






# Impact of the Increase in Electric Vehicles on Energy Consumption and GHG Emissions in Portugal

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**Abstract.** The sector with the higher weight in final energy consumption is the transport sector, reflecting the one responsible for most greenhouse gas (GHG) emissions. In this context, and given the increasing penetration of zero or low GHG emissions vehicles with high energy efficiency, this work intends to contribute to the future identification of the impact of the transport sector on energy consumption and resulting emissions. It aims at identifying the energy consumption in the sector and quantify the GHG levels from the comparative analysis of the increase of electric based vehicle fleet in detriment of those based in internal combustion engines, considering five scenarios until the year 2030. The study is applied in mainland Portugal considering the fleet of light passenger and commercial vehicles, which comprise the vast majority of the Portuguese fleet. The Bottom-up model, where the hierarchical tree detailing is constructed from detail to the whole, is applied to the study to determine the energy consumption and GHG emissions variables. The analysis is performed through the application of the simulation tool Long-range Energy Alternatives Planning system (LEAP) of scenario-based and integrated modelling, herein utilized to determine energy consumption and account for GHG emission sources. Results show that the increase of electric vehicles directly influences the reduction of GHG emissions and final energy consumption while electric energy consumption increases.

**Keywords:** Electric vehicles · Energy consumption · Greenhouse gas emissions · Bottom-up model

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## 1 Introduction

Energy consumption and associated greenhouse gas (GHG) emissions have, in recent years, become the target of major worldwide investments so that the medium and long term impacts are mitigated through various measures, such as, for example, increasing equipment efficiency, whether for residential applications, transport or industry.

This work aims to analyse and forecast the impacts on energy consumption and GHG emissions, following the increase in the penetration of electrically based vehicles in the Portuguese mobility system, in replacement of internal combustion engines based vehicles. The study considers five different scenarios, with different levels of penetration of light (passenger and commercial), electric, hybrid, and plug-in vehicles.

The model developed to analyse energy consumption in the light vehicle transport sector, corresponds to a hybrid approach, combining characteristics of bottom-up and top-down models. The projection of energy consumption in the light vehicle segment is determined from disaggregated data in order to describe the energy end users and technological options in detail, according to the requirements of the bottom-up model [1–5]. The forecast of the total car fleet has been implemented exogenously, seeking to increase the robustness of the model. By adopting this approach, the model gathers a top-down characteristic, in a hybrid approach. This model focuses on the economy and on various relationships inherent to it, addressing the simulation of future supply and demand for a given product.

The analysis of GHG emissions is based on the bottom-up model, consolidating the method adopted by the Portuguese National Inventory Report on Greenhouse Gases, which considers the recommendations of the Intergovernmental Panel on Climate Change (IPCC) regarding the use of methodologies based on disaggregated levels in the estimates of carbon dioxide (CO<sub>2</sub>) and non-CO<sub>2</sub> gas emissions [4].

Several studies have assessed the growth of the fleet with the increase in electric vehicles, based on the bottom-up model. The study [2] estimated the future energy demand and GHG emissions from China's road transport until 2050. The work developed in [1] determined the energy consumption and GHG emissions in the transport sector of São Paulo city, Brazil, considering three different scenarios until 2035. Moreover, [6] estimated the composition of the vehicle market and calculated the energy consumption and CO<sub>2</sub> emissions of light passenger vehicles in Japan, in a long-term basis.

This paper is organized in three major sections, the first of which concerns the presentation of the current scenario of the transport sector in Portugal. Then, the methodology used to determine the energy consumption and GHG emissions of vehicles, the object of this study, is developed. Finally, section four presents and analyses the emissions levels and the energy consumption for the different scenarios under consideration, as well as the main consequences in the Portuguese energy system.

## 2 Theoretical Framework

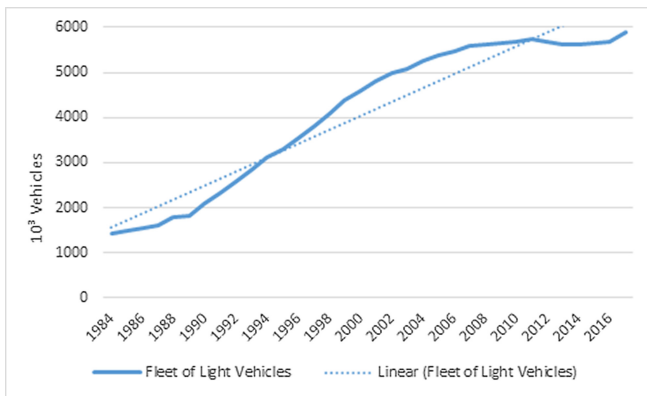
### 2.1 Portuguese Transport Sector

According to the Portuguese Private Business Association (ACAP), responsible for publishing the Automobile Sector Statistics (ESA) yearbook, the vehicle fleet in Portugal is divided into two major categories, light and heavy, being predominantly composed of light vehicles, with approximately 97.5% of the total [7], as indicated in Table 1. Thus, the study is limited to this category, given that it is the most likely to change from the technological point of view, i.e., replacement of vehicles based on combustion engines for vehicles with electric traction, totally or partially.

**Table 1.** Vehicle fleet in Portugal (2011) [7]

Vehicle fleet		Units	(%)
Light	Passenger	4 522 000	77
	Commercial	1 206 000	20.5
Heavy		145 000	2.5

According to data provided by ACAP [7], it can be seen that Portuguese fleet of light vehicles had a significant increase in last years. Figure 1 shows the evolution of the fleet of light vehicles from 1984 until 2017, where there is a significant growth trend between the years 1988 and 2006. Between 2006 and 2011 there was a slow-down, but the trend was still of increasing. In recent years, 2012 until 2016, the fleet stabilized and increased again in 2017 to levels close to 6 000k.



**Fig. 1.** Fleet of light vehicles (passengers and commercial) in Portugal (1984–2017) [7].

Figure 2 presents the data related to the sales of light vehicles (passenger and commercial) in Portuguese territory for the same period, observing a downward trend in sales when considering a 35-year time horizon [7].

The combination of information related to the data above allows identifying some important factors, such as the high average age of the circulating fleet in the country. The insertion of new vehicles does not increase at the same way the existing fleet, being this hypothesis corroborated from the automotive statistics sector data at 2011 [7], identifying that 63.2% of the fleet is over 10 years old, with an average age of 12.6 years (passenger) and 13.7 years (commercial) [7].

When conducting the previous analysis in a smaller sampling period, the last five years, the scenario changes, with the sales growing considerably. This growth may be explained as the result of the exponential technological development in the last decade, reflected in consumer goods; the conditions offered to the consumer are more advantageous and attractive, with more efficient and modern vehicles. In addition, there are incentives that promote the insertion of electric vehicles in the current vehicle fleet, since it relates to one of the country's goals for future reduction in GHG emissions.

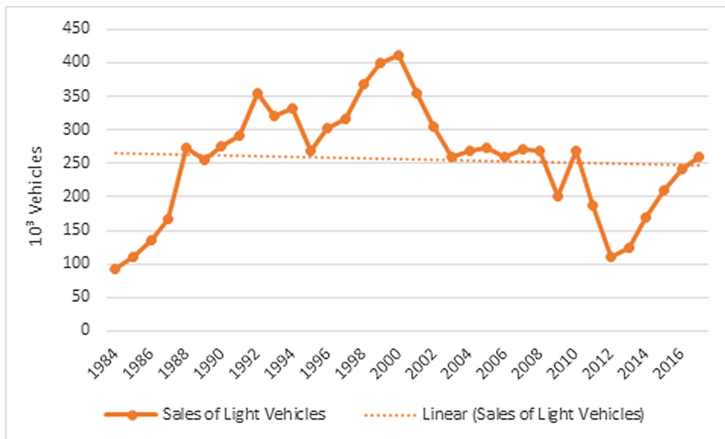


Fig. 2. Sales of light cars (passengers and commercial) in Portugal (1984–2017) [7].

## 2.2 Portuguese Energy Balance and Greenhouse Gas Emissions

The Directorate-General for Energy and Geology (DGEG), in a study carried out in 2017 pointed out that the transport sector continues to be the main final energy consumer, accounting for 37.2% of the energy consumed. The industry sector accounts with 31.3% of the final energy consumption, the domestic sector with 16.4%, the services sector with 12.2% and the agriculture and fisheries sector with 2.9% [8], as shown in Fig. 3. Thus, the transport sector is one of the main sectors with a higher impact on the economy, tracking the progress made towards reducing the environmental impacts associated with energy production.

The technological development of the sectors, including transport, combined with the change in the lifestyle of the population, with the increase in the Gross Domestic Product (GDP) per capita, are directly reflected in the increase in energy consumption worldwide [9].

The demand for energy and the increase in mobility from 1990 onwards reflect Portuguese economic evolution, which in turn triggered the increase in GHG emissions. According to the Report of the State of the Environment from the Portuguese Environment Agency (APA) [10], the stabilization of the levels of GHG emissions started with the technological development of pollution control systems and energy efficiency. In addition, the emergence of fuels with lower polluting rates and the increase of energy based in renewable sources from the 2000s, contributed to the GHG emissions actual state. However, according to [10], the transport sector presents itself as one of the main emitters during the historical series. In 2017, the percentage of emissions was 24.3% in the country, with a growth of 4.53% compared to 2016.

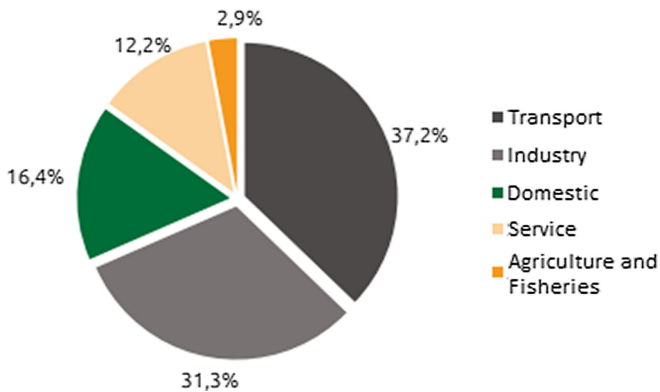


Fig. 3. Final energy consumption by sector (%) in Portugal (2017) [8].

### 2.3 Goals Related to Energy and Climate 2021–2030

The Regulation on the Governance of the Energy Union and Climate Action [Regulation (EU) 2018/1999] [11], established that all Member States must prepare and submit to the European Commission an integrated National Energy and Climate Plan (NECP), with a medium-term perspective (horizon 2021–2030) [12]. The European Council approved targets related to energy and climate, which linked an internal reduction of  $-40\%$  in GHG emissions related to 1990 levels. It was also set the following energy targets: increasing energy efficiency by at least  $32.5\%$ , increasing the share of renewable energy to at least  $32\%$ , with  $14\%$  of renewables in transport, and guaranteeing at least  $15\%$  electricity inter-connection levels between neighbouring Member States [12].

Portugal's targets for 2030 GHG emissions are comprised between  $-45\%$  and  $-55\%$ , compared to 2005 levels, and the renewable energy contribution is estimated in  $47\%$  of the national gross final consumption of energy, with  $20\%$  of renewables in the

transport sector. Regarding energy efficiency, the proposed contribution is more modest, with projected values of  $-2.3$  Mtoe (million tonnes of oil equivalent) of primary energy consumption due to energy efficiency [13].

### 3 Methodological Approach

The methodology for forecasting the impact on energy consumption due to the increased penetration of electric vehicles, is performed using the bottom-up and top-down hybrid model. To estimate the levels of GHG emissions, from the consumption forecast, the bottom-up model is applied.

The bottom-up model seeks to perform a structural detailing of the technology used in the energy conversion and usage, using disaggregated data aiming at describing the final energy utilization and technological options in detail. In the model methodology, technologies and replacement indexes of the analysed equipment can be identified, in this case, vehicles. On the other hand, the top-down model takes into account only carbon dioxide (CO<sub>2</sub>) emissions from energy production and consumption data, without detailing how this energy is consumed.

For the development of the present research, light vehicle fleet, commercial and passenger typologies were classified separately, since the characteristic parameters of each one of those variants presented slightly different indicators.

The determination of energy consumption of any class in the transport sector uses three factors: fleet, average annual mileage and average specific consumption. The average distance travelled is directly related to the need of society to transport people and goods, according to economic development, which in turn may be related with the frequency of use of the vehicle and the age of the existing fleet [14]. The average consumption of these vehicles, whether passenger or commercial, depends mainly on the underlying technology used.

The model used in the present study is developed using the environment and energy modelling tool based on scenarios, the Long-range Energy Alternatives Planning system (LEAP) [15], developed by the Stockholm Institute for the Environment with the aim of conducting energy policy analyses and assessing climate change mitigation.

#### 3.1 Variable Modelling

For the application of the proposed model, the energy consumption in the transport sector is defined based on the product of the related variables, also implemented in [2], given by:

$$\begin{aligned} \text{Energy Consumption}_{f,v,y} &= \text{Stock of Vehicles}_{f,v,y} \times \text{Annual Vehicle Mileage}_{f,v,y} \\ &\times \text{Fuel Economy}_{f,v,y} \end{aligned} \quad (1)$$

where  $v$  is the type of vehicle considered (passenger or commercial),  $f$  is the type of fuel (gasoline, diesel, electricity or liquefied petroleum gas) and  $y$  is the calendar year in which the energy consumption is to be determined. The variables stated in Eq. (1) are detailed as follows.

The stock of vehicles is given by

$$\text{Stock of Vehicles}_{f,v,y} = \sum_s \text{Sales}_{v,s} \times \text{Survival}_{v,y-s} \quad (2)$$

where subscript  $s$  relates to the vintage (i.e., the year in which a vehicle starts its use). The stock of vehicles of a specific type is, therefore, given by the total sum of the sales times the survival index, which represents the fraction of the vehicles of the considered typology in the year  $y$  minus the vintage year,  $s$ .

Regarding the vehicle's average annual mileage, it is estimated through

$$\text{Annual Vehicle Mileage}_{f,v,y} = \text{Mileage}_{v,y} \times \text{MIDegradation}_{y,y-s} \quad (3)$$

from which the average miles driven by vehicle type  $v$ , with fuel type  $f$ , in the year  $y$  is expressed by the vehicle mileage of the type  $v$  into use in the year  $s$ , times the degradation of the vehicle mileage of the type  $v$ , considering  $y - s$ . By this way, the degradation is modelled through an exponential function.

The average consumption is estimated through the distance travelled, in kilometres, by vehicles of type  $v$  in the year  $y$  and it is considered constant throughout the life span of the vehicle, on the assumption that maintenance is carried out with the correct periodicity.

With regard to GHG emissions, their determination is carried out using the emission factor,  $EF$ , times *Activity*, which translates the amount of energy consumed or distance covered by a given mobile source, i.e.,

$$\text{Emissions} = EF_{i,f,v} \times \text{Activity}_{f,v} \quad (4)$$

being  $i$  the gas ( $\text{CO}_2$ ,  $\text{CO}$ ,  $\text{NO}_x$ ,  $\text{CH}_4$ , etc.),  $f$  the type of fuel and  $v$  the type of vehicle.

The above procedure is applied by LEAP and is in accordance with the guidelines of the Intergovernmental Panel on Climate Change (IPCC) [16]. In detail, it translates as follows:

- Determine the amount of energy consumed in terajoules (TJ), by type of fuel, for each sector and sub-sector;
- Multiply the amount of energy consumed by the specific emission factor for each fuel, for each sector and sub-sector, in tonnes/TJ. The GHG emissions in Eq. (4) are presented in tonnes (t).

To convert the emissions as given by Eq. (4) to tonnes of carbon dioxide equivalent ( $\text{tCO}_2\text{eq}$ ), the following applies:

$$\text{tCO}_2\text{eq} = \text{tonnes}(\text{gas}) \times \text{GWP}(\text{gas}) \quad (5)$$

being GWP the Global Warming Power which corresponds to one of the five IPCC Assessment Reports (AR1-AR5) [16]. These reports are established by the relative importance of each gas related to carbon dioxide, in the production of an amount of energy per unit volume several years after an emission impulse, i.e., the GWP values measure the heating potential of one tonne of each gas in relation to one tonne of  $\text{CO}_2$ .

### 3.2 Historical Data and Projections

From the construction of the base scenario, the relevant data for the construction of the hierarchical tree are gathered, where the main data structure is displayed. The base year is 2011 and the forecast is made until 2030, considering only mainland Portugal. The tree is structured as follows:

- Passenger vehicles
  - Internal combustion engine
  - Purely electrical, hybrid and Plug-in
- Commercial vehicles
  - Internal combustion engine
  - Purely electrical

Hybrid and plug-in vehicles are not considered in the light commercial fleet because, according to Automotive Sector Statistics from ACAP 2018 yearbook [7], there are no data in the sales history till 2017. The construction of the base scenario is dependent on the historical data in the base year. The determination of future energy consumption considers various indicators related to the projection of the amount of energy in the transportation sector and they are presented in the following sections. It should be noted that the order of insertion of the data does not interfere with the final result.

#### Fleet

Historical fleet data were obtained from the automotive sector statistics from ACAP yearbooks [7] where it is possible to characterize the vehicle fleet presumably in circulation by vehicle type and according to the main fuel. As introduced in the previous Sect. 2.1, this study is limited to light passenger and commercial vehicles. Total number of vehicles in these two categories in 2011 (the base year) is presented in Table 1.

#### Survival

The survival of the vehicles under study was estimated according to the Gompertz curve [17], given by:

$$S(t) = e^{-e(a+bt)} \quad (6)$$

where  $S(t)$  is the function that describes scrapped vehicles,  $t$  is the age of the vehicle and  $a$  and  $b$  are curve adjustment parameters, variable according to each type of vehicle, assuming, in this work, the values presented in the Table 2. The adopted parameters were determined from the calibration of the model using historical data presented in the reference report of the GHG emissions by mobile sources in the energetic sector from the first Brazilian inventory of anthropogenic GHG emissions [18].

#### Fleet Profile of Existing Vehicles

The existing fleet in the years under study consists of vehicles of different ages and, as such, the identification of the fleet' profile reflects directly in the algorithm of the future



**Table 2.** Adjustment parameters of Gompertz model.

	<i>a</i>	<i>b</i>
Passengers	1,798	-0,137
Commercials	1,618	-0,141

fleet. Historical data were obtained from the Automotive Sector Statistics from ACAP [7] and are shown in Table 3. The fleet life cycle profile was determined as 25 years old and differentiated between the two categories under analysis.

**Table 3.** Fleet of road passenger vehicles presumably in circulation, by age (2011) [7].

Category	Passenger	Commercial
Vehicle age	%	%
1 year	5.54	3.93
2 years	4.08	3.32
3 years	5.72	4.70
4 years	5.58	5.62
5 years	5.35	5.38
6 a 10 years	26.79	30.59
11 a 15 years	27.67	29.39
16 a 20 years	15.32	13.06
21 a 25 years	3.95	4.03

## Sales

Historical sales data were obtained from ACAP data (Automotive Sector Statistics) [7], where it is possible to survey sales for the base year. In 2011, 153 404 passenger cars and 34 963 light commercial vehicles were sold, each type subdivided into two other categories according to the propulsion system: internal combustion engine and propelled on electrical energy using at least one electric motor, purely electric, hybrid or plug-in, as shown in Table 4.

**Table 4.** Sales of light vehicles by category and type of fuel (2011) [7].

Propulsion		Passenger	Commercial
Internal combustion	Gasoline	44 544	3
	Diesel	106 832	34 955
	Liquefied petroleum gas (LPG)	839	0
Electric	Purely electric	203	5
	Hybrid	932	0
	Plug-in	54	0

### Fleet Forecast

Although there is a wide range of different models for forecasting and several ways to build a model, there might be a best way to build a particular model for a specific purpose. In the present study and for the specific problem, to determine the future fleet of both groups of vehicles, the simple linear regression model will be applied. The simple linear regression is a statistical method that allows summarising and studying relationships between two continuous variables [19].

Equation (7) represents the simple linear regression model. The dependent variable is designated by  $Y$  and the independent variable by  $X$ . The unknown parameters in the model are the intercept  $\beta_0$  and the slope  $\beta_1$ , being  $\epsilon$  the random or stochastic error and the variance  $\sigma^2$  [19].

$$Y_i = \beta_0 + \beta_1 X_i + \epsilon_i, \quad i = 1, 2, 3, \dots, n \quad Y_i = \beta_0 + \beta_1 X_i + \epsilon_i, \quad i = 1, 2, 3, \dots, n \quad (7)$$

where  $E(\epsilon_i | X_i) = 0$  and  $V(\epsilon_i | X_i) = \sigma^2$ .

In the current problem, after several trials, GDP per capita is found as the most suitable independent variable ( $X$ ) to forecast the number of light vehicles (passenger and commercial vehicles) as dependent variable ( $Y$ ).

It is important to evaluate the suitability of the regression model for making forecasts. To do so, it will be necessary to calculate the coefficient of determination,  $r^2$ , to analyse the fit quality of the model and to know the correlations between variables, which is fundamental to use the value of one variable to predict the value of another. To achieve correlations between variables, Pearson's correlation coefficient,  $r$ , will be used.

For the problem under analysis an  $r^2$  of 0.933 was obtained, which means that 93.33% of the variability stems from the independent variable,  $X$  (in this case, GDP per capita), of the light passenger fleet. For the light commercial vehicle fleet, an  $r^2$  equal to 0.8472 was found, from which GDP per capita explains 84.72% of this category of vehicle fleet.

It is also possible to verify that there is a strong positive correlation between the variables GDP per capita and light passenger vehicle fleet and also with light commercial vehicle fleet, being the correlation higher in the first case than is the second one,  $r = 0.966$  and  $0.92$ , respectively.

### Annual Average Vehicle Mileage

The annual average vehicle mileage, or the intensity of use, is understood as the estimated average distance travelled by each vehicle in the circulating fleet in the time unit under analysis (yearly basis).

The values used for this projection were obtained from the Portuguese National Inventory Report on Greenhouse Gases, 1990–2012 [20].

This report proposes a degradation rate of usage as a function of the age, given by a model developed based on data from vehicle inspection centres [20]. The distance travelled (in kilometres) in a yearly basis is estimated through:

$$A_2 + \frac{(A_1 - A_2)}{1 + (age/x_0)^p} \quad (8)$$

being  $A_1$ ,  $A_2$ ,  $x_0$  and  $p$  parameters defined by vehicle technology as presented in Table 5.

**Table 5.** Usage curve parameters [20].

	$A_1$	$A_2$	$x_0$	$p$
Gasoline, LPG, hybrid passenger vehicles	13354.668	737.09264	19.69152	2.4209
Diesel-powered passenger vehicles	19241.066	6603.86725	17.45625	2.53695
Diesel-powered commercial vehicles	20800.215	2597.42606	15.44257	2.32592

### Fuel Consumption

Energy consumption is directly linked to the type of fuel used. These values were estimated using the LEAP tool database [15], where there are pre-determined values for the two main propulsion systems, those based on internal combustion and the ones using electric propulsion, including pure electric, hybrid and plug-in vehicles. The consumption of the vehicles under analysis adopted are shown in Table 6.

**Table 6.** Consumption by category and type of fuel [15].

Propulsion	Fuel	Consumption	
Internal combustion	Gasoline (l/100 km)	8.4	
	Diesel (l/100 km)	9.4	
	LPG (km/m <sup>3</sup> )	12 754.3	
Electric (full or partial)	Electric (kWh/100 km)	19.88	
	Hybrid	Gasoline (l/100 km)	4.9
		Diesel (l/100 km)	4.3
	Plug in	Gasoline (l/100 km)	4.9
		Electric (kWh/100 km)	18.64

### Emission Factor

The emission factor parameters used are shown in Table 7 and were obtained through the fifth assessment report (AR5) from IPCC [16].

**Table 7.** Emission factors

Fuel	tCO <sub>2</sub> eq/TJ
Diesel	73.28
Gasoline	68.56
LPG	62.71

### 3.3 Characterization of the Scenarios

For the study proposed in this work, four scenarios were defined from the insertion of electric, hybrid and plug-in vehicles and a theoretical scenario where there is no insertion of this class of vehicles, in the period under analysis, as outlined below:

- Base Scenario: the rate of sales made in the base year (2011) are maintained in the time frame of the study for all types of vehicles disaggregated by type of propulsion;
- Scenario 10%: penetration of electric, hybrid and plug-in vehicles in detriment of sales of internal combustion engines based vehicles, with a rate of 10%;
- Scenario 30%: penetration of electric, hybrid and plug-in vehicles in detriment of sales of internal combustion engines based vehicles, with a rate of 30%;
- Scenario 60%: penetration of electric, hybrid and plug-in vehicles in detriment of sales of internal combustion engines based vehicles, with a rate of 60%;
- Scenario 100%: penetration of electric, hybrid and plug-in vehicles in detriment of sales of internal combustion engines based vehicles, with a rate of 100%.

The scenarios were chosen in order to enable the establishment of a comparative analysis between them. The 100% scenario presents a purely theoretical configuration with the objective of establishing a maximum value for the insertion of electric powered (fully or partially) light vehicles.

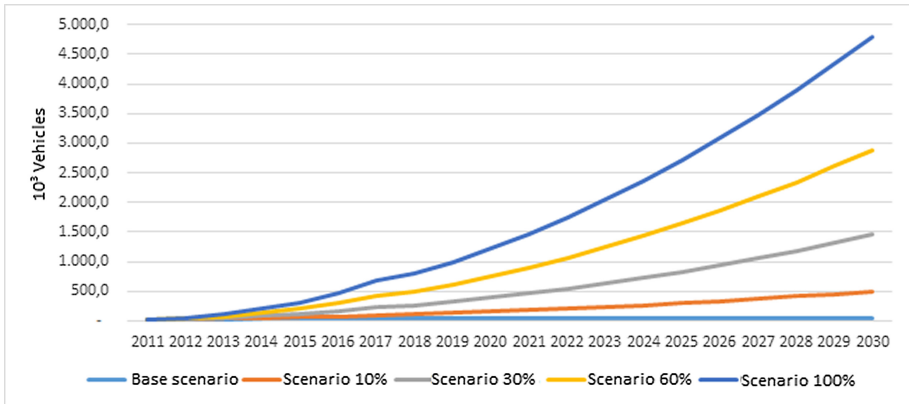
The study considers that electric based vehicles started to be introduced in the Portuguese market in the base scenario (2011) according to a linear model until the year 2030.

## 4 Results and Analysis

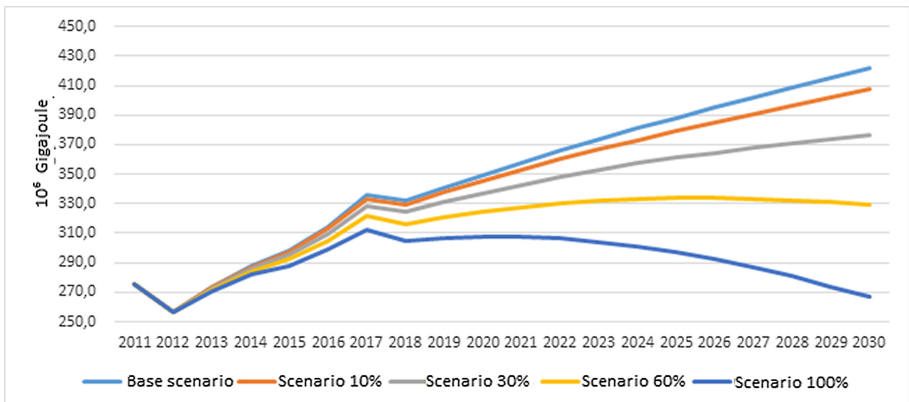
### 4.1 Fleet Forecast

From the forecast proposed by the methodology described in Sect. 3, the results regarding energy consumption and GHG emissions for the five proposed scenarios can be viewed from the projections obtained through the LEAP tool.

Figure 4 presents the projection of the fleet of purely electric, hybrid and plug-in vehicles from the year 2011 until 2030, within the proposed scenarios. The fleet for each year is composed of vehicles of different ages (vintage) and thus varies from year to year.



**Fig. 4.** Projection of the fleet of electric, hybrid and plug-in vehicles.



**Fig. 5.** Comparison of energy consumption between the proposed scenarios.

## 4.2 Energy Consumption Forecast

The total energy consumption for the different scenarios under consideration are presented in a comparative way in Fig. 5.

The behaviour of the predicted energy consumption is similar for the base, 10% and 30% scenarios, while for the other two scenarios, the behaviour is slightly different. The former ones present a total energy consumption with an increasing tendency, while the energy consumption remains almost constant for 60% scenario and decreases under the 100% scenario.

This behaviour can be explained in view of the higher energy efficiency of electric propulsion based vehicles, which have an increased penetration in these two scenarios, able to maintain or decrease the predicted total energy consumption, for the 60% and 100% scenarios, respectively. In light of these results, the penetration of electric propulsion based vehicles favours the reduction of the country’s energy dependence.

The energy consumption mentioned above refers to total energy consumption, including fossil fuel and electric.

In order to preview the impact the fleet change may have in the electrical grid infrastructure and electric energy demand, an analysis based on the forecasting of the electric energy consumption for the different scenarios under consideration is also performed (Fig. 6). From the estimates, it is possible to conclude that the penetration of electric propulsion based vehicles will translate in an increase in electrical energy demand, as would be expected. In the year 2030, the analysis forecasts that for each 10% increased penetration of electric, hybrid and plug-in vehicles, the electricity consumption will increase about 700 MWh (megawatt hours).

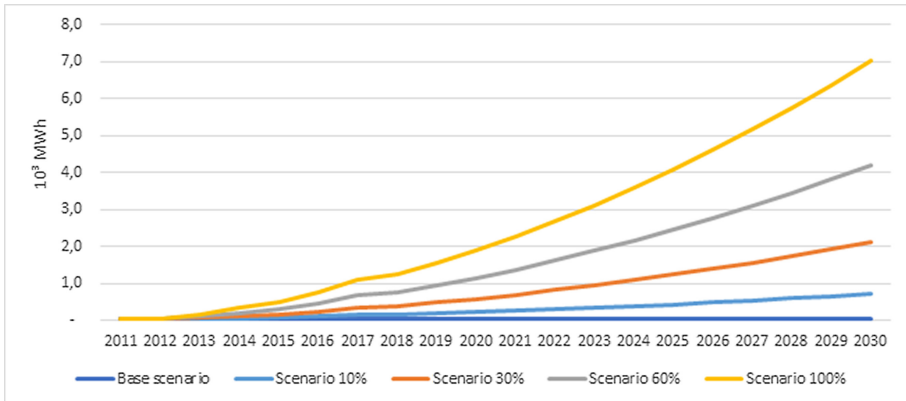


Fig. 6. Comparison of electric energy consumption between the proposed scenarios.

### 4.3 Greenhouse Gas Emissions Forecast

The GHG emissions forecast for the considered scenarios is shown in Fig. 7. As would be expected, the higher the penetration of electrically-powered vehicles in the commercial and passenger fleet, the lower are GHG emissions levels. With a considerable penetration of these vehicles (60% and 100% scenarios), it can be seen a decrease in the GHG emissions forecast in the transport sector.

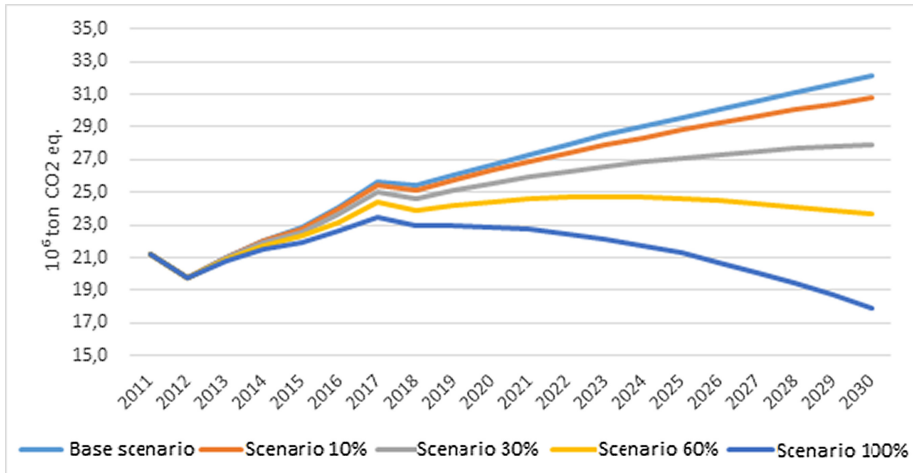


Fig. 7. Comparison of GHG emissions between the proposed scenarios.

## 5 Conclusions

Forecast analyses involving energy consumption and GHG emissions are of paramount importance for issues involving global sustainability. In this way, the international community has been discussing objectives and targets for sectors to seek technological development with greater energy efficiency and effectiveness with the objective to decrease environmental impacts.

From a macro perspective, this work indicates that the modernization of the transport sector for personal use reflects on positive rates in relation to the reduction of national energy dependency. In addition, it contributes to the control of GHG emissions from internal combustion vehicles that comprise the vast majority of the actual country's transport fleet.

Concerning total energy consumption, with a considerable penetration in sales of electric propulsion based vehicles in detriment of internal combustion engines based vehicles, the energy demand decreases. This is because electric vehicles present higher energy efficiency in the transport sector, specifically in light passenger and commercial vehicles.

The analysis between the scenarios shows that for every 10% increase in pure electric, hybrid and plug-in vehicles in the fleet, in 2030 there will be a 3.84% reduction in total energy consumption, in comparison to the base scenario. However, the penetration of electric vehicle propulsion technologies will shift the energy source used in the vehicles. The electricity demand will increase, from which may be required an upgrade of the electrical grid infrastructure including energy sources, as renewable ones, for instance.

Following the behaviour of total energy consumption, electric propulsion based vehicles are one of the main alternatives for clean transport, in the viewpoint of GHG emissions with reduced impacts on the environment. For every 10% increase in purely electric, hybrid and plug-in vehicles in the fleet, in detriment of internal combustion engine vehicles, there is a reduction of 4.46% of GHG emissions, when comparing the levels reached in the year 2030 to the values of the base scenario.

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