share falls to 46% for ICEVs at the end of the simulation.

DISCUSSION AND FURTHER RESEARCH

The model developed is still in its preliminary stage and is now being validated for the Luxembourgish context. Many parameters can vary, thus leading to very different results. It is now necessary to study the influence of these parameters and, since many of them are linked, define some cornerstone scenarios as defined by Pesonen et al. (2000).

The agent based model will be coupled with LCA data to assess the environmental impact of the various scenarios. These data will have to cover the different types of cars included in the model (ICEVs, PHEVs, EVs of different sizes) and be updated during the simulation (for instance, if the simulation duration is 10 year, the electricity mix shall be updated).

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