Evaluation of alternative mobility solutions in a postal distribution fleet

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October 2021

Abstract

The transport sector, given its dependence on fossil fuels, is one of the major consumers of final energy, contributing to climate change. The companies that operate in this sector have high energy consumption, being the target of successive policy measures for the preservation of energy resources and in the mitigation of emission of polluting gases. This work, developed at the postal company CTT, under the Galp21 program, aimed at evaluating measures to improve the energy performance of the fleet, starting with its energy characterization in the postal distribution process, and evaluation of different scenarios implemented in two different studies: 1) optimization of the fleet and shift to alternative propulsion systems and load capacity; and 2) introduction of 3 or 4-wheel vehicles in pedestrian delivery, as a solution to the increase in e-commerce using a case study of a postal distribution center in Lisbon. In the first study, it was concluded that electric vehicles had the highest cost, on average 20% higher in F4 vehicles, 35% in F8 and 50% in F10 compared to diesel vehicles, and the ones that produce the lowest number of CO_2 emissions, with a reduction of 63%. In the second study, four solutions were developed. The 3rd solution, with the implementation of a 100% electric fleet (vans and tricycles), revealed to be the best one, estimating a reduction of total annual costs of 3.5%, with a reduction of 60% in CO_2 emissions and almost 40% in energy consumption, representing a payback time of 3.9 years.

Keywords: E-commerce; Postal distribution; Fleet management; Energy and environmental impacts; Urban logistics

1 Introduction

Nowadays, the transport sector is one of the biggest contributors to energy consumption, a trend characterized by its constant growth [1]. In the EU-28, road transport was estimated to account for 31% of final energy consumed in 2018 and 25.8% of pollutant gas emissions [2]. This fact justifies the need to develop and create alternative solutions in this sector, having already been initiated through regulations and objectives established by the EU, more specifically in the reduction of CO_2 emissions for the most recent passenger cars [3]. Thus, an agreement between manufacturers and European Commission has also been implemented with the aim of improve the overall vehicle´s efficiency for new vehicles sales in 2021, by setting a goal of 95 g/km of CO_2 [4].

In city centers there is a high number of vehicles, mostly dependent on fossil fuels [5], so it is appropriate to adopt vehicles with alternative technology, namely electric vehicles in order to overcome all these issues. This type of vehicles is more efficient, leads to reductions in noise pollution and does not emit harmful gases into the atmosphere (accounting only for its phase of use) since EV present substantial advantage in the Tank-to-Wheel stage [6][7].

One of the sources that causes these problems in urban environments lies in the logistics operations which are estimated to represent 8 to 15% of the total traffic flow in EU [8], representing one of the main sources of local pollution, revealing concerns for those who live and work in these areas [9]. Thus, in order to control the energy consumption for the transport sector in Portugal, a regulation was created (RGCEST) to improve the energy efficiency of the sector in companies whose energy consumption, during the previous year, was greater than 500 toes, being subject to an evaluation every 3 years [10]. Therefore, it is relevant to introduce not only alternative solutions in the transport sector, but also to quantify and regulate pollutant emissions and energy consumption of vehicles under specific traffic conditions. To quantify these factors there are experimental and numerical methods that can be used. For both experimental and numerical methods, energy consumption and respective pollutant emissions depend essentially on the vehicle's technology, the type of road the vehicle travels, the driver behavior, the planning and choice of the route, the traffic environment and the total weight of the vehicle. Of all the factors mentioned, the vehicle's propulsion technology (e.g., internal combustion engine vehicles, hybrid electric vehicles, plug-in hybrid electric vehicles, battery electric vehicles) is likely to be the most prominent factor in a vehicle's environmental and energy impact [11].

In a study [12] carried out in England involving 40 vehicles of different propulsion technologies, internal combustion engine vehicles (ICEV) obtained the highest energy consumption circa 3 to 4 times higher than electric vehicles (EV), which revealed the lowest impacts. Regarding the types of roads where the vehicle is running, several studies [13] [14] [15] have been carried out with the purpose of estimating the impact on the emission of pollutants and fuel consumption by vehicles on hilly roads, concluding that there may be an increase on average of 40 to 100% in fuel consumption in a light vehicle, together with the average NOx emissions higher by a factor of 4, when driving on roads with slopes equal to or greater than 5% [14].

Concerning driver behavior, a study carried out in Belgium [16] concluded that with an aggressive driving style, the average fuel consumption may increase up to 40% together with an increase in emissions up to a factor 8, also concluding that diesel vehicles are the most independent of the driver's driving style, while in gasoline vehicles there were the greatest differences in fuel consumption and emissions emitted.

Regarding the weight of the vehicle, a study estimated that the vehicle's fuel consumption may increase by 6 to 7% for every 100 kg of extra cargo carried and by approximately 5% for each occupant in the vehicle [17].

During the last decades, in the logistics operations in urban areas, attempts have been made to find more environmentally friendly solutions in order to meet the needs of not only society, but also suppliers [18]. Currently, the postal distribution service has undergone a revolution in the way it has adapted to the market. With the growth of e-mail or e-commerce, typical mail is no longer based on letters, but on large-volume orders. One of the potential solutions could be the use of small electric vehicles (SEV), not only due to all the advantages mentioned above, but also due to their ease of movement in traffic [18]. However, a study carried out in the city of Oporto [18] concludes that the extent of SEV coverage in the city's logistics operations, should be as short as the street level, representing only a niche market such as the delivery of postal services. In this context, another study [19] carried out in the city of Rio de Janeiro evaluated different strategies for implementing this type of vehicles under the last mile regime in the postal distribution service and its outcome impact, concluding that when SEVs were implemented in the distribution process, the total costs decreased 27.9%, with an increase in productivity of 26% and a reduction in CO_2 emissions of 98.5% [19].

In this sense this research work addresses the introduction of measures aimed at the energy efficiency of a postal distribution company, trying to reduce the energy consumed and CO_2 emissions associated with postal distribution services. This study will focus specifically on a postal distribution center located in the metropolitan area of Lisbon.

2 Methodology

In this work, developed at the company CTT - Correios de Portugal, SA, the company's fleet was characterized by analyzing the viability of acquiring alternative energy vehicles, with an emphasis on energy consumption (in toe) and CO_2 emissions in the last mile regime, also considering the economic impact.

This study is based on two different approaches: the first approach is related to a global analysis where the economic, environmental and energy impacts in the replacement of current vehicles with alternative energy vehicles in different scenarios of annual mileage are quantified; the second one focuses on a local analysis of a specific CDP (postal distribution center) in the center of Lisbon, where it analyzes not only the economic, environmental, energetic and volumetric impacts of the fleet in the replacement of the current vehicles with alternative energy vehicles, but also in the impacts from the acquisition of electric vehicles with 3 and/or 4 wheels to be implemented in pedestrian delivery.

2.1 Global approach

By the end of March 2020, CTT's fleet in its entirety is made up of 3,596 vehicles, most of which are allocated to last mile distribution with a total of 2,657. Of these 2,657 vehicles, the use of vans of approximately 2, 4 and 8 cubic meters of capacity (F2, F4 and F8) stands out as the vehicles in greatest number. F10 vans do not exist in a significant number, however, F10 and F8 vehicles are in higher demand nowadays justified by the increase in the volume of orders due to e-commerce. Vans larger than F10 do not exist, because it would constitute a problem in distribution logistics in last mile regime, given its larger size. On the other hand, smaller vehicles such as F2 and F4 will also continue to be in demand and to be fundamental in postal mail distribution operations due to its practicality. Thus, this study will analyze F4, F8 and F10 vans, in different scenarios of annual mileage of 14, 20, 24 and 26 thousand kilometers, quantifying the correspondent economic, environmental and energy impacts between each type of vehicle.

When choosing new van vehicles with alternative technologies for acquisition by CTT, it will be necessary to take into account not only the market offer for van vehicles with alternative energy, but also the existing infrastructures in the present and in the near future so that the acquisition is viable. In this context, looking at all the solutions available to date, the only ones that are viable are vehicles powered by compressed natural gas (CNG) and electricity. In relation to CNG, the great advantages of this type of fuel are that vehicles of this nature have high tax benefits in Portugal, the exhaust emissions of CNG vehicles are significantly lower than vehicles powered by gasoline or diesel and, unlike oil, the existence of natural gas reserves has been proven for many centuries and there still is the possibility of producing biomethane [20]. Regarding the infrastructure of the CNG supply network, at the moment there are only 2 filling stations in Lisbon, with the promise of Dourogás to open 2 more soon (negotiations have been underway with Galp) [21]. One of the stations in operation is located on Avenida Mar. Gomes da Costa, a few meters from a CDP, thus making it a viable option for the future of a small part of the CTT fleet.

Despite the existence of several possible technologies, electric vehicles seem to be the most viable trend in the short/medium term, not only due to the greater investment in infrastructure, but also due to the wide range of vehicles already on the market. According to the European Car Manufacturers Association (ACEA), in the first quarter of 2019, demand for cars powered by alternative energy in the EU increased by 25.9% [22]. This growth was due to an increase of vehicles with electric charging, which grew by 40%, accounting a total of 99,174 vehicles. Within these values, it was the electric vehicles (BEV) that grew the most in a total of 84.4% [22]. In Portugal this growth, compared to the same period of the previous year, was 46.8% higher, entering the 10 countries with the highest growth within the EU for alternative energy vehicles (including BEV, PHEV, CNG and GPL vehicles) [22].

There are numerous advantages related to electric cars, namely CO_2 emissions are non-existent during their use, economic savings on fuels, absence of noise, tax incentives, among others. One of the disadvantages of electric vehicles is undoubtedly the autonomy, however, in the context of CTT this would not be a problem, as the range of an electric vehicle would be sufficient for daily delivery and the battery would be charged at a charging station of a CDP during the night while the vehicle is not in service.

Considering the previous characterization of the fleet and based on the existing offer in the current market for electric vehicles, for the F4 vehicles the best options are already found in the fleet such as the Renault Kangoo Maxi, for the F8 vehicles it would be the Nissan NV-200 XL and for the F10 be the Volkswagen e-Crafter. Regarding CNG, the vehicle analysed will be the Volkswagen Caddy for the F4, Fiat Doblo Cargo Maxi for the F8 and for F10 vehicles there is not none available in the national market and as such it will not be part of the analysis.

2.1.1 Economic impact

Regarding the calculation of the economic impact on the purchase of vehicles, it was divided into two parts:

- **Annual fuel cost** for each vehicle, which will be the total cost of fuel consumption in a given annual mileage scenario taking into account the consumption of each vehicle presented in table 1;
- **Annual acquisition cost**, which can be divided into two parts: annual fixed costs (insurance and the total monthly rental of operational car rental); and annual variable costs (e.g., non-contractual maintenance)

The sum of the two costs originates the **total annual cost** (equation 1) of each vehicle that will be compared within each vehicle type according to each annual mileage scenario.

$$Total\ annual\ cost = Annual\ fuel\ cost + Annual\ acquisition\ cost \tag{1}$$

Table 1 - Average consumption of the different vehicles

Type of vehicle	Energy consumption		
	Diesel (l/100km)	Electric (kWh/100km)	CNG (kgCNG/100km)
F4	8.0	26.9	7.5
F8	11.1	29.8	7.9
F10	11.2	37.6	-

In the process of acquiring electric vehicles, given the size of CTT's fleet, it will have to be analysed *a priori* where and when electric vehicles can be charged. Regarding the infrastructure related to electric mobility in Portugal, it has been noted in recent years that it has not been following the exponential growth in sales of electric vehicles, both in terms of the number of service stations and the quality of service [22]. Thus, in a company like CTT, when the acquisition of a significant number of electric vehicles instead of conventional diesel vehicles is imminent, the installation of their own charging stations becomes practically mandatory. This way, charging would become more convenient, quick and safe and there could also be greater control over consumption of each vehicle. A project developed by CTT quantified that the installation of its own charging stations for 12 vehicles and 15 tricycles would cost approximately 70 thousand euros. Thus, the total annual cost of electric vehicles will take into account this cost of electrification of the CDP amortized by each vehicle and by its years of useful life.

2.1.2 Environmental impact

The calculation of the environmental impact generated by different types of fuels, will be quantified through the Life Cycle Assessment (LCA) analysis. This analysis allows a more complete assessment of the vehicle's associated emissions, not only because it assesses the period of use of the vehicle, but also all the impact caused from its manufacturing process until the end of the vehicle's life (including vehicle disassembly and recycling materials). This analysis is divided into three different levels, Well-to-Tank (WtT), Tank-to-Wheel (TtW) and Well-to-Wheel (WtW), with WtW being the sum of TtW and WtT. Table 2 shows the values of CO_2 emissions WtW for each fuel, together with the values WtT and TtW.

Table 2 – CO_2 emissions for different types of fuels

Stages	CO_2 Emissions		
	Diesel ($kgCO_2$/litre)	**Electricity** ($kgCO_2$/kWh)	**CNG** ($kgCO_2$/kgCNG)
WtT	0.55	0.349	0.586
TtW	2.641	0	2.891
WtW	3.191	0.349	3.477

2.1.3 Energy Impact

To calculate the energy impact, the values of the low heating value for diesel and for natural gas in toe per ton were obtained [23], LHV_{diesel}: 1.022 toe/ton and LHV_{CNG}: 1.077 toe/ton. Since the density of diesel is approximately equal to 0.83 kilograms per litre, using equation 2, the toe value per litre of diesel is obtained and through equation 10, the toe value per kilogram of natural gas.

$$\text{Toe}_{\text{Diesel}}(toe/l) = \text{LHV}_{\text{Diesel}}(toe/ton) \times \rho_{\text{Diesel}}((kg/l) \div 1000 \quad (2)$$

$$\text{Toe}_{\text{CNG}}(toe/kg) = \text{LHV}_{\text{CNG}}(toe/ton) \div 1000 \quad (3)$$

For electricity, APA (Portuguese environmental agency), establishes that 1 kWh is equivalent to approximately 290.0 * 10 ^ -6 Toe [24]. Table 2 shows the values of each unit of equivalent fuel in toe.

Table 3 - Toe values of different energies

	Diesel (1 litre)	**Electricity** (1kWh)	**CNG** (1kg)
Toe	848,3x10^-6	290,0x10^-6	107,7x10^-5

2.2 Local approach

In order to implement specific measures this work will be restricted to only one CDP. Thinking about the near future, the number of CDPs in Lisbon will be reduced. The only one that will be in a more central area will be the CDP 1300 (in Junqueira), which will also be expanded with the fleet that exists to date in the CDP 1200. Thus, in this work the CDP 1300+1200 fleet will be analysed, characterizing it not only in terms of total annual costs, but also in terms of energy, environment and total volume. CDP's pedestrian delivery and its associated fleet will also be analysed.

Regarding the CDP fleet, through the analysis made previously of vehicles with alternative technology, scenarios of direct replacement of vehicles of the current fleet will be applied. These scenarios will be compared in terms of the economic impact resulting from the direct replacement, in terms of annual acquisition costs (sum of all fixed and variable costs) and the cost of energy associated with the same kilometres travelled in 2019 by the current fleet. They will then also be compared in terms of environmental impact (LCA analyses) and energy impact. The final analysis will be made through the total annual cost ratio of the fleet by the total volume (total cost per cubic meter), in terms of emissions generated WtT per total volume of the fleet (kilogram of CO_2 per cubic meter) and in terms of energy per volume total fleet (Toe per cubic meter).

Altogether, in the direct replacement of vehicles in the CDP 1200+1300 fleet, 6 scenarios were created (represented in the table 5), giving rise to a 100% electric fleet in 3 of the scenarios, 1 scenario 100% CNG and 2 others with the mix of the two types of vehicle technology. Table 4 shows the current fleet of CDP 1200+1300.

Table 4 - Current CDP 1300+1200 fleet

	F2 _ELE	F4 _ELE	F4	F5	F8	Other	Total
CDP 1300+1200	3	9	2	1	3	12	**30**

Table 5 - CDP 1300+1200 Vehicle Replacement Scenarios

Scenarios	Current Vehicles replaced	Proposed Vehicles	CDP
1	3 F8, 2F4, 1F5	3 F8_ELE, 3F4_ELE	100% Electric
2	3F8, 1 F5, 2 F4	2 F8_ELE, 2 F10_ELE, 2 F4_ELE	100% Electric
3	3 F8, 1 F5,2 F4, 9 F4_ELE	2 F8_ELE, 2 F10_ELE, 11F4_ELE	100% Electric
4	3 F8, 2 F4, 1 F5	3 F8_CNG, 3F4_CNG	100% Alter. energy
5	3 F8, 1 F5, 2 F4	2 F10_ELE, 2 F8_CNG, 2 F4_CNG	100% Alter. energy
6	3 F8, 2 F4, 1 F5, 3 F2_ELE, 9 F4_ELE	3 F8_CNG, 15 F4_CNG	100% CNG

2.2.1 Pedestrian delivery solutions

In the postal delivery process under the last mile regime, the connection between the CDPs and the customers is mainly made through pedestrian postmen, in some cases by bicycle, mopeds and also through vehicles. Due to the increase of e-commerce, a postman cannot transport the cargo destined for an entire shift at once, causing CTT to assign certain vehicles to reload every postman. On average, these reloading vehicles (RV vehicles), supply about 6 to 8 postmen in the urban centres, with each postman being reloaded 2-3 times during his shift. In other words, the RV vehicle makes between 12 and 24 reloads per day. Each postman carries a maximum of 50 litres of cargo at a time with the support of a small car, which with 3 refills reaches a maximum of 200 litres of cargo transported.

Many of the stops in these large urban centres use public transport, which means traveling to transport, plus all the time wasted on the trip itself. In this way, there is the hypothesis that the postman uses his own vehicle of smaller dimensions than a van vehicle (figure 1- a) and that can transport the entire cargo equivalent to the entire shift with reloading (at least 200 litres of cargo). In this sense, if a significant number of postmen use one of these vehicles, the RV vehicles could be discarded as well as all the associated impacts to their operation. With regard to the postmen who do not need public transport to carry out their shifts the solution to be able to discard RV vehicles are to be able to carry all the necessary load at once with the help of an electric trolley (figure 2 - b).

Figure 1 - a) Ligier Pulse 3 fromCTT and b) e-Trolley Kyburz

The CDP 1300 consists of a total of 18 vehicles, of which 8 are RV vehicles and the other 10 are vehicles with 3 and 4 wheels already used in distribution and a total of 27 postmen, of which 24 use public transportation and the other 3 do not. On average, each postman from CDP 1300 that uses public transport loses 43.8 minutes in the transport itself and about 20.4 minutes to go to the transport and from the transport to the start of delivery. Each postman who does not use transportation, loses an average of 13 minutes on the way to the start of delivery. Thus, through the 43.8 minutes travel time for postmen using public transport, and the value indicated by Carris with an average speed in 2019 of 13.8 km/h of public transport [25], the distance covered is, on average, of 10072.1 meters.

Adding to the route 1358.3 meters (20.4 minutes by walking at a speed of 4 km/h) for postmen using public transport, a total distance of 11430.4 meters is reached in a total time of 64.2 minutes (1.07 hours). Along with this lost travel time, the postman has an internal time at the CDP of 2 hours. Subtracting these 3.07 hours from the shift of 7.8 hours, a useful time of 4.73 hours per postman is obtained.

In this way, multiplying the value of the useful time by the 24 postmen, a total useful time of 113.53 hours is completed. If tricycles are implemented, they would be able to cover the same distance of 11430.4 meters with a speed of 19 km/h [10], in 28.08 minutes or 0.47 hours. Adding to the working time of 4.73 hours, a total useful time end up at 5.2 hours. Dividing the 133.53 hours previously obtained by 5.2, a value of 21.84 is achieved, that is, if 22 pedestrians start to make their shift with an electric tricycle, it is possible to reorganize the deliveries so that these 22 postmen complete the total route of the 24 postmen, without the need for reloading.

Therefore, 3 scenarios were created with the implementation of 32 or 34 tricycles, all of which also replace 10 vehicles with 3 and 4 wheels already existing in the fleet, and other 2 scenarios, the 4th and 5th, where another type of tricycle with a higher load will also be implemented (Babboe pro Trike XL), but with limitations in traveling speed. In the 4th scenario, 34 Babboe tricycles will be acquired, while in the 5th scenario will be acquired 10 Babboe and 24 Ligier tricycles. In all scenarios it will be acquired 3 e-trolleys for the other postmen as well. In the end, based on the best scenarios implemented, solutions will be created that encompass not only the implementation of vehicles of alternative energy to the vehicles of the fleet, but also the replacement of the reloading vehicles by the tricycles and trolley previously proposed. Thus, 4 solutions will be created, of which 3 present a 100% electric CDP fleet and the 4th presents a mix of electric vehicles (tricycles and e-trolleys) with CNG vehicles.

3 Results and analysis

3.1 Global Analysis with Economic, Environmental and Energy impacts

For the different stipulated annual mileage scenarios of 14, 20, 24 and 26 thousand kilometres, the annual fuel cost and subsequently the total annual cost of each vehicle were quantified based on the annual values of acquisition for each vehicle. Regarding the fuel price, the average price used by CTT in 2019 was 1,271€ per litre of diesel and 0.171€ per kilowatt hour. Natural gas, on the other hand, currently has a market value of 1.15€ per kilogram. The variation in the total annual cost of each type of vehicle (F4, F8 and F10) for each scenario of annual mileage, is shown in figures 3.

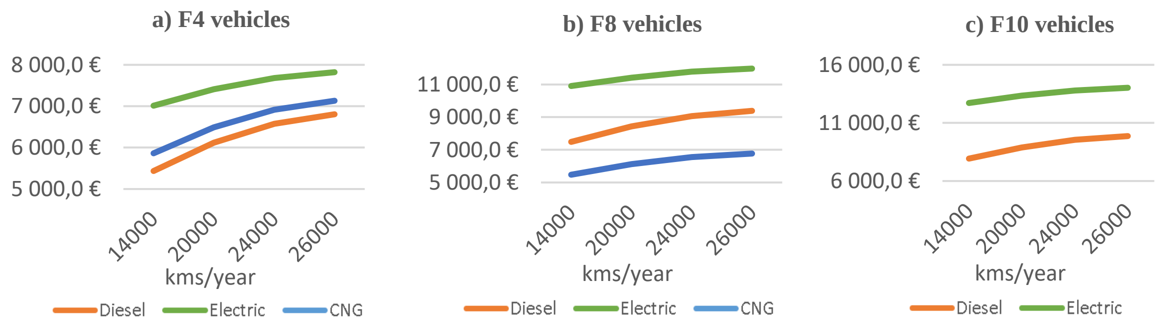

Figure 2 - Evolution of the total annual cost for the different scenarios of annual mileage, being the figure a) relative to the F4 vehicles, b) of the F8 and c) of the F10 vehicles

It appears that for a scenario of 14 thousand kilometres, the electric F4 vehicle has a total annual cost approximately 29% higher than the current diesel one, while the CNG vehicle has a cost 7.9% higher, being that as the mileage increases the difference drops to 5%. Regarding F8 vehicles it appears that, like F4 vehicles, electric vehicles will always have a higher total cost, *circa* 45.7% for 14 thousand kilometres and 27.6% for 26000 km. However, for this case, the vehicle with the lowest total cost is the CNG vehicle (approximately 27% lower than the diesel one). For F10 vehicles, regardless of the scenarios, the diesel vehicle is always more economic than the electric vehicle, in a range between 60.4% and 42.2% difference.

In relation to the environmental impact generated by the different types of fuels, based on the consumption of each vehicle (table 1), the kilometres travelled for each scenario and the values in table 2, the values for the amount of CO_2 emissions emitted by each vehicle were obtained. It was found that regardless of the scenarios and vehicles, electric vehicles have the lowest number of CO_2 emissions with reductions of 63.25%, 70.6% and 63.3% for F4, F8 and F10 vehicles respectively. As for CNG vehicles, there was a reduction of 22.5% in F8 vehicles and an increase of 2.6% in F4 vehicles. This result can be explained by the difference in the consumptions of each vehicle. That is, while GNC vehicles have a similar consumption in different types, in diesel vehicles this difference is already very significant. Concerning the energy impact, based on the consumption of each vehicle (table 1), the kilometres travelled for each scenario and the values in table 3, the values for the energy consumption in toe by each vehicle were obtained. For F4 vehicles, the electric option has an energy consumption 14.72 % higher, while the CNG vehicle is 19.26% higher than the current diesel. Conversely, in F8 vehicles the diesel vehicle is the one with the highest energy consumption, with the electric F8 having a reduction of 8.40% and the F8 GNC a reduction of 9.82%. In F10 vehicles, the electric vehicle consumes 14.54% higher.

3.2 Local Analysis with different scenarios

3.2.1 Fleet replacement in CDP 1300+1200

Based on the kilometres travelled by each vehicle in 2019, their consumption, the unit price of each energy fuel (diesel, natural gas and electricity) and the annual cost of acquisition of each vehicle, it is possible to estimate the economic, environmental and energy impact of the CDP 1300+1200 presented in the table 6. In the last column of the table, there is the CDP service referring to the sum of the carrying capacity of the total number of vehicles.

Table 6 - Annual impacts of CDP 1300+1200 in 2019

	Economic impact	Environmental impact			Energy impact	Service
	Total annual Cost	TtW	WtT	WtW	Toe	m^3
Total	164,964 €	12,096	16,963	29,059	15.9	88

By analysing the scenarios of table 5 and by quantifying the parameters already mentioned (economic, environmental, energy and service impacts), it is observed that, through the data in table 7, the first 3 scenarios with 100% electric CDP present a total annual cost higher than the current CDP, justified by the high cost of acquiring electric vehicles compared to conventional diesel vehicles present in CDP's current fleet. Scenario 2 is the one with the highest total cost with a value of 10.10% higher than the current CDP. However, and similarly to the 3rd scenario, it presents an increase in the volume of transported cargo of 7.95%. Despite this increase in total cost in all the 3 scenarios, CO_2 emissions are significantly lower compared to the current CDP, with a reduction of approximately 32% in the 3 scenarios. Energy consumption only increased slightly in 2nd and 3rd scenario. Observing the data in table 8, it is concluded that the 1st scenario is the one with the highest total annual cost per available cubic meter of the 3 scenarios with the fleet 100% electric. The 6th scenario, based only on CNG vehicles, presents the highest increase in CO_2 emissions (66.47%) and the lowest total annual cost (-7.10%). Table 8 shows that despite the 6th scenario presents the lowest total annual cost ratio of CDP per cubic meter of cargo transported, it presents the highest ratio of kilograms of CO_2 emitted per cubic meter of available cargo of all scenarios.

Table 7 - Comparison of scenarios in total annual cost, kilograms of CO2 emitted, energy consumption in toe and in total fleet volumetric gains with the current CDP 1300+1200

Scenarios	Total annual Cost	Emissions ($kgCO_2$)	Energy consumption (Toe)	Total fleet volume (m^3)
1	5.71%	-33.35%	-0.66%	-1.14%
2	10.10%	-32.12%	1.21%	7.95%
3	8.63%	-32.44%	0.72%	7.95%
4	-3.17%	-7.66%	0.49%	-1.14%
5	4.20%	-15.46%	2.05%	7.95%
6	-7.10%	66.47%	1.75%	2.27%

Table 8 - Comparison of scenarios in total annual cost per m^3, kilograms of CO_2 emitted per m^3, energy consumption in Toe per m^3 of the fleet with the current CDP 1300 + 1200

Scenarios	Total annual cost/m^3	Emissions of $kgCO_2/m^3$	Energy consumption in Toe/m^3
Current	**1,874.9 €**	**331.1**	**0.18**
1	2,004.4 €	222.6	0.18
2	1,911.8 €	207.6	0.17
3	1,886.3 €	206.7	0.17
4	1,836.0 €	308.4	0.18
5	1,809.3 €	258.6	0.17
6	1,702.7 €	537.5	0.18

3.2.2 Pedestrian delivery analysis

Based on all the elements present in the postal distribution process of pedestrian delivery (postmen, RV vehicles and drivers), based on the year 2019, the different impacts of the CDP were quantified (table 9). It should be noted that, in the calculation of the volume of cargo, it was not taken into account the volume of cargo of the RV vehicles, since they are only used for reloading of postmen.

Table 9 - Annual impacts caused by the current CDP 1300

	Economic impact	Environmental impact			Energy impact	Service
	Total annual Cost	TtW	WtT	WtW	Toe	m^3
Total	1,168,99 €	5,073	10,680	15,753	9.6	2,586

As represented in tables 10 and 11, in the 1st scenario there is a very significant reduction in the total cost of 17%, justified by the extinction of 2 vehicles and their respective drivers and also 2 postmen. There is a reduction of 66.86% on CO_2 emissions and 54.78% for energy consumption, also due to the elimination of RV vehicles, despite the purchase of a substantial number of tricycles. The 4th scenario, with the acquisition of the Babboe tricycle, is effectively the one with the best results in all categories. However, since there are some limitations on the speed that this vehicle can reach, the 5th scenario where there is a mixture of both tricycles may prove to be the best option.

Table 10 - Comparison of the proposed scenarios with the current scenario in percentage terms

Scenarios	Total annual Cost	Emissions ($kgCO_2$)	Energy consumption (Toe)	Total fleet volume (m^3)
1	-17.0%	-64.7%	-52.1%	53.5%
2	-14.7%	-63.9%	-51.0%	57.9%
3	-12.4%	-63.1%	-49.9%	62.3%
4	-19.2%	-88.5%	-84.4%	211.4%
5	-14.4%	-70.6%	-60.1%	93.0%

Table 11 - Comparison of scenarios in total annual cost per m^3, kilograms of CO_2 emitted per m^3, energy consumption in Toe per m^3 of the fleet with the current CDP 1300+1200

Scenarios	Total annual cost/m^3	Emissions of $kgCO_2/m^3$	Energy consumption in Toe/m^3
current	**452.0 €**	**6.1**	**37.3**
1	244.4 €	1.4	11.6
2	244.2 €	1.4	11.6
3	244.1 €	1.4	11.5
4	117.3 €	0.2	1.9
5	200.6 €	0.9	7.7

3.2.3 Analysis of solutions for the entire fleet of the CDP 1300+1200

Based on the previously analysis, the same impacts have now been quantified for the entire CDP 1300+1200, with all stakeholders, such as all vehicles, the respective drivers and postmen of the CDP 1300, present in the table 12.

Table 12 - Total annual impacts of the entire CDP 1300+1200

	Economic impact	Environmental impact			Energy impact	Service
	Total annual Cost	TtW	WtT	WtW	Toe	m^3
Total	2,6242,69 €	12,157	16,976	29,133	15.9	6,703

Based on the best scenarios implemented in the previous sections, solutions were created that now encompass not only the implementation of alternative energy vehicles to the fleet vehicles, but also the replacement of reloading vehicles by the previously proposed tricycles and trolleys. Thus, the solutions presented are:

- **1st Solution**: permanence of F2 electric vehicles in the fleet of both CDPs with acquisition of a total of 7 F4 electric vehicles (1 for the collection of landmarks in the CDP 1300 and 6 for the replacement of the older 2 F4, 1 F5 and 3 F4 electric vehicles in the fleet of the CDP 1200) and 1 electric F8 to replace the F8 on the CDP 1200. Acquisition of 32 Ligier and 3 tricycles and trolleys for the CDP 1300 pedestrians.

- **2nd Solution:** identical to the 1st solution, however with the introduction of 33 Ligier tricycles.
- **3rd Solution:** same as the 1st solution, though with the introduction of 24 Ligier tricycles, plus 10 Babboe Pro tricycles similar to the 5th scenario in the previous analysis to pedestrian delivery.
- **4th Solution:** same as the 3rd solution, but with the replacement of all F4 electric vehicles by F4 CNG and the F8 electric vehicle replaced by F8 CNG.

Based on the same kilometres travelled in 2019 for each vehicle of each CDP, the economic impact of the 4 solutions was estimated, as well as the environmental, energy and volumetric impact present in table 13, compared as a percentage with the current CDP.

Table 13 - Proposed solutions compared to the current scenario in percentage terms

Solution	Total annual Cost	Emissions ($kgCO_2$)	Energy consumption (Toe)	Total fleet volume (m^3)
1	-4.69%	-56.53%	-34.02%	20.36%
2	-3.64%	-56.09%	-33.35%	22.05%
3	-3.49%	-59.71%	-38.84%	40.66%
4	-4.16%	-22.74%	-37.92%	40.66%

Table 14 shows the comparison of solutions in total annual cost, kilograms of CO_2 emitted and energy consumption in toe per available cubic meter of the current CDP 1300+1200, together with the different solutions.

Table 14 - Comparison of solutions in total annual cost, kilograms of CO_2 emitted and energy consumption per m^3, of the entire fleet with the current CDP 1300+1200

Solution	Total annual cost/m^3	Emissions of $kgCO_2/m^3$	Energy consumption in Toe/m^3
current	391.5 €	4.34	2.37
1	310.0 €	1.57	1.30
2	309.1 €	1.56	1.30
3	268.6 €	1.24	1.03
4	266.8 €	2.38	1.05

Through the results, there is a gain in the total annual cost of approximately 4% in all solutions compared to the current one. However, it is in the 3rd and 4th solution where, through the increase in the total volume of the fleet, the cost ratio per available cubic meter is lower. With the implementation of these solutions, energy consumption is substantially lower in both (almost 40%). However the 4th scenario, with the acquisition of CNG vehicles and electric tricycles for pedestrians, reveals to implement the lowest reduction in CO_2 emissions (22% less than the current) of all 4 solutions. In terms of CO_2 emissions, the 3rd solution turns out to be the best one, with a reduction of approximately 60%.

The below table 15 shows the payback period (PBP) of each solution, based on the investment made with the acquisition of all the tricycles and e-trolleys for each solution and the annual savings of the difference of the total costs of each solution with the current scenario.

Table 15 - Investment and PBP for implemented solutions

Solution	Investment	Annual savings	PBP (year)
1	399,522.7 €	122,950.7 €	3.2
2	411,360.9 €	95,548.0 €	4.3
3	355,817.0 €	91,496.3 €	3.9
4	355,817.0 €	109,059.9 €	3.3

4 Conclusions

With the main objective of identify and characterize the impacts of solutions to reduce the energy consumed and the emission of pollutants associated with the postal distribution service of CTT, it is concluded that the adoption of electric vehicles are the best option to replace conventional diesel vehicles.

In the global analysis, in terms of CO_2 emission, regardless of the annual mileage scenarios, electric vehicles always have the lowest number of CO_2 emitted, with a reduction of 63%, 70% and 63% in F4, F8 and F10 vehicles, respectively, compared to the current vehicles. CNG vehicles, given the current lack of a supply network for natural gas, may not me a good solution in the near future. Regardless, they showed solid results in F8 vehicles with a reduction of 22.5% in CO_2 emissions and 9.8% in the energy consumption, while as the most economical vehicle of the 3.

Concerning all solution developed for the CDP1300+1200 (pedestrians and vehicles), it was concluded that the 3rd solution, with the implementation of 10 Babboe and 24 Ligier tricycles and electric vans, that revealed the best results in all criteria in relation to the volume of cargo available in the fleet, with a payback period of 3.9 years. If the acquisition of natural gas vehicles does not pose any logistical problem, then the implementation of the 4th solution with the acquisition of CNG vans and electric tricycles, is also a good option, pointing to a return on investment of approximately 3.3 years

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