

A FLEET-BASED LIFE-CYCLE ASSESSMENT OF ELECTRIC VEHICLES IN PORTUGAL

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Abstract *The adoption of alternative vehicle technologies and fuel pathways has been presented as a way of reducing the use of energy and fossil fuels as well as the emission of pollutants in the transportation sector. The assessment of the environmental impacts of these emerging technologies and pathways requires a life-cycle approach in order to avoid environmental-problem shifting. Moreover, the selection of new technologies and related systems choices may require both a dynamic approach and a change-oriented approach to tackle indirect effects, such as an increase on electricity demand or a shift in the energy pathway. This paper proposes a novel life-cycle (LC) modelling framework incorporating consequential and dynamic fleet-based modelling for the environmental assessment of electric vehicle (EV) systems in Portugal. Life cycle (LC) primary energy consumption and GHG emissions for the Portuguese passenger vehicle fleet over the 1995-2030 period were calculated for two extreme fleet penetration scenarios. Preliminary results show that a high penetration of EVs can reduce energy consumption by 32% and GHG emissions by 27%, compared to a fleet with no EVs. The results are particularly sensitive to the annual fuel and electricity consumption reduction in new vehicles and the electricity generation mix.*

1. INTRODUCTION

The transportation sector is responsible for a large portion of the energy consumption and pollutant emissions. About 32% of the final energy consumption in the EU-27 [1] and 37% in Portugal [2] are transport-related. It is crucial to reduce the use of fossil fuels and emission of pollutants in the transportation sector and several measures have been proposed. One of these measures is the displacement of conventional fuels and engines (e.g. diesel, gasoline) for alternative vehicle technologies and fuel pathways, e.g. battery electric vehicles, plug-in-hybrid vehicles, or biofuels.

The assessment of the environmental impacts of these emerging technologies and pathways requires a life-cycle (LC) approach in order to track all stages of the product life cycle and avoid environmental-problem shifting. Moreover, the question of whether and when the substitution of old vehicles for new, cleaner and efficient alternatives is environmentally beneficial requires simultaneously a dynamic fleet approach and a change-oriented approach to tackle indirect environmental impacts, such as an increase in electricity demand or a shift in the energy pathway.

This paper proposes a novel LC modelling framework incorporating consequential and dynamic fleet-based modelling for the environmental assessment of electric vehicle (EV) systems in Portugal. LC primary energy consumption and GHG emissions of the Portuguese passenger vehicle fleet over 1995-2030 time period were calculated for two extreme fleet penetration scenarios. This paper presents an overview of the framework together with some preliminary results. This research is currently being developed in the scope of a doctoral dissertation (first author) in Sustainable Energy Systems.

2. LITERATURE REVIEW

Life cycle assessment (LCA) aims at estimating the environmental impacts of a product throughout its entire life cycle. One of the applications of LCA is the comparison of alternative products for decision support. There are several studies that have evaluated the environmental impacts associated with electric vehicle (EV) production and use (e.g. [3][4][5][6][7][8]). Most of these studies use the traditional LCA approach, so called attributional LCA, which is not able to assess system changes comprehensively. Moreover, most of them are static analyses of single vehicles. Field et al. [9] demonstrated that static single vehicle analysis can have significantly different outcomes from dynamic fleet-based analysis. However, the few studies comprising a fleet approach lack an integrated perspective on the effects of EV introduction on the grid, namely by either not extensively modelling the electricity sector and/or not comprehensively addressing parameters such as recharging behavior or fleet penetration rates [10][11]. Moreover, the majority of the studies only considered GHG emission reductions, while other impacts were excluded from the assessment.

In order to assess the impacts of the introduction of EVs in the vehicle fleet and its consequences on the electricity grid, both a fleet-based and a consequential approach are needed. A fleet-based LCA is able to grasp the dynamics of a transition to EVs and, at the

same time, provides an appropriate unit for assessing the effects on the grid. On the other hand, consequential LCA is able to comprehensively address those effects, since it aims to answer the question of which effect the decision to purchase an additional kWh of electricity has on the electricity market and on the environmental impacts [12].

3. RESEARCH APPROACH

The development of a LC framework incorporating consequential and fleet-based modelling for the assessment of electric vehicle systems requires the modelling of both the transportation and electricity systems. Therefore, the research encompasses the development of three models: i) a model of the Portuguese passenger vehicle fleet until 2030; ii) a comprehensive life-cycle (LC) model of the Portuguese electricity sector; and iii) a fleet-LCA model of the passenger vehicle system, which combines the previous two. This paper focuses on the fleet model and on a first approach to the fleet-LCA model. Two extreme scenarios regarding EV penetration in the fleet are implemented and a sensitivity analysis to the most relevant fleet model parameters is also performed.

3.1. Fleet-based life-cycle model

A spreadsheet-based fleet model of the vehicle stock, automotive material, fuel and electricity use, and the corresponding life-cycle primary energy consumption and GHG emissions over time, from 1995 to 2030, was developed. Figure 1 shows an overview of the LC-fleet model, which addresses six different vehicle technologies (i.e. powertrains): battery electric vehicles (BEV), plug-in hybrid electric vehicles of 10- and 40-mile range (PHEV10 and 40), hybrid electric vehicles (HEV), gasoline internal combustion engine vehicles (gasoline ICEV) and diesel internal combustion engine vehicles (diesel ICEV). The following main life cycle phases were considered: materials and vehicle production; fuel and electricity production; and vehicle use. For the EVs (BEVs and PHEVs), a LC model of electricity generation in Portugal was developed, including the modelling of the main electricity generation systems used in Portugal (e.g. coal, natural gas, biomass, wind, hydro).

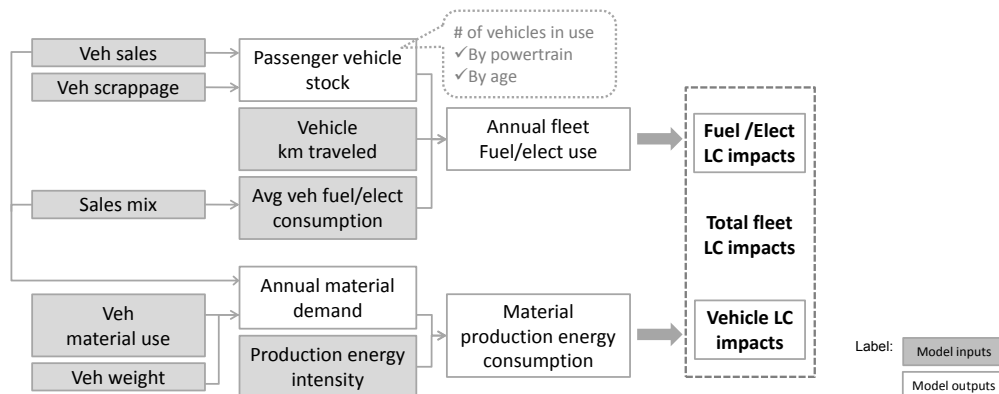


Figure 1. Overview of LC fleet model (veh: vehicle).

The LC fleet model estimates the annual stock of vehicles by powertrain, the age of vehicles in the fleet, and the number of vehicles, by year of production, that leave the fleet every year, from 1995 up to 2030. Preliminary results regarding fleet-LC energy consumption and GHG emissions over the 2010-2030 time period are presented in the next section, as a result of the implementation of two extreme scenarios: i) a business-as-usual (BAU) fleet dominated by ICEVs (BAU scenario); and ii) a fleet integrating EVs (electrification scenario).

Figure 2 shows the share of each vehicle technology in the fleet according to the two scenarios. The BAU scenario assumes no penetration of electric vehicles in the fleet and that gasoline/diesel share stabilizes at 30/70 in 2030. The electrification scenario assumes a total electric new vehicle fleet, comprised of 25% of PHEV10, 25% of PHEV40 and 50% of BEV. In the electrification scenario, the total fleet is composed of 37% of diesel ICEV, 26% BEVs, 16% of gasoline ICEV, 12% PHEV40 and 12% PHEV10 in model year 2030. It should be noticed that more than 50% of the fleet in 2030 is still comprised of ICEVs, which results from ICEVs on the road today and new ICEVs entering the fleet until 2030.

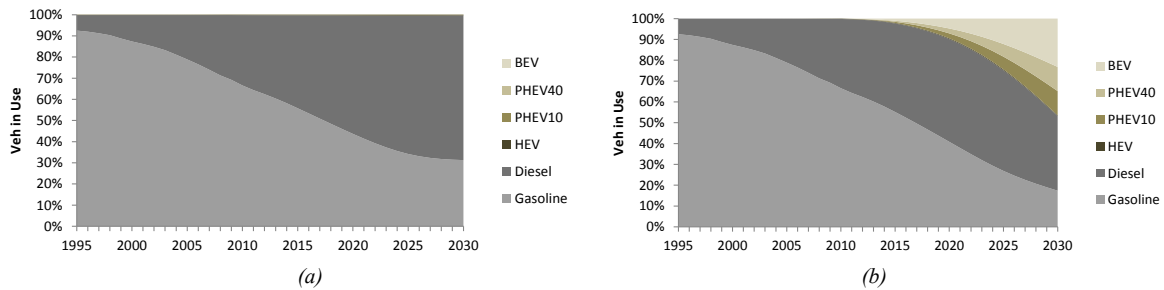


Figure 2. Share of vehicle technologies in the fleet in the BAU scenario (a) and electrification scenario (b).

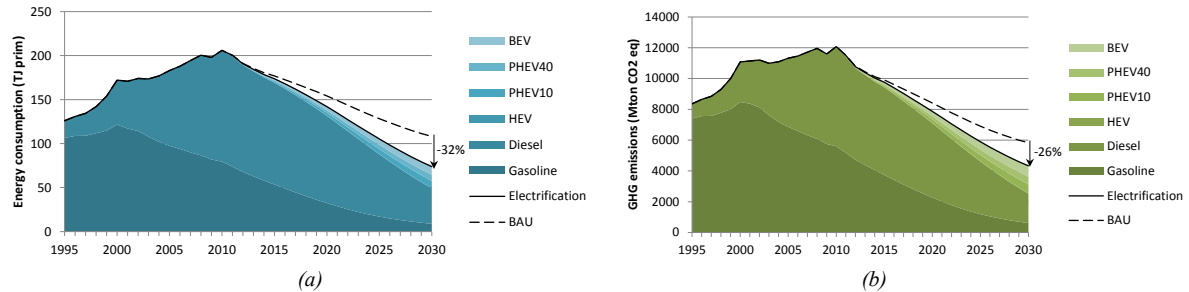


Figure 3. Fleet LC primary energy consumption (a) and GHG emissions (b).

A sensitivity analysis to the influence of the most relevant model parameters (annual fuel consumption reduction in new vehicles; short term (2006-2020) and medium term (2020-2030) vehicle kilometre travelled annual growth; average annual growth in total vehicle sales; and electricity mix in 2030) in the fleet LC GHG emissions in 2030 for both BAU and electrification scenarios was performed. Table 1 shows the minimum and maximum values considered for each input parameter. Figure 4 shows the difference in results between the baseline (BAU: 5832 Mton CO₂ eq; electrification: 4336 Mton CO₂ eq) and the results

obtained by changing each parameter at a time according to the values in Table 1. Similar results were obtained for primary energy. As can be seen, depending on the fleet penetration scenario considered, the relative importance of the parameters in the results differs. The annual fuel consumption reduction in new diesel ICEVs is the parameter that influences the most BAU scenario results (up to 22% compared to the baseline). For the electrification scenario, results are also sensitive to the annual fuel consumption reduction in new gasoline vehicles (ICEVs and PHEVs), the annual electricity consumption reduction in new EVs and the electricity mix (around 6% compared to the baseline). For the other parameters, differences are less than 4% compared to the baseline.

Table 1. Input parameters for sensitivity analysis.

Parameters	Min	Baseline	Max
Annual FC reduction new DICEVs [13]	-4%	-2%	-0.2%
VKT annual growth (2006-2020) [13]	0.26%	0.50%	0.74%
Annual FC reduction new GICEVs [13]	-4%	-3%	-0.5%
Avg. annual growth in total veh sales [14]	-0.09%	0.10%	0.29%
VKT annual growth (2020-2030) [13]	0.07%	0.25%	0.43%
Annual veh weight reduction [15]	-2%	-1.30%	-0.50%
Annual Elec. C reduction new EVs [13]	-6.5%	-2%	0%
Electricity mix in 2030	30% non-renewable ^a	2012 mix ^b	70% non-renewable ^c

^a 35% wind, 30% hydro, 15% coal; 15% NG, 5% biomass;

^b 25% coal, 20% NG, 20% wind, 13% hydro, 6% biomass, 16% imports;

^c 35% coal, 35% NG; 15% wind; 15% hydro.

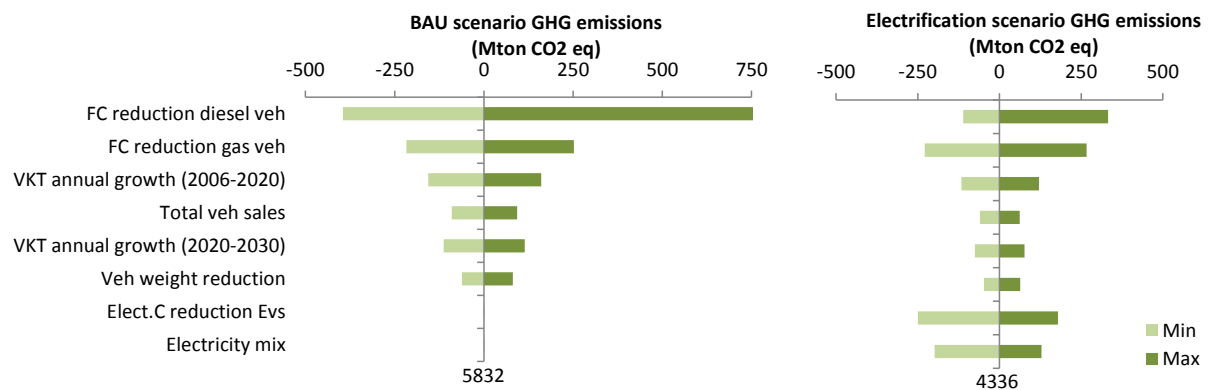


Figure 4. Sensitivity analysis results for fleet LC GHG emissions in model year 2030 (FC: fuel consumption; VKT: vehicle kilometer travelled; veh: vehicle).

5. CONCLUSIONS

This paper presented an overview of a novel consequential fleet-based LC modelling framework developed to assess EV systems. LC primary energy consumption and GHG emissions for the Portuguese passenger vehicle fleet over the 1995-2030 period were calculated for two extreme fleet penetration scenarios. Preliminary results show that a high penetration of EVs can reduce primary energy by 32% and GHG emissions by 26%,

compared to a fleet with no EVs. The results are particularly sensitive to the annual fuel and electricity consumption reduction in new vehicles and the electricity generation mix. A comprehensive model of the electricity system as a function of the recharging profiles of EVs and fleet penetration rates is currently being developed to capture the consequences of an increase in electricity demand due to the introduction of EVs in the fleet.

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