Energy Optimization of a company´s car fleet

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Abstract

This project focuses on the energy characterization of a company automobile fleet, based on the data available for 2018, to quantify the energy, environmental and economic impacts associated with the implementation of three measures developed to reduce its energy consumption. The project was developed at *SOTÉCNICA- Sociedade Eletrotécnica S.A*, within the scope of the *Galp 21* program. The 1st measure consisted in replacing 38 less efficient light duty vehicles by models with lower fuel consumption, resulting in a reduction of energy consumption and CO_2 emissions of 2.3% and a cost reduction of 3.5%. The 2nd measure consists of educating 127 drivers to the practice of efficient driving habits through training actions, allowing reductions of 7.5% to 2.8% (optimistic or less optimistic scenario) on energy consumption, CO_2 emissions and total costs. Finally, the replacement of 8 light duty vehicles with equivalent electric models was also analyzed, indicating a cost reduction of only 1.2%, which is therefore less significant than the other measures presented. However, this measure has high impacts on reducing energy consumption (5.2%) and pollutant emissions (4.7%). The combined implementation of the three measures analyzed requires a total investment of 20 258 €, with a payback period between 4 and 7 months. These measures result in a reduction of energy consumption of 12.2 to 7.5%, a reduction in CO_2 emissions from 12.6 to 7.9% and an annual saving of 61 248 to 36 449 €, corresponding to a reduction in total costs associated with fleet utilization between 11.5% to 7.2%.

Keywords: Energy characterization; energy/financial/environmental impact; optimization of vehicles; eco drive; electric vehicles.

1. Introduction

The transportation sector is currently one of the highest contributors to energy consumption, as well as the emission of polluting gases, representing about 31.6% of the total final energy consumption and around 25% of GHG emissions in Europe [1].
Furthermore, it was verified that 93% of the total final energy consumption for this sector comes from oil [2], hence suggesting that there is a major imbalance in the transport sector, which must be tackled with alternative technologies or sources of energy, cleaner and more efficient, thus contributing to the diversification of energy sources in this sector.
In Portugal, a concern in terms of intensive energy consumption has been in practice for a while. For this reason, a specific regulation [3] was approved (ordinance Nº 228/90 of 27 March 2010) to be applied to entities with a high energy consumption. This regulation, known has RGCEST (Regulation of Energy Consumption Management for the Transport Sector), defines rules that aim to rationalize the energy consumption of transport companies and companies with their own fleet, which exceed an annual energy consumption of 500 toe, forcing these companies to regularly assess their energy consumption situation. This assessment is carried out through energy audits, resulting in proposals for energy efficiency that should be implemented to reduce the fleet's energy consumption, pollutant emissions and total costs by 5% within a period of three years [3].
Many factors have been shown to influence vehicle's emissions and energy consumption, including the propulsion technology type of the vehicle [4] [5], driver's behavior [6] [7], traffic flow conditions [8] [9], choice of route, cargo transported and occupancy rates [10]. Despite the importance of all factors, the main parameters that influence the vehicle energy consumption are the first two: propulsion technology and driver's behavior.
Several studies comparing different types of vehicles such as, EV (Electric Vehicles), PHEV (Plug-in Hybrid Electric Vehicles, HEV (Hybrid Eletric Vehicles) and ICEV (Internal Combustion Engine Vehicles) demonstrated that propulsion technology represents the dominant factor in energy consumption and that EV presented the lowest average energy consumption from all (up to 40% lower than the global average) [11] [4] [5].

The literature review also indicated that aggressive driving may reflect an increase of up to 24% in fuel consumption [10], and the practice of efficient driving measures may reduce the fleet's average fuel consumption by up 8% [7].
Considering the increasingly present environmental consequences and the specified regulation above mentioned the main objective of this work is, to quantify the energy, environmental and financial impacts associated with the implementation of measures to reduce its energy consumption, by performing a characterization of the company's automobile fleet. The measures developed can be applied in the real context of any company with its own automobile fleet.

2. Methodology

This section describes the case study considered and the methodology used for the characterization of the company's fleet, as well as the description of the measures to be implemented and the methodology used to quantify the respective financial and environmental impacts.

2.1 Case study

This work was carried out at *Sotécnica* which is a multinational company with multi-technical services and currently has several branches (*Faro, Évora, Lisboa, Coimbra, Porto*). The company has different areas of activity (Business Units, BU), thus implying a distinct use of vehicles when compared with each other. From all existing BU the vehicles assigned to the following were analyzed: Head Office (HO), Vinci Facilities (VFP), North and South Maintenance areas (AMTN/S), Omexom (OMX), Omexom continuous contracts (OMX-EC), Mechanical and Hydraulic installations area (AIM), Low Voltage area (ABT), and Manufacturing area (AFB).
Given the diversity of business areas, the company naturally has a large fleet (216 vehicles) and a wide variety of vehicle types, ranging from light-duty passengers and goods transportation vehicles to heavy vehicles such as machines and backhoe loaders. Regarding the sample used, of the 216 existing vehicles, only 191 were considered, since, as it will be explained in section 2.2, the study was based on data collected for the entire 2018 year. The remaining vehicles (excluded) were either vehicles from 2019 or vehicles without mileage registration.

2.2 Energy characterization of the automobile fleet

The company's supply system is made through Galp service stations, using the Galp fleet card. The fueled liters are registered automatically, unlike the mileage record, which must be done by the driver when refueling the vehicle. The characterization was based on the real data recorded by this software for the entire year of 2018. The vehicles were separated by the various BU, with the following information being detailed:

- **Typology of vehicles**: description of the brand, model, engine, type of vehicle and fuel used;
- **Energy consumption per vehicle**: liters of consumed fuel, corresponding cost in euros, distance traveled (km), and finally the respective calculation of the average consumption in liters of fuel per 100 km traveled;
- **Environmental impact**: corresponding to the value of CO_2 emissions per km traveled announced in the vehicle's technical sheet.

For the sample considered (2018) around 5 089 745 km were covered, with a consumption of 397 098 liters of fuel (average of 7.4 $l\,/\,100km$), corresponding to 345 toe of energy consumed and an annual associated monetary cost of 532 502 €. The characterization determines that the most representative class of vehicles consists of light-duty vehicles (passengers and goods), constituting 92.7% of the total automobile fleet. This class also represents 88.3% of the total fuel expenditure. This way, in order to reduce the energy consumption of the fleet more efficiently the measures to be introduced are focused in these categories.
Once the class of vehicles on which the study is to be focus has been defined, it is then intended to determine which BU contributes most significantly to the total fuel consumption. For this purpose, the following energy efficiency indicators were calculated (see Figure 1): average cost per kilometer (€/km), average fuel consumption per 100 km (l/100km), average fuel cost per vehicle (€/vehicle) and finally the average value of CO2 emissions per kilometer traveled (g CO_2e/km).
As it can be seen in Figure 1, the cost per kilometer traveled is related to the average consumption of vehicles belonging to each BU, being higher for higher values of average fuel consumption. Regarding these first two indicators, it is concluded that the higher values are recorded for OMX-EC and OMX, with

average values of 16.9 l/100km (0.1529 €/km) and 14.1 l/100km (0.1204 €/km), respectively.
From the characterization presented, it can be concluded that the BU, AMTNS and OMX-EC, are the most representative in terms of total fuel costs. Both due to the high number of vehicles allocated (AMNTS and OMX-EC), distances traveled (AMTNS), as well as the type of vehicles attributed with high fuel consumption fuel (OMX-EC).
So, measures to reduce the energy consumption that focus on these two specific areas should be developed. For AMTNS, given the high number of distances traveled, it is essential to develop measures that result in the use of more efficient vehicles to minimize the impacts associated with their use. As for OMX-EC, it is important to implement good driving practices, such as eco-driving, that minimize the average fuel consumption given the high value of this parameter. Nonetheless, the implementation of measures applicable to all BU were sought, to maximize the reduction of energy consumption from the automobile fleet.

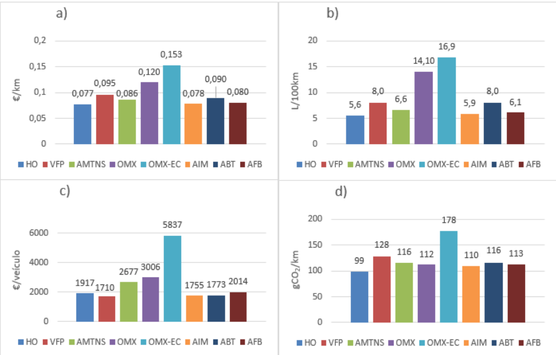

Figure 1- Comparison of energy efficiency indicators by BU: a) Average cost per km; b) Average fuel consumption; c) Average cost per vehicle; d) Average CO2 emissions.

2.3 Definition of energy efficiency measures

2.3.1 Replacement of inefficient conventional vehicles

Considering the diversity of vehicles in the company's car fleet with the same typology and function, namely, for the most representative vehicle class (light-duty vehicles), this measure aims to replace vehicles with higher energy consumption by more efficient models (lower fuel consumption).
The fleet is composed by a fraction that actually belongs to the company (35%), but the remaining vehicles (65%) are rented. In this case, depending on the conditions of the renting contract (kms, duration of the contract, maintenance, tires, etc.), a monthly amount is defined to be paid to the renting car company. The updating or permanence of the vehicles belonging to the fleet, is related to the renewal of the renting contract, at the end date of the contractual period. Thus, to maintain the use of a determined vehicle, a new investment in the renewal of the renting contract would always be necessary.
The measure underlying the optimization of the utilized vehicles, focuses on the current analysis of the most efficient vehicles, so that when the renting contract is renewed, the vehicle in question is replaced by the model belonging to the same class, which proves to be more economical. Consequently, this replacement does not represent an additional investment, thus allowing to reduce the expense associated with fuel consumption and, if the rental value is lower, also reducing the overall cost associated with the car fleet.
To compare the average fuel consumption between the various existing vehicle models, four different comparison classes were created, two for light duty passengers' vehicles (LP) and two for the light-duty goods' transportation vehicles (LM):

- First LP class (class 1-LP): corresponding to smaller LP vehicles (hatchback type bodywork);
- Second LP class (class 2-LP): corresponding to larger LP vehicles (wagon type bodywork);
- First LM class (class 1-LM): corresponding to smaller LM vehicles (bodywork type L1); and
- Second LM class (class 2-LM): corresponding to larger LM vehicles (bodywork type L2).

After the definition of the most efficient vehicle for each class (reference vehicle), the equation for the calculation of the total cost reduction (in euros) resulting from the implementation of these measure is presented (Eq. 1):

$$\textbf{Annual cost reduction} =$$

$$\sum_{i=1}^{N}\left[\left(FC_{(i)} - FC_{ref(i)}\right) \times \frac{km_{(i)}}{100} \times FP_{(i)} + \left(R_{(i)} - R_{ref(i)}\right) * 12\right], (Eq. 1)$$

In which $FC_{(i)}$ represents the average fuel consumption for the analyzed vehicle (i) and $FC_{ref(i)}$ the average fuel consumption for the reference vehicle (which will replace the analyzed vehicle), both in liters of consumed fuel per 100 km traveled

($l/100km$). The $km_{(i)}$ represents the annual distance traveled (in km) and $FP_{(i)}$ the fuel price (in euros per liter, €$/l$) for the analyzed vehicle (i). $R_{(i)}$ and $R_{ref(i)}$ represents the monthly value for the renting contract (in €$/month$) of the analyzed vehicle and the reference vehicle, respectively. The total annual cost reduction of this measure is given by the summation for the N analyzed vehicles, in which the value of the Eq.1 was positive, representing that way a cost reduction by the substitution of the analyzed vehicle (i). This way Eq.1 allows to determine if the analyzed vehicle should be replaced ($Eq. 1 > 0$) or not ($Eq. 1 < 0$) as well as the actual value for the cost reduction.

To calculate the total reduction in energy consumption, in tons of equivalent oil (toe), it is initially necessary to calculate the reduction of consumed fuel (in liters) related to the replacement of the analyzed vehicles (Eq.2). Subsequently, this value is converted to tons of equivalent oil (toe), through the Lower Heating value (LHV in toe/ton of fuel) and the specific mass (ρ_{fuel} in Kg/L) for the considered fuel (Eq.3).

$$Annual\ reduction\ in\ fuel\ consumption = \left(FC_{(i)} - FC_{ref(i)}\right) \times \frac{\boldsymbol{km_{(i)}}}{\boldsymbol{100}}\ , (Eq. 2)$$

$$\boldsymbol{Annual\ reduction\ in\ fuel\ consumption} = \sum_{i=1}^{N} (Eq. 2 \times \frac{\rho_{fuel}}{1000} \times LHV_{fuel})\ , (Eq. 3)$$

The environmental impact resulting from these measure (Eq. 8), in tonCO_2e, is obtained by multiplying the value for the reduction of energy consumption, in toe (Eq.3), by the emission factor (EF) of the considered fuel (in kgCO_2e/toe).

$$\boldsymbol{Annual\ reduction\ in\ emissions\ of\ CO_2} = Eq. 3 \times \frac{EF_{fuel}}{1000}, (Eq. 4)$$

2.3.2 Efficient driving measures (eco drive)

This measure acts at the level of the driver, raising awareness to the adoption of more efficient driving practices.

To calculate the financial and environmental impact associated with the implementation of this measure, it is necessary to define efficient driving profiles through fleet analysis, to determine the percentage of reduction in average fuel consumption resulting from the implementation of these measure. Therefore, two scenarios were considered, one more optimistic and the other less optimistic, and, for both scenarios, an additional value was considered relative to the cases in which there was only one vehicle corresponding to the analyzed model (single models).

For the **first scenario** (optimistic), after analyzing the various fuel consumption values per model, it was assumed that only the driver with the lowest average fuel consumption practices efficient driving, so, through training actions on efficient driving, all other drivers with the same model of vehicles could reduce their average fuel consumption to the value presented by this employee.

However, this hypothesis may result in conclusions that are too optimistic since fuel consumption is influenced by several factors, in addition to driving behavior, such as [10]:

- The use of **auxiliary systems** (A/C use may increase fuel consumption up to 9%);
- The **aerodynamics** of the vehicle, related to the use of transport accessories on the vehicle roof, or trips with open windows (increases of 5 and 5,1%, respectively);
- **Climatic conditions** (increase of fuel consumption up to 30% for periods of heavy precipitation);
- **Vehicle maintenance status**;
- **Transported cargo** (for each 100 kg of additional cargo transported an increase in consumption of 6 to 7% is estimate); and
- **Occupancy rate**, given that more passengers transported reflect more weight to transport (5% increase in fuel consumption per extra passenger).

Thus, when the average values of fuel consumption are compared for the same model, it can be assumed that some factors related to the vehicle's aerodynamics, maintenance status, occupancy rate and to some extent the transported load (for vehicles with similar function), do not individually influence the fuel consumption of the analyzed vehicles, as they are transversal to the same model analyzed. Nevertheless, there are still some factors that cannot be controlled or corrected by the driver, which influence directly the individual consumption of each vehicle, such as weather conditions (varying by region, taking into account the distribution of vehicles throughout the national territory), factors related to the road traveled, given the variation in traffic conditions and road slope, when comparing different geographic regions of the country.

In addition to all these factors, the success of the implementation of this type of training essentially depends on the willingness/availability of drivers to join and raise awareness with the purpose of training in eco driving [13] [14], therefore justifying the development of a **second scenario** (less optimistic), for which it was considered that it might not be possible to reduce the average fuel consumption to the minimum registered value.

Alternatively, for this scenario it was proposed that, only drivers with an average fuel consumption equal or lower to the average value for the model analyzed, practice efficient driving measures, hence making it possible for these drivers to reduce its average fuel consumption to this value (average of the model analyzed).

The **additional scenario** (to be added to both scenarios) consists of cases in which there is no vehicle with the same model analyzed and the real value for the fuel consumption is higher than the value obtained by the vehicle's technical sheet by about 15% for diesel vehicles and by 12.5% for petrol vehicles. This criterion was established to avoid including vehicles in which, a higher value for the fuel consumption was justified by the poor representativity of the NEDC test [14] [15] and therefore the vehicle's technical sheet value, and not by aggressive driving habits.

The additional value to be considered for both scenarios corresponds to a reduction in fuel consumption by 6.3%, given that this value is considered the average value of fuel consumption reduction after training in efficient driving [16].

The reduction of costs (in euros), for the 1st scenario, is estimated through the application of the equation 5, similar to the equation 1, replacing in this case, the fuel consumption of the vehicle of the reference ($FC_{ref(i)}$ from Eq.1) with the minimum average fuel consumption resisted for the model analyzed ($FC_{min(i)}$ in l/100km for Eq.5).

$$\boldsymbol{Annual\ cost\ reduction\ (1^{st}\ scenario)} = \left(FC_{(i)} - FC_{\min(i)}\right) \times \frac{km_i}{100} \times FP_{(i)}, (Eq.5)$$

For the 2nd scenario (Eq.6), $FC_{min(i)}$ is replaced by the average value for the average fuel consumption calculated for the model analyzed ($FC_{average(i)}$ also in l/100km).

$$\boldsymbol{Annual\ cost\ reduction\ (2^{nd}\ scenario)} = \left(FC_{(i)} - FC_{average(i)}\right) \times \frac{km_i}{100} \times FP_{(i)}, (Eq.6)$$

Equation 7 calculates the reduction in energy consumption (in toe) for the 1st scenario.

$$\boldsymbol{Reduction\ in\ fuel\ consumption\ (1^{st} scenario)} = \left(FC_{(i)} - FC_{min(i)}\right) \times \frac{km_{(i)}}{100} \times \frac{\rho_{fuel}}{1000} \times LHV_{fuel}, (\boldsymbol{Eq}.7)$$

For 2nd scenario the reduction in energy consumption (in toe) is estimated by Equation 8.

$$\boldsymbol{Reduction\ in\ fuel\ consumption\ (2^{nd} scenario)} = \left(FC_{(i)} - FC_{average(i)}\right) \times \frac{km_{(i)}}{100} \times \frac{\rho_{fuel}}{1000} \times LHV_{fuel}, (Eq.8)$$

For the 1st scenario the environmental impact, in $tonCO_2e$, associated with this measure is calculated through the equation 9.

$$\boldsymbol{Annual\ reduction\ in\ emissions\ of\ CO_2\ (1^{st} scenario)} = (Eq.7) \times \frac{EF_{fuel}}{1000}, (Eq.9)$$

For the 2nd scenario the environmental impact, in $tonCO_2e$, is calculated through the equation 10.

$$\boldsymbol{Annual\ reduction\ in\ emissions\ of\ CO_2\ (2^{nd} scenario)} = (Eq.8) \times \frac{EF_{fuel}}{1000}, (Eq.10)$$

For the additional scenario, Equation 10, 11 and 12 estimate the financial (euros), energy (toe) and environmental (tonCO2e) impacts, respectively.

$$\boldsymbol{Annual\ cost\ reduction\ (ad. scenario)} = FC_{(i)} \times 0{,}063 \times \frac{km_i}{100} \times FP_{(i)}, (Eq.10)$$

$$\boldsymbol{Reduction\ in\ fuel\ consumption\ (ad. scenario)} = \left(FC_{(i)} \times 0{,}063\right) \times \frac{km_{(i)}}{100} \times \frac{\rho_{fuel}}{1000} \times LHV_{fuel}, (Eq.11)$$

$$\boldsymbol{Annual\ reduction\ in\ emissions\ of\ CO_2\ (ad. scenario)} = (Eq.11) \times \frac{EF_{fuel}}{1000}, (Eq.12)$$

The calculation of the total cost reduction, for the 1st/2nd scenario, is obtained by the sum of the cost reduction for all vehicles included in the 1st/2nd scenario and the sum of all vehicles included by the additional scenario. The same is true for the total reduction of fuel consumption and CO_2 emissions for both scenarios.

2.3.3 Replacement of conventional vehicles with electric vehicles

As indicated before the EV presented the lowest average energy consumption from all types of vehicles [4] [11]. Therefore, as the company's automotive fleet features a wide variety of vehicles, including two HEV, three PHEV as well as one EV, this measure intends to:

1) Validated the hypotheses of the studies above mentioned recurring to real driving data;
2) Evaluate the limitations related with the autonomy values of EV; and
3) Assess the viability of the implementation of EV.

2.3.3.1 Best mobility solution

For the first objective, the best cases (lower energy consumption) of the various existing alternatives were compared (diesel, petrol, HEV, PHEV and EV) for each category of vehicles (LP and LM). This evaluation was done through the creation of three indicators (values shown in the results):

- The average energy consumption, in MJ/km, given that different types of vehicles are compared;
- CO_2 emissions per km (gCO_2e/km); and
- The cost per kilometer traveled (euros/km).

The average energy consumption, in MJ/km, for the ICEV, PHEV and HEV is estimated by Eq.13:

$$Energy\ consumption\ (MJ/km) = \frac{FC_{(i)}(L/100km)}{100} \times \rho_{fuel}(Kg/L) \times LHV_{fuel}(MJ/L), \quad (Eq.13)$$

For the EV, the energy consumption (MJ/km) is calculated by Eq.14, recurring to the estimated average energy consumption for the EV (EC_{EV} in $kWh/100km$) and considering that $1kWh = 3.6MJ$

$$Energy\ consumption\ (MJ/km) = \frac{EC_{EV}\ (kWh/100km)}{100} \times 3.6\ , (Eq.14)$$

The environmental impacts for each type of vehicles were estimated by Eq.15:

$$WTW\ emissons\ (gCO_2e/km) = TTW\ emissions\ +\ WTT\ emissions\ \ , (Eq.15)$$

The $WTW\ emissons$ correspond to the Well-to-Wheel emissions, representing both the, emissions related to the extraction/production process for the source of energy (Well-to-tank, WTT) utilized by the vehicle (fuel or electricity) and also the emissions related to the vehicle's circulation (Tank-to-Wheel, TTW). Therefore, Eq.15 ensures a valid comparison between the values of the CO_2e emissions for all analyzed vehicles, as it wouldn't be appropriate to compare only the TTW emission values between ICEV and EV, given that for the last, the TTW emissions are null but, in reality, the total emission of pollutants (WTW) are dependent on the production energy source for the electricity used to charge the batteries of the EV (WTT).
Thus, for the EV the environmental impacts are calculated by Eq.16, in which $EF_{eletricity}$ corresponds to the emission factor for the production of electricity (gCO_2e per kwh consumed)

$$WTW\ emissons\ (gCO_2e/km) = 0\ + \frac{EC_{EV}\ (kWh/100km)}{100} \times EF_{eletricity}\ , (\ Eq.16)$$

For the other vehicles, the environmental impacts are given by Eq.17, in which EF_{fuel} represents the emission factor ($in\ kgCO_2e/GJ$) for the circulation of the vehicle using a certain type of fuel (diesel or petrol) and $EF_{PROD.fuel}$ the emission factor for the extraction/production phase of fossil fuel considered (diesel and petrol).

$$WTW\ emissons\ (gCO_2e/km) = \ Eq.13\ (MJ/km) \times \frac{EF_{fuel}(kgCO_2e/GJ)}{10^3} \times 10^3 + Eq.13 \times EF_{PROD.fuel}(gCO_2e/MJ), (\ Eq.17)$$

The cost per km is taken directly from the data given by the energy characterization (division of the annual total cost, in euros, by the annual distance traveled, in km) for all the examples considered, except for the LP-EV, since this is not a real case of the car fleet, therefore there is no record of the distanced travelled.

2.3.3.2 Limitations related with the autonomy of EV

To evaluate the limitations associated with the autonomy of the EV proposed for the substitution of convectional vehicles, the total cost reduction of two different scenarios were analyzed. For the first scenario, it was considered that all light-duty vehicles (LP and LM) could be substituted by EV. For the

second scenario, however, the daily averages of kilometers traveled by the vehicles for each month were analyzed (assuming a uniform distribution throughout the 20 working days), so that only vehicles for which the maximum value registered was inferior to the autonomy considered for the EV of substitution would be included.
After establishing these two scenarios the total cost reduction (in euros) for both scenarios was calculated (Eq.18) and its value was compared (shown in the results)

$$Cost\ reduction\ (subs.\ by\ EV) = \left(FC_{(i)} * PF_{(i)} - EC_{EV} * P_{Electricity}\right) * \frac{km_{(i)}}{100}\ ,(Eq.18)$$

In which $P_{Electricity}$ represents the price of electricity (in Euros/kWh) to charge the EV.

2.3.3.3 Viability of the EV's implementation

This measure is similar to the first one, as it is proposed that when the renting contract of the analyzed vehicle is renewed, the vehicle in question should be replaced by a more efficient model. Although for this measure, the analyzed vehicle is substituted by an EV, instead of a more efficient ICEV as proposed for the first measure. The equation (Eq.19) for the annual cost reduction resulting from the implementation of EV is therefore similar to Eq.1.

$$Annual\ cost\ reduction = \left(FC_{(i)} \times FP_{(i)} - EC_{EV} * P_{Eletricity}\right) \times \frac{km_i}{100} + (R_i - R_{EV}) \times 12, (Eq.19)$$

The total reduction in energy consumption (Eq. 22 in toe), is given by the difference between the annual energy consumed by the analyzed vehicle for the distanced traveled (Eq. 20) and the energy that the substitution EV would consume for the same travelled distance (Eq. 21).

$$Energy\ consumption\ (analyzed\ vehicle\ i)\ in\ MJ = L_{(i)fuel} \times \rho_{fuel}(kg/L) \times LHV_{fuel}(MJ/Kg)\ ,(Eq.20)$$

$$Energy\ consumption\ (EV)\ in\ MJ = EC_{EV}(kWh/100km) \times \frac{kmi}{100} \times 3{,}6(MJ/kWh), (Eq.21)$$

$$Reduction\ of\ energy\ consumption\ (toe) = (Eq.20 - Eq.21)/41868\left(\frac{MJ}{toe}\right), (Eq.22)$$

The environmental impact resulting from these measure (Eq. 23), in tonCO_2e, is therefore also obtained by the difference between the emissions of both vehicles. The value for the CO_2 emissions is obtained multiplying the energy consumption by the corresponding emission factor (EF_{fuel} for the analyzed vehicle and the $EF_{electricity}$ for the EV, both in tonCO_2e/MJ).

$$\boldsymbol{Annual\ reduction\ in\ emissions\ of\ CO_2} = Eq.20 \times EF_{fuel} - Eq.21 \times EF_{electricity}\ , (Eq.23)$$

The final scenario consists of all vehicles that presented a positive value for Eq.19 and the maximum value for the daily averages of kilometers traveled was inferior to the autonomy considered for the EV of substitution would be included.

3. Results

This section presents the results obtained, the description of strategies and times of implementing for the proposed measures, as well as the investments required to implement them and the respective payback times. The reduction percentages for the results obtained will always be related to the initial situation, that is, for an annual energy consumption of 345 toe, corresponding to an expense of 532 502 € and the emission of 1086.58 tonCO_2e.

3.1 Replacement of inefficient conventional vehicles

For the 1st measure, the application of the described methodology resulted in the proposal to replace 43 light-duty vehicles by models with a lower fuel consumption (14 LP and 29 LM), for a total reduction in energy consumption of 7.90 toe (2.29%), corresponding to an annual cost reduction of 18 687 € (3.51%) and the reduction of CO_2 emissions by 24.46 tonCO_2e (2.29%).
The measure presented is of gradual implementation, given that the end dates of the renting contracts for the vehicles to be replaced must be respected, since the prior termination of these contracts would imply the payment of 30% of the value of the contract until the end date of the same.
Hence, the replacement of vehicles proposed in this measure does not present the need for an additional investment. The payback period of this measure is therefore immediate.
Of the 43 vehicles proposed for replacement, 5 may be replaced by the end of 2019, 14 will be replaced

by the end of 2020, 20 by the end of 2021 and 4 vehicles by the end of 2022.

3.2 Efficient driving measures (eco drive)

For the 2nd measure, through the methodology described to determine which drivers would benefit from training in efficient driving, it was determined that a set of 127 drivers could be trained for the most optimistic scenario, while for the less optimistic scenario only a total of 82 drivers should be trained.
It is estimated that the proposed measure allows a reduction in energy consumption between 25.76 to 9.57 toe (7.47 to 2.77%), resulting in an annual cost reduction between 39 822 to 15 023 € (7.48 to 2.82%), allowing a reduction of emissions of CO_2 from 79.81 to 29.65 tonCO_2e/ year (7.47 to 2.77%). The higher and lower values presented correspond to the optimistic and less optimistic scenario, respectively.
To assess the accuracy of the results obtained, the average value for the percentage of reduction in fuel consumption of each driver was calculated for both scenarios. An average value of 12.2 and 4.4% was obtained for the first (more optimistic) and second scenario (less optimistic), respectively. Considering the average values for the reduction in fuel consumption after training in efficient driving (6 to 8%), presented in the literature [10] [16], the developed scenarios constitute a good estimate for the range of values (financial and environmental / energy impact) resulting from the implementation of the proposed measure.
The investment required to implement this measure consists, obviously, of the cost associated with training drivers, corresponding to 15 240 €, according to data collected from training proposals presented to the company. These proposals reveal that it is possible to train 12 drivers at the same time (per class), and the value per training consists of 1440€ per class, corresponding to a value of 120€ per trainee. Thus, for this measure the payback period corresponds to 5 months, if the most optimistic scenario is verified, or 12 months for the least optimistic scenario. The necessary time to implement this measure will depend on the availability of the company responsible for training the drivers and the decision on the frequency of these driving formation by the beneficiated company.

3.3 Replacement of conventional vehicles with electric vehicles

The analysis of the defined indicators, for the various types of propulsion technology, concludes that EV are the best mobility solution (as indicated by the literature [4] [11]). Since, when compared to the ICEV (diesel) alternative for the LM vehicle, the EV presents an inferior energy consumption of around 66.2%, allows a reduction of 67% of CO2 emissions per km traveled and presents an inferior cost per km of 67.5%. Also, when compared (EV) to the second-best option for LP vehicles (diesel), it presents a lower energy consumption of about 65.2%, allowing a reduction of 65.3 % of CO2 emissions per km traveled and a cost per km lower by around 64.4%. These results consequently validate the feasibility of the implementation of this measure.
After the validation of the results obtained for the analysis of the best mobility solution, Figure 2, shows the comparison of the percentages of cost reduction (in relation to the annual cost for the entire automobile fleet) obtained for the two scenarios previously defined, separated by LP and LM vehicles.

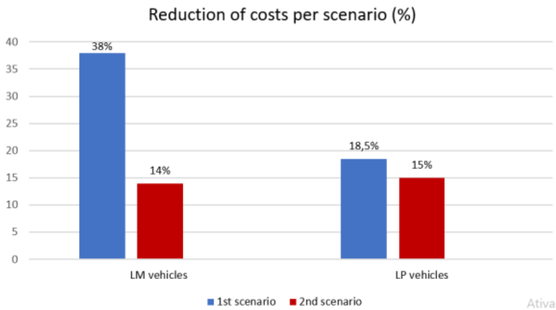

Figure 2- % of cost reduction, per vehicle category, for the 1st and 2nd scenario

As shown (Fig.2), the autonomy of the EV to replace LM vehicles (light-duty good's transportation vehicle) is still quite limited for most vehicles analyzed and due to this circumstance, there is a difference in the percentage of cost reduction by around 24 percentage points from the 1st to the 2nd scenario. For the case of the EV to replace LP vehicles (light-duty passenger vehicles), this limitation does represent such a severe impact on the percentage of cost reduction, given that the difference in percentages between the two scenarios is only 4.5%.
Finally, the results obtained for the final defined scenario are presented. The application of the methodology described concluds that it is possible to replace 15 light-duty vehicles with electric vehicles (4 LP and 11 LM), resulting to a reduction of energy consumption by 17.81 toe (5.17%), a reduction of the emission of 50.36 tonCO_2e/year (4.71%)

corresponding also to an annual cost reduction of 6 434€ (1.21%).

As with the first measure, the implementation of these measure is gradual given that the ending dates of the renting contracts must be respected. Of the 15 vehicles proposed for replacement, 1 will be replaced by the end of 2019, 6 will be replaced by the end of 2020.7 by the end of 2021 and 1 vehicle by the end of 2022. The investment required to implement this measure, consists of 9 409€ (VAT incl.), corresponding to the installation of 15 charging stations for the EV, as the most conservative hypothesis was assumed considering that in the worst case, none of the vehicles could be charged in the same location. The return time of this measure after replacing the 15 vehicles corresponds to 18 months.

3.4 Integrated implementation of measures

The three measures presented were developed in a way that allow them to be implemented individually. However, the final objective certainly includes the implementation of all three measures proposed. Yet, there were some cases, in which it was proposed the replacement of a vehicle for a conventional model with lower fuel consumption (1st measure) and simultaneously the replacement of the same vehicle with an EV (3rd measure).

To define to which of the measures the substitution of the vehicle should be assigned, the comparison of the financial impact (reduction of costs) resulting from the replacement of the vehicle, for both measures were made, defining that the replacement which results in a higher financial impact should prevail over the other measure. The application of the described methodology resulted simply in the reduction of vehicles replaced for the 1st and 3rd measurements. For the 1st measure, instead of replacing 43 light vehicles, 37 vehicles are replaced (namely 12 LP vehicles and 25 LM vehicles. Regarding the 3rd measure, it was concluded that only 8 light vehicles should be replaced by VE, namely 3 LP vehicles and 5 LM vehicles.

The energy (Figure 3), environmental (Figure 4) and economic (Figure 5) impact, depending on the years of replacement of the vehicles analyzed (in the 1st and 3rd measurements), resulting from the integrated implementation of the three measures are shown below. It should be noted that, for the graphs presented, the energetic (Figure 3), environmental (Figure 4) and economic (Figure 5) impact of the 2nd measure, is concentrated from the first to the second year of implementation of the proposed measures, i.e., from 2019 to 2020, given that the time for implementing this measure is practically immediate. As for the other measures presented (1st and 3rd measures), it is possible to observe their impacts gradually.

Considering that the implementation of the measures

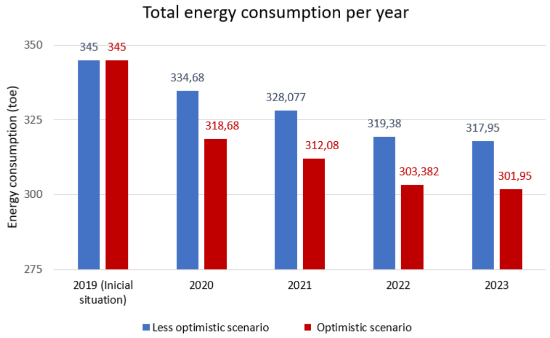

Figure 3- Total reduction of energy consumption due to the years of vehicle replacement for the 3 measures presented.

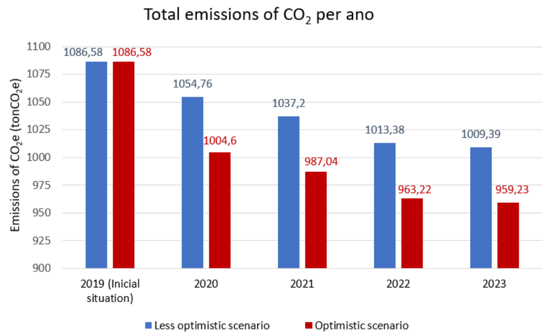

Figure 4- Total reduction of CO_2 emissions due to the years of vehicle replacement for the 3 measures presented.

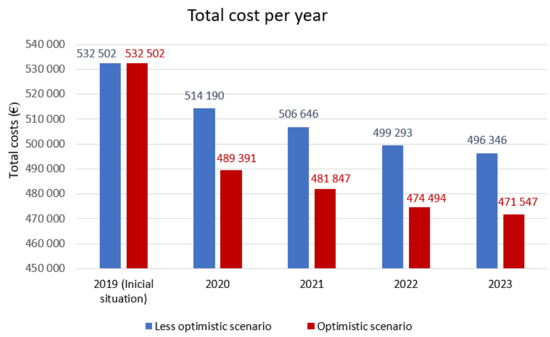

Figure 5- Total cost reduction of due to the years of vehicle replacement for the 3 measures presented.

begins at the beginning of 2019, three years later, that is, for the beginning of the year 2022, the value for the total energy consumption of the company's fleet consists of 319.38 toe (Figure 3), corresponding to the emission of 1013.38 tonCO2e (Figure 4) and an associated annual cost of 499 293€ (Figure 5) (for the less optimistic scenario). Hence corresponding to a 7.3% reduction in energy consumption, a 6.7%

reduction in CO_2 emissions and a cost reduction of 6.2% for the period considered.
Therefore, the objective defined by the RGCEST is fulfilled (reduction of 5% in energy consumption, CO_2 emissions and costs, for a period of 3 years) even for the less optimistic scenario.

4. Conclusions

The main objectives of this work were the energy characterization of the automobile fleet, the introduction and development of measures to reduce energy consumption and the quantification of the energy, financial and environmental impact resulting from the implementation of the same.
The energy characterization of the fleet identifies the critical classes that contribute more significantly to the energy consumption (light-duty vehicles).
Through the definition of the highest fuel consumption vehicles in the fleet and its replacement by more efficient models allows a reduction of energy consumption and CO_2 emissions by approximately 2.3 % and a total cost reduction of about 3.5% (1st measure). This measure is an excellent option, given that it presents an immediate return (zero investment), although its implementation must be done gradually.
The practice of efficient driving measures allows reductions of 7.5% to 2.8% (optimistic or less optimistic scenario) of energy consumption, CO_2 emissions and total costs. The methodology used allows the definition of efficient driving profiles that are quite realistic, given the similarity between the fuel reduction values obtained by applying it and those presented in the literature [10] [15].
It is also concluded that EV correspond to the best option in terms of energy and environmental impact. However, the replacement of vehicles (ICE) with VE (3rd measure) is still a somewhat limited alternative, with the current VE technology, related to the autonomy of vehicles and the high prices of renting contracts compared to conventional vehicles. However, its implementation for cases in which it proves favorable, should not be ignored, given the high impacts on the energy consumption and CO_2 emissions resulting from its implementation.
Considering all measures studied, a final intervention plan to comply with the 5% reduction in energy consumption, pollutant emissions and financial costs, is presented with the following characteristics:

- A total investment of 20 258 € was proposed, with a global return time of between 4 and 7 months;
- Replacement of 46 vehicles (38 for the 1st measure and 8 for the 3rd measure) and the training of 127;
- Reduction in energy consumption of 12.2 to 7.5% (42,11 to 25,92 toe), a reduction of 12.6 to 7.9% (134,92 to 84.76 tonCO_2e) in CO_2 emissions; and
- Annual savings of between 61 248 and 36 449 €, corresponding to a reduction of 11.5% to 7.2% in the total costs associated with the use of the automobile fleet.

Literature cited

[1] Eurostat, Energy, transport and environment indicators, 2015.
[2] IEA, "IEA - Transports," 2016.
[3] D. d. República, "Regulamento da gestão do consumo de energia para o setor dos transportes," 1990
[4] D.A. Howey, R.M. Martinez-Botas, B. Cussons, L. Lytton, "Comparative measurements of the energy consumption of 51 electric, hybrid and internal combustion engine vehicles".
[5] J. Van Mierlo, L. Vereecken, G. Maggetto1, V. Favrel, S. Meyer and W. Hecq, "Comparison of the environmental damage caused by vehicles with different alternative fuels and drivetrains in a Brussels context", Université Libre de Bruxelles.
[6]- Vlieger, I. De, Keukeleere, D. De, e Kretschmar, J. G., 2000, «Environmental Effects of Driving Behavior and Congestion Related to Passenger Cars», Atmospheric Environment, 34, pp. 4649–4655.
[7] Yang Wang and Alessandra Boggio-Marzet, "Evaluation of Eco-Driving Training for Fuel Efficiency and Emissions Reduction According to Road Type", 2018, Universidad Politécnica de Madrid, Spain;
[8] Frey, H. C., Zhang, K., e Rouphail, N. M., 2008, «Fuel use and emissions comparisons for alternative routes, time of day, road grade, and vehicles based on in-use measurements», Environmental Science and Technology, 42, pp. 2483–2489
[9] Choudhary, A., e Gokhale, S., 2016, «Urban real-world driving traffic emissions during 80 interruption and congestion», Transportation Research Part D: Transport and Environment, 43, pp. 59–70
[10] N. G. Zacharof and G. Fontaras, "Review of in use factors affecting the fuel consumption and CO2 emissions of passenger cars" 2016, Joint Research Centre (JRC), the European Commission's science and knowledge service
[11] Lorf, C., Martinez-Botas, R. F., Howey, D. A., Lytton, L., e Cussons, B., 2013, «Comparative analysis of the energy consumption and CO2 emissions of 40 electric, plug-in hybrid electric, hybrid electric and internal combustion engine vehicles», Transportation Research Part D: Transport and Environment, 23
[12] Fiat, "Ecodriving uncovered-The benefits and challenges of eco-driving, based on the first study using real journey data".
[13] Ecomobile, "Eco-Driving Training pilot project for light vehicles".
[14] Mellios, G., Hausberger, S., Keller, M., Samaras, C., Ntziachristos, L., Dilara, P., e Fontaras, G., 2011, Parameterisation of fuel consumption and CO2 emissions of passenger cars and light commercial vehicles for modelling purposes, JRC Scientific and Policy Reports, Report nº 24927 EN.
[15] G.O. Duarte, G.A. Gonçalves, T.L. Farias,2016, Analysis of fuel consumption and pollutant emissions of regulated and alternative driving cycles based on real-world measurements, Transportation Research Part D,44, pp.43-54