Electric vehicle diffusion in the Portuguese automobile market

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Measures to decrease carbon dioxide emissions have been put into action not only to meet the Kyoto Protocol targets but also to improve the air quality and decrease the dependency on foreign oil products. The present research focuses on EVs as part of the Portuguese policy to make the transportation system more energy and environmentally efficient. The main goal is to estimate the fleet wide energy consumption and corresponding CO$_2$ emissions up to 2030 and examine to what extent the introduction of EVs will reduce those indicators through a system dynamics model of the Portuguese car fleet. It was found that EVs can reach up to 7.6% of the total vehicle fleet by 2030 whereas hybrid vehicles could reach up to almost 60%. A decrease in energy intensity (in toe/10$^3$€) and carbon intensity (in ton CO$_2$/toe) of at least 51% and 5%, respectively, compared to the 1990’s levels, can be achieved. These results show that, despite the higher concern for the environment, people will hardly shift to EVs. Hybrid vehicles will emerge as the best solution as people struggle to lower their fuel budget while maintaining their current travel demand.

**Key-words:** Electric vehicle, technology diffusion, car fleet, discrete choice model, scenario analysis, Portugal

1 Background

In 2010, Portuguese GHG emissions without land-use, land-use change and forestry were estimated at about 70 Mt CO$_2$eq (17% increase since 1990) [1]. Energy is the highest emitting sector accounting for 70.8% of total GHG emissions in 2010 and about 92% of total CO$_2$ emissions as, during the period 1990-2010, 83% of the primary energy consumed was produced from fossil fuel combustion [1]. Transportation has had a 89.6% increase in exhaust GHG emissions (90.4% increase in CO$_2$ emissions) since 1990 [1] due to the rapid growth in private car ownership and road travel both associated with the increase in household income and supported by the strong development of road infrastructure. The Kyoto Protocol establishes emission reduction targets and, under the EU burden-sharing agreement, Portugal is committed to limit its emissions, in the first commitment period, to no more than +27%.

The present research focuses on the transportation sector, and more specifically, on the electric drive vehicles as part of the Portuguese policy to make the transportation system more energy and environmentally efficient. The Program for Electric Mobility was created under the National Energy Efficiency Action Plan (Plano Nacional de Acção para a Eficiência Energética) in order to launch and promote electric mobility in Portugal. Financial incentives of 5,000€ to the first 5,000 private purchasers of an EV, plus 1,500€ in case of scrappage of the replaced ICE vehicle, were established as well as the exemption of vehicle purchase and circulation taxes. In addition, an income tax benefit for private buyers of about 800€ per vehicle was instituted. The Portuguese Government and the Renault-Nissan Alliance partnership established a supply of EVs in early 2011 while an extensive charging network would be built across Portugal, responsibility of MOBIE. In a pilot phase, 1300 normal charging points (charge in 6 to 8 hours) and 50 rapid charging points (charge in less than 30 minutes) are to be installed all over the country by the end of 2011. Currently, there are 1,166 charging points in 425 charging locations [15].

The main goal is to analyze to what extent electric vehicles are expected to diffuse in the Portuguese car fleet and to estimate the resulting fleet wide energy consumption and corresponding CO$_2$ emissions up to 2030. This will be analyzed for three scenarios as well as several transportation policy instruments.

schemes are ideal to reduce regulated emissions (CO, NO$_x$, NMHC) but not CO$_2$ emissions from a life-cycle emissions perspective. Regarding the implementation time, it is suggested that these schemes are only temporarily effective when there are many "dirty" vehicles (Kim et al, 2004 [11]) and so should be implemented as a "one-shot" program. Permanent scrappage schemes may even have negative environmental effects (ECMT, 1999 [18]). Cash-for-scrappage schemes were found to be more efficient than cash-for-replacement ones as they do not have any obligations concerning the replacement choice (ECMT, 1999 [18]).

An alternative is changing the structure of the taxation system (ECMT, 1999 [18]). The german experience showed that the annual taxation of older vehicles according to their emissions characteristics can accelerate the replacement of old vehicles. Enhancing inspection and maintenance programs, particularly the environmental component, can also encourage the replacement of a vehicle if its operation becomes too costly. A final alternative is replacing vehicle parts that may be responsible for the low environmental performance of the vehicle instead of replacing it entirely.

According to Eggers et al (2011) [7], there are limitations to the adoption of alternative fuel vehicles if there are no incentives or regulations which may include tax reductions, the development of public charging stations and the education of vehicle buyers about environmental consciousness. A feebate system to switch to more energy-efficient vehicles while keeping the same vehicle size was found to achieve a 3.1-3.3% and a 2.8-3.3% reduction in fuel consumption and CO$_2$ emissions, respectively, without significant market disturbance (de Haan et al, 2009 [6]). A 33% emission reduction in hydrocarbon emissions can be achieved when the combination of feebate systems with scrappage programs is implemented (BenDor et al, 2006 [4]). Mabit et al (2010) [14] concludes that if EV tax reductions were to be implemented, these vehicles could reach a market share similar to ICE vehicles. All implemented policies meant to introduce cleaner technologies must be strong and stay in force for extended periods of time in order to let them develop until they can compete with the conventional ones (Köhler et al, 2009 [12]).

There are also policies to reduce emissions that involve lifestyle changes which include switching to public transports, or even to slow modes such as cycling or walking, switching to homeworking (ICT) and creating mixed-zone developments which decrease the demand for transport. Köhler et al (2009) [12] conclude that technological transitions are more likely to occur than lifestyle changes.

The literature suggests two main modeling techniques to analyze the transportation system, as well as the effect of implemented policies, that differ in terms of the aggregation that is presumed in agents: a System Dynamics Modeling approach (SDM) and an Agent-Based Modeling approach (ABM). In ABM, objects are individualized, their behavior rules stated and implemented, and their direct or indirect interaction takes place in a predetermined and designed environment. In SDM, the information is aggregated in levels and the interaction between various elements is done through stock-and-flow diagrams and their respective feedback loops that will dictate the rate and direction of change in the system.


The literature review shows that the SDM methodology is strongly suitable to approach modeling in the energy and transportation sector whereas some characteristics of ABM are not determining factors (relationship between agents and their environment).

2 Methodology

Both energy consumption and CO$_2$ emissions evolution are estimated through a system dynamics model of the Portuguese car fleet that include among others, the following variables: macro-socioeconomic drivers (demography and Gross Domestic Product), annual average mileage per inhabitant, motorization rate, modal share, energy costs, vehicle costs, fiscal taxes and subsidies, modal share, technological structure of the fleet (concerning both vehicle and fuel technologies) and the annual mileage of vehicles (see Figure 1). In this model the car stock is divided into six fuel technologies (gasoline, diesel, LPG, hybrid, diesel hybrid and pure electric), four types of vehicles based on their average size and use (city, utility, family and SUV) and, finally, in thirty segments based on their age (from new cars (zero years) to 30 year old vehicles).
For each year, the model calculates the total number of new vehicles based on the estimated motorization rate until 2030 and the retirement of used cars. The market share of new vehicles is used to calculate the distribution between fuel technologies and vehicle types and estimate the technological turnover of the fleet. The estimation of market shares is based on Rational Utility Maximization (RUM) theory by estimating a Discrete Choice Model where utility functions measure the satisfaction perceived by consumers when deciding upon a finite set of mutually exclusive alternatives (in this case, combinations of fuel technology and vehicle type). A series of discrete choice model specifications were made in order to calibrate the utility functions of the alternatives considered, using the software LIMDEP, based on data collected from a Stated Preferences survey for Portugal.

The methodology adopted is similar to that described in Moura (2009) [16]. According to the car ownership model classification by Jong et al. (2004) [10], Moura (2009) [16] develops a combined model of aggregate time series to estimate the car demand over time (motorization rate) with a static disaggregate car type choice model to build an approximation of the Portuguese car fleet. In aggregate time series models, the development of car ownership over time (as a function of income or GDP) is modeled by a sigmoid-shape function, that is, it increases slowly in the beginning, then rises steeply and by the end approaches a saturation level (Jong et al., 2004 [10]).

Despite the fact that the same combination of models will be used, the static disaggregate car type choice model (forecast the size and composition of the car fleet) will not be the same as the choice set does not include EVs resulting in the exclusion of the most relevant EV attributes.

In Beggs et al. (1981) [3], vehicle descriptions consisted on combinations of the attributes: initial price, fuel cost per 10,000 miles, conventional gasoline powered or battery powered, full tank/charge range, top speed, acceleration, number of seats, air conditioning and type of warranty. In Calfee (1985) [5], five attributes were included in the estimated utility function: purchase price, capacity, top speed, daily range, operating costs and an EV dummy. Mabit et al. (2011) [14] estimate a mixed logit model with random effects where the vehicle attributes considered were: purchase price, annual cost (maintenance and fuel costs and annual taxes), operation range, refuelling frequency, acceleration time and a service dummy (needs service.
and repairs beyond those included in the maintenance cost attribute). In Lieven et al. (2011) [13], price, maximum cruising range, environmental impact, performance, durability and convenience are the attributes considered to influence consumer choice. Eggers et al. (2011) [7] concludes that there are several critical factors for the adoption of EV: purchase price, range, timing of the market entry and environmental evolution. The vehicle attributes included in Hidrue et al. (2011) [8] are: driving range, charging time, fuel saving, pollution reduction, performance (acceleration) and price difference.

Taking into account this review, each vehicle presented in the Stated Preferences survey for Portugal is characterized by seven attributes: fuel technology, price, operational costs, number of makes and models in the market, maximum velocity, range and refueling time. Four scenarios were presented to each respondent who was asked to choose one vehicle in each. Each scenario had four vehicles to choose from: a city car, a utility car, a family car or a SUV.

The execution of the system dynamics model involves solving differential equations in order to reach the final behavior of the system. Software tools use simulation for computing results time step by time step, computing the changes in stocks resulting from the relations in the stock and flow diagram, avoiding complete equation solving and thus making the process viable. One such example of simulation software is Anylogic®, produced by XJ Technologies, used in this research. A time step of one year was used and the calculations started in 1960 so that the 30 year old vehicle fleet was complete by 1990 (base year for the Kyoto Protocol emission reduction program).

Only CO$_2$ emissions are taken into account due to the fact that these make up almost 100% of the total road transport emissions. Further reductions in other GHG emissions are no longer cost effective (cost-effective measures already implemented) due to technological barriers and, as such, are not considered. Lifecycle CO$_2$ emissions will be accounted for in this research.

The variables used as indicators were chosen in order to analyse how each scenario affects the vehicle fleet, and its characteristics, as well as the final fuel demand. As such, the structure of the fleet, that is, the percentage that each fuel technology occupies in the market was chosen as one indicator. This will demonstrate, for example, whether the innovative technologies (hybrid and pure electric vehicles) penetrate the market. Furthermore, the energy intensity (EI) is calculated for each scenario. EI is the ratio between total consumption and GDP, thus measuring the impact of the car stock technological evolution on the Portuguese economy. The same indicator could be calculated for the carbon intensity (CI) of the Portuguese economy but similar results would be obtained. Therefore, an additional indicator of CI was calculated (ratio between total emissions and total consumption) to quantify the impact of EV policies on the car stock overall intensity.

\[ EI \ [\text{toe}/10^3€] = \frac{\text{Total fuel consumption}}{\text{GDP}} \]

\[ CI \ [\text{ton CO}_2/\text{toe}] = \frac{\text{Total CO}_2 \text{ emissions}}{\text{Total fuel consumption}} \]

3 Scenario and policy analysis

Scenarios are conjectures about what can happen in the future based on our past and present experience of the world (IEA, 2003 [9]). Scenario planning uses alternative scenarios to assess the future where each scenario is a plausible evolution of key factors, although nothing can be said about its likelihood of occurring. In “Energy to 2050 Scenarios for a sustainable future” (IEA, 2003 [9]), the energy system is under investigation and the key factors that affect the system (main drivers that have a potentially high impact on the system) were identified based on existing knowledge: speed of technological change; attitudes and preferences towards the global environment; economic growth; population growth; globalisation and degree of market openness; structure of power and Governance and global security issues.

In this research, only the first three are considered although it is believed that the speed of technological change is closely related to economic growth as the latter is essential to obtain the former. As such, economic growth/technological change and environmental concern were chosen as the axes along which the scenarios are characterized. The axis on economic growth varies from stagnation to fast growth and the environmental concern axis varies from unconcerned to concerned. An infinite number of scenarios can be studied taking into consideration the two-dimensional space formed by the two axes. However, following the methodology used by IEA (2003) [9], only the extreme cases will be studied (shown in figure 2). “By focusing on the extreme cases
we have a chance to explore the full range of uncertainties deriving from those factors/drivers”, as stated by IEA (2003) [9].

Figure 2: Explanatory scenarios (based on the IEA - Energy to 2050 Scenarios for a sustainable future [9])

**Clean but not sparkling** describes a future where economic growth is slow but there is high concern for the environment. In **Dynamic but careless**, the future is characterized by a fast economic growth but a low environmental concern. Finally, in **Bright skies**, there is a fast economic growth coupled with a high concern for the environment. The qualitative directions of change of the key factors of the studied scenarios are presented in the table below where “**Stagnation**” is the reference scenario.

Table 1: Explanatory scenarios - Qualitative directions of change

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<tr>
<th></th>
<th>GDP</th>
<th>Fuel efficiency</th>
<th>Motorization rate</th>
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<tr>
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<td>→ →</td>
<td>→ →</td>
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<td>Dynamic but careless</td>
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<td>↑ +</td>
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<tr>
<td>Bright skies</td>
<td>↑ +</td>
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A series of transportation policy instruments, mainly applied to the taxation system, will be implemented in each scenario in order to observe which is the most efficient in decreasing total emissions and increasing the EV diffusion. Increases in the petroleum products tax (TPP), meant to encourage the purchase of either more fuel efficient vehicles or even EVs, the vehicle purchase tax (VPT) and vehicle circulation tax (VCT), to encourage the purchase of vehicles with lower emissions (g/km) or even zero emissions (EV), will be studied. In addition, the effect of a mobility electricity tax (MET), applied only for EV charging and used to make up for the lost tax income provided by fossil fuel sales, will be examined. All of these taxes have a direct impact on the consumers’ vehicle choice (TPP, VCT and MET on the operational costs and VPT on the car price). The effect of a 50% increase of these policies will be examined for each scenario.

Regarding the “Bright skies” scenario, two further policies will be applied: a policy which encourages the diffusion of rapid charge points for EVs as this is thought to accelerate the penetration of EVs in the market and an urban sprawl control policy where individuals are encouraged to change their lifestyles decreasing the travel demand per capita.

4 Results and Discussion

The results presented in the following sections will be compared with the reference scenario (“Stagnation”) using the indicators described above. The final year of simulation is 2030 whose results are compared with those of 1990 (reference year of the Kyoto Protocol).

The reference scenario assumes that: current transportation policies regarding the taxation system are maintained up to 2030, ICE vehicle fuel efficiency increases over time by 1.5% per year and GDP remains constant from 2010 until 2030 (null GDP growth rate).

Energy and carbon intensities decrease over time (shown in figure 3), as expected, as fuel consumption decreases due to the introduction of hybrid vehicles and EVs in the market. These vehicles reach 67% of the automobile market by 2030, out of which 60% are hybrids, making fuel consumption decrease rapidly. Carbon intensity decreases as the diffusion of EVs in the market increases, reaching 8% in 2030. As these vehicles have a much lower CO$_2$ life-cycle emission factor, CO$_2$ emissions decrease faster than total fuel consumption thus decreasing CI over time.

4.1 Scenarios

In table 2 the results of the studied scenarios are shown in terms of vehicle fleet structure in 2030 and decrease in energy and carbon intensities since 1990 until 2030.
4.1.1 Clean but not sparkling

In the “Clean but not sparkling” (CS) scenario there is a strong environmental concern in a slow growing economy. The latter does not allow the investment in R & D leading to a limited technological progress. This is reflected on the increase of fuel efficiency of conventional vehicles. In the first few years, CO$_2$ emission reduction goals are met through behavioral changes as travel demand decreases due to a negative GDP growth rate, that is, the decrease in GDP per capita leads to fewer kilometers driven (there is less money to purchase fuel) thus reducing fuel consumption and probably shifting those trips to public transportation or, less probably, to soft modes after changing residence and/or job locations. We note that the impacts of these transfers are not accounted in the present research. Although, later on, GDP slowly starts to increase, environmental goals are put in second plan as the focus is on encouraging economic growth.

The vehicle fleet structure is not affected, aside some slight fluctuations, as the GDP growth rate (only variation with regard to the “Stagnation” scenario) does not have a direct impact in it. The variation of the energy and carbon intensity indicators is negligible. The former decreases due to a steeper increase in GDP than in fuel consumption and the latter increases as CO$_2$ emissions grow faster than fuel consumption due to a minor transfer from EVs to petrol and petrol hybrid vehicles (higher CO$_2$ life-cycle emission factor).

4.1.2 Dynamic but careless

In the “Dynamic but careless” (DC) scenario, environmental problems are a very low priority for both citizens and politicians with the main priority being an unhindered economic growth. Low energy prices and security of supply are considered an important condition for economic growth. With such a fast growing economy, there is high investment in technology which is reflected on a higher fuel efficiency increase. As progress is faster in fossil fuel based technologies, fossil fuel demand grows rapidly helping to maintain low prices (resulting from both higher travel demand per capita and higher number of circulating vehicles). As such, it is believed that rapid technological change is the answer to threats such as climate change with no need of further policy intervention in this area.

As the fuel efficiency of conventional vehicles increases, it becomes closer to that of hybrid vehicles. As a result of this tighter competition, some transfer from hybrids to conventional vehicles occurs. EI decreases as GDP grows faster than fuel consumption due to the higher vehicle fuel efficiency. A decrease in CI also occurs as a result of fuel consumption growing slightly faster than CO$_2$ emissions. A closer look at the results showed that this discrepancy is caused by an increase in kilometers driven by EVs despite the reduction in the number of EVs.

4.1.3 Bright skies

The “Bright skies” (BS) scenario is characterized by a fast growing economy, and the resulting fast technological progress, and a high concern for the global environment. The government agrees to take action to deal with the climate change threat by reversing current GHG emission trends. Policies that encourage transport-related GHG emission reduction are designed and implemented thus making the motorization rate decrease. There is also high investment in R&D of new technologies for climate change mitigation. Through these efforts, environmental goals are met.

The lower motorization rate is compensated by the increase in the kilometers driven per year per vehicle as travel demand is mainly dependent on GDP. The transfer from hybrids to petrol and diesel vehicles is higher than in the DC scenario as technological progress allows a further 1% increase in the conventional vehicles’ fuel efficiency.

As GDP grows faster than fuel consumption, energy intensity decreases. The carbon intensity is higher than in the “Stagnation” scenario at first but by 2030 the opposite is true. This is a result of a higher increase
rate of CO₂ emissions over fuel consumption at first due to the market transfer of EVs to ICE vehicles. By 2020, when the inversion occurs, fuel consumption has a higher increase rate due to an increase in kilometers travelled by EVs, despite the reduction in the number of EVs.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Petrol (%)</th>
<th>Diesel (%)</th>
<th>LPG (%)</th>
<th>Hybrid</th>
<th>Diesel Hybrid (%)</th>
<th>Electric (%)</th>
<th>EI (%)</th>
<th>CI (%)</th>
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<td>30.96</td>
<td>7.57</td>
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<td>7.23</td>
<td>58.35</td>
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### 4.2 Transportation Policy Instruments

Table 3 presents the results, in terms of vehicle fleet structure in 2030 and decrease in energy and carbon intensities since 1990 until 2030, of the application of TPIs in all the studied scenarios. The results of each TPI will be compared with the reference of each scenario (e.g., TPP-CS compared with Ref-CS). The market percentage of LPG is not affected by any of the applied policies as the number of LPG vehicles is external to the model.

#### 4.2.1 Tax on Petroleum Products

The increase in TPP has a clear impact in the vehicle fleet structure in 2030 resulting in the decrease of petrol and petrol hybrid vehicles and the increase in EVs by 22% on average when compared with their corresponding references. Both diesel and hybrid diesel vehicles also increase, although not as much as EVs, as diesel is cheaper than petrol and the tax percentage in the final fuel price is lower. The lower CO₂ life-cycle emission factor of electricity results in a decrease of CI in all the scenarios as the consumption transfer from petrol to electricity occurs. This also makes EI remain practically unchanged. In the BS scenario, the increase in EI is slightly more accentuated as the decrease in petrol vehicles is lower than in the remaining scenarios. It results in a decrease of the 2030’ market percentage of petrol and diesel vehicles in all scenarios except BS. Diesel vehicles are more affected in both the “Stagnation” and the DC scenarios as the amounts applied per g/km are higher. The opposite occurs in the CS scenario which can be due to the random effect of the operational costs variable in the calculation of the new vehicles’ market share. The transfer is either to petrol or diesel hybrids depending on the scenario (only pay half of the applied tax) and to EVs (exempt) that increase on average 3% when compared with their corresponding references. The increase in hybrid vehicles results in a decrease in EI due to their higher fuel efficiency. The increase in EVs results in a decrease in CI. However, both of these reductions are quite small.

Regarding the “Bright skies” scenario, the higher impact on diesel vehicles is accentuated as only the market percentage of these vehicles decreases by 2030. The transfer is distributed equally through the remaining technologies. The higher fuel efficiency of conventional vehicles can play a role in these results as petrol vehicles become more competitive with hybrids while maintaining their advantage in terms of initial price. The increase in petrol vehicles results in an increase in EI while the increase in EVs makes CI decrease.

#### 4.2.2 Vehicle Purchase Tax

The effect of the increase in VPT is not as pronounced as the previous TPI as the increase in the price of an already expensive good affects less the consumer’s choice than the price increase of a cheaper good such as fuel.

#### 4.2.3 Vehicle Circulation Tax

A VCT increase does not have a precise impact on the structure of the vehicle fleet as the variations are random across scenarios. Diesel vehicles are the only ones that increase in all scenarios (remain the same in DC). Petrol cars increase in the CS and DC scenarios. Petrol hybrids increase in the “Stagnation” and DC scenarios.
while diesel hybrids increase in CS and BS scenarios.
EVs increase in the “Stagnation”, DC and BS scenarios. In the CS scenario, EI increases and CI decreases (only scenario where EVs decrease) while the opposite occurs in the remaining scenarios.

4.2.4 Mobility Electricity Tax
The implementation of a MET results in a decrease in the EV market percentage in all scenarios. The remaining fuel technologies are not affected by this tax making the fluctuations a result of the replacement of EVs with no bias towards any technology. Diesel hybrid increase in all scenarios, petrol hybrid increase only in DC and BS scenarios, diesel vehicles increase in all scenarios except in BS and, finally, petrol vehicles increase in the “Stagnation” and BS scenarios and remain the same in CS. As fuel consumption is transferred from electricity to the remaining technologies (all with higher CO\textsubscript{2} emission factors), CI increases in all scenarios. EI decreases in all scenarios, except for BS where it remains unchanged, due to the increase in hybrids which have higher fuel efficiencies.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Petrol</th>
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4.2.5 Acceleration of fast-charging points for EVs
The investment in rapid charge stations increases the probability of charging an EV faster which is reflected in an increase of 6% in EVs when compared with “BS-Ref”. All the remaining technologies decrease their market percentages by 2030 except diesel hybrids as the transfer to EVs occurs. As a result, CI decreases.
EI increases slightly which can be a result of the randomness of the operational costs variable in the calculation of the new vehicles’ market share, as mentioned previously.

4.2.6 Urban sprawl control

Measures to reduce vehicle circulation altogether (for example: encourage public transports use, tolls at the main road entrances of urban areas), instead of its replacement with more efficient vehicles or even zero-emission ones, affects directly travel demand as behavioral changes are encouraged. As the impact is solely on travel demand, the small fluctuations observed in the vehicle fleet structure are due to the random factor applied to both the operational costs and EV range when market share is calculated. EI decreases steeply by 40% when compared with the corresponding reference scenario as fuel consumption decreases due to the decrease in kilometers driven. CI decreases slightly as EVs increase by less than 1% in comparison with the BS reference scenario.

5 Conclusions

This research aims to identify the extent to which EVs diffuse in the Portuguese market and the resulting fleet wide energy consumption and corresponding CO₂ emissions up to 2030. The final results’ energy and carbon intensities as well as the EV market diffusion were compared.

The scenario analysis methodology was used to study three alternative scenarios. According to the results presented in table 2, it is concluded that a fast growing economy is the best driver to a decrease in both energy and carbon intensity, even when there is no particular concern for the environment. EV diffusion in the market decreases for both fast growing economy scenarios (DC and BS) as ICE vehicles become more appealing due to their higher fuel efficiency evolution stemming from fast technological progress.

Regarding the TPIs applied, it was found that the increase in TPP is the most efficient measure to increase EVs in the market and reduce carbon intensity. However, this policy results in market disturbance as past experience as shown. An increase in VPT also increases the percentage of EVs by 2030 and decreases carbon intensity but not as efficiently as TPP which means that, even with more expensive conventional and hybrid vehicles, the initial price of EVs is still not competitive. The market disturbance of the implementation of this policy is smaller than in the case of an increase in TPP as cars are already expensive goods. The implementation of a mobility electricity tax results in a decrease in EVs by 2030 and an increase in carbon intensity making it an inefficient policy. However, it is the most efficient policy in terms of reducing the energy intensity although none of the analyzed policies have a relevant impact on this indicator (except the urban control policy applied to BS). Although the increase in the availability of rapid charge points increases EVs and decrease carbon intensity, it is not a very efficient measure as it results in an increase of only 6% of EVs by 2030 in comparison with the BS reference scenario. The implementation of urban sprawl control policies would be very efficient in terms of reducing the energy intensity. However, policies that involve behavioral changes are not as easily accepted as alterations to the taxation system. The increase in VCT does not have a precise effect on the structure of the fleet.

Despite the higher concern for the environment (present in all scenarios but higher in CS and BS), people will not turn to EVs. Hybrid vehicles will emerge as the best solution to decrease fuel consumption as people struggle to lower their monthly fuel budget while maintaining their current travel demand.

5.1 Research limitations

One of the main limitations of this research is the utility function used in the new vehicles’ market share calculation. The data used to calibrate this function is biased towards the purchase of hybrid vehicles (over-representation of people with higher education level and underrepresentation of individuals older than 65 years old) which is not reflected on the present experience. To overcome this limitation, data from the stated preferences scenarios could be coupled with socioeconomic data in order to obtain socioeconomic specific calibrated coefficients. Furthermore, an attempt to improve the survey data could be made in order to complement the missing population strata by targeting specific groups.

References


