Conference Paper

Growing Evolution of the Electrification Rate on Heavy Vehicles

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Abstract

In response to environmental impacts and all the limitations caused by fossil fuels, we have been witnessing in recent decades to the sharp development of hybrid electric and electric vehicles, particularly in heavy-duty passenger vehicles. Its proliferation is now widespread in virtually every major vehicle brand, reflecting operator confidence. In order to further mitigate the use of fossil fuels, the trend is to increase supply in 100% electric versions. However, the evolution of recent years, both in manufacturers commercial strategy of major brands and bodybuilders and in sales volume, seems to indicate a new demand stage for this kind of vehicles, which are still making the first steps in Portugal. However, high acquisition costs and limited autonomy are still major obstacles to a faster proliferation of electrification in heavy vehicles. Its strengths such as lower air and noise pollution, in addition to lower operating and maintenance costs, led to a growing acquisition in the Portuguese vehicle market, where 16 new heavy-duty passenger BEV have been sold this year. Real-world operational impacts of these vehicles indicate a energy use between 0.91 and 1.65 kWh/km depending on driving context. It has been also observed that operators are still adapting and not always using the full battery capacity.

Keywords: Electrified heavy vehicles, Energy assessment, Driving mode, Load support, State of charge

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1. Introduction

Limitations of fossil fuel reserves and price fluctuations, as well as the environmental impact of greenhouse gas emissions, have prompted governments and carmakers to seek alternative energy solutions. Indeed, it is in the transportation sector that such alternatives are most urgent: in OECD member countries, 60% of the consumption of petroleum products is associated to this sector, accounting for about 25% of global CO_2 emissions [1]. According to Figure 1a), road transport contributes with the largest share - 37% of final Energy consumption by sector. In recent years, hybrid electric (HEV) and purely electric (BEV) vehicles have become the most promising alternatives to conventional vehicles based on internal combustion engines (ICE). Advances in multiple technological fields have contributed to arise of these alternative propulsion systems, such as electric machines, power electronics, energy storage and control systems [2], [3].

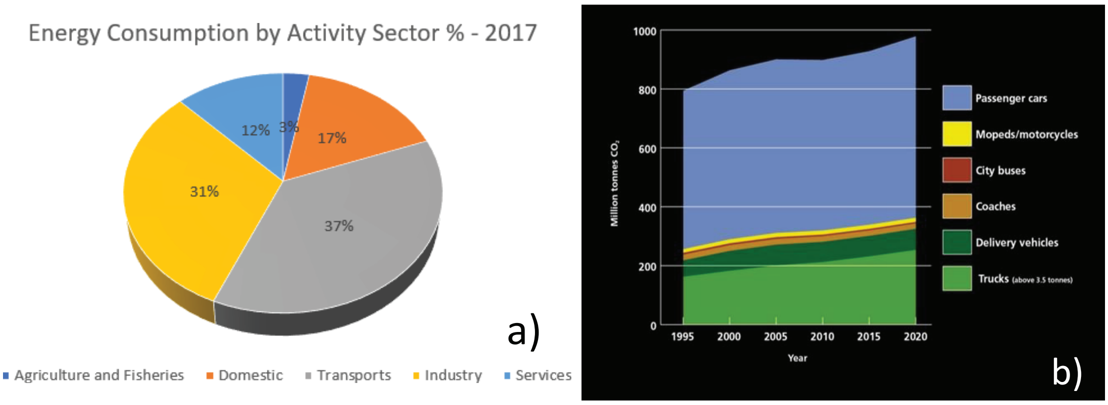

Figure 1: a) Energy consumption by activity sector (INE 2017); b) Projected CO2 - EU road transport emissions [1]

In the transportation sector, focusing only on the road sector, there is still a heavy reliance on fossil fuels, with direct impacts on CO_2 emissions, as shown in Figure 1b). Despite CO_2 emissions from heavy vehicles represent around 25% of total CO_2 emissions from road transport in the EU, they are not currently regulated at European level and there are currently proposals from the European Commission to introduce legislation regulating CO_2 emission limits, based on testing under operating conditions [1].

Increasing pressure from governments to limit pollutant emissions (particularly in urban centers) has motivated the automotive industry to intensify and diversify its efforts to continually improve the performance, reliability, safety and comfort of conventional vehicles with a tight cost control [3], [4]. The European Parliament (EP) has proposed a target of 35% reduction in carbon dioxide (CO_2) emissions from new heavy vehicles by 2030, above the 30% proposed by the European Union (EU). In an approved text resulting from a vote of 373 votes in favor, 285 against and 16 abstentions, an intermediate target to reduce CO_2 emissions by 20% by 2025 is set. The proposal has yet to be negotiated with the Council of the European Union (EU), in order to reach agreement on the final legislation. However, it sets that heavy- duty vehicles (for goods and passengers) with no emissions or low emissions should represent 20% of the market share in 2030, with an intermediate value of 5% in 2025 [14], [15], [16], [17].

Consequently, there has been a clear strategy defined by the manufacturers to increase the commercial offer of HEV and BEV, particularly visible in the last 5 years. In the case of HEV, the tendency is for a growing electrification of the propulsion system. The evolution of alternatives to conventional vehicles (ICE) by the automotive industry coincides with the emission level restrictions implemented in some cities and countries. Conventional hybrid (HEV) models, from multiple manufacturers, are currently marketed worldwide, with good dynamic performance and fuel consumption levels up to 30% compared to the diesel vehicle [5].

Hybrid vehicles include the designations HEV (conventional hybrids), and PHEV (plug-in). More specifically, the classification shown in Figure 2 includes the most common designations associated with the electrification of propulsion systems. The sequence of the following descriptions is based on an increasing rate of the electrical component level in vehicle propulsion: this implies a decrease in the power of the ICE, accompanied by an increase in the power of the electric motor(s) as well as such as power converter(s) and batteries. This contributes to an increase in the final price and weight of the vehicle compared to the ICE versions. The current state of battery technology has a very significant influence here.

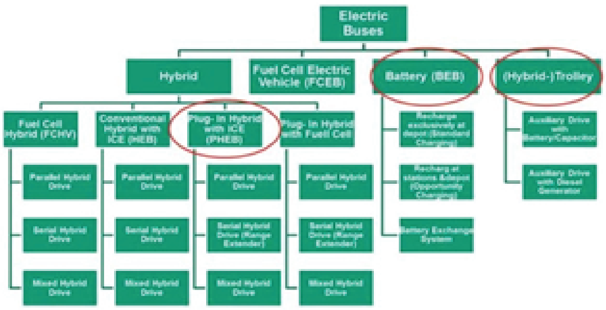

Figure 2: Propulsion System Designations (electrification level function) considered [9].

In the hybrid vehicle group, three levels are usually considered as a function of electrical integration: micro, mild and full hybrid. In the Micro hybrid configuration, compared to conventional vehicles, the difference is that the built-in generator can operate as an engine during the ICE (Integrated Starter Generator - ISG) startup. This saves energy when the vehicle is stationary (ICE off). Some variants with higher power generators allow regenerative braking (in some documents they are called Micro-Mild hybrid), mostly geared towards city driving (frequent starts and stops). Its cost is slightly higher than the conventional vehicle, given the low degree of electrification.

In turn, in a Full hybrid system, the propulsion system is series or parallel (Figure 3), with two electric machines (motor and generator) and ICE. Power transmission systems are more complex (eg planetary gears), making the division of power required (between ICE, electric motor (EM) and energy storage system) more flexible. Consequently the performance of the ICE can be optimized (eg maximum performance with minimum emissions). The following propulsion modes (including regenerative braking) [6], [7] are possible: (a) EM (start / stop); b) ICE (cruising mode, optimal performance) and; c) Combined mode: EM (or electric generator) + ICE.

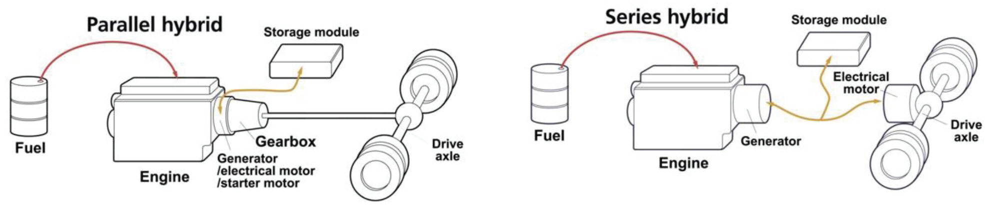

Figure 3: Propulsion systems- Parallel or series [9].

Regarding PHEV (Plug-in Electric Vehicles) [6], [7], the propulsion system is similar to "Full- Hybrid". The batteries are charged by an external source of electricity, also taking advantage of regenerative braking. The battery system has larger capacity compared to previous configurations, although smaller than in purely electric vehicles (BEV). The following operating modes should be highlighted: a) Charge depleting - Mostly electric propulsion, with the batteries providing most of the required energy; b) Charge sustaining - When the battery charge level (SOC) is below a set value, ICE propulsion is activated (hybrid mode).

As already mentioned, the current energy use has led to global warming issues, caused by the excessive greenhouse effect that results from the increasing level of CO_2 emissions and the imminent depletion of primary origin energy resources. In order to fight climate change, it is necessary not only to reduce carbon emissions but also to reduce the current carbon concentrations already existing in the atmosphere. Bearing this in mind, electric vehicles are a very convenient solution, since electricity production can be independent from the use of fossil fuels and with low impacts on CO_2 emissions and pollutants.

One of the main components of electric vehicles is the batteries where the energy is stored. While some significant advances in battery technology are to be highlighted, there are still important limitations that have not yet been overcome (e.g. high price, high weight and volume, power densities and autonomy beyond charging times). These disadvantages are responsible for the reduced demand for BEVs. In turn, HEVs combine the characteristics of conventional vehicles with the advantages of electrical propulsion (higher efficiency with lower pollutant emissions and braking energy recovery), without the limitations of the range of BEVs [8], [12], [13]

Currently, the most commonly used batteries in BEV and PHEV are nickel metal hydrides (NiMH) and lithium ion (Li-Ion). Especially in the latter, considerable increases in energy density have been obtained (currently much higher than other types of batteries).

The size and volume of the batteries act as conditionings of the project be it at structural level of the vehicle or its price. There is a clear tendency for their integration with super capacitors, taking advantage of their high-power density values. Lithium batteries are similar to humans in terms of operating temperature, according to Figure 4.

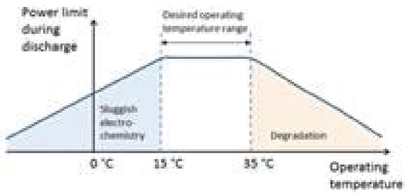

Figure 4: Working area as a function of temperature [12], [13].

Battery charging and recharging time depend on battery capacity and charger power. PHEV and BEV can receive both normal and fast charging. Therefore, the charger power can range from 40kW to 150kW and the average recharge time is 5 to 6 hours, depending on battery capacity. However, while high power results in short charging downtime, they tend to shorten battery life. To maximize its life, batteries should be recharged to 30% of their capacity and considered end-of-life when reaching 70 ~ 80% of initial capacity [12], [13].

Regarding market implementation of electric vehicles, the main critical success factors are the adequate development of infrastructures, mindset change regarding a new form of mobility, the automotive industry's commitment in developing battery technology, the increase of energy costs especially oil, the consolidation of imminent changes in the electricity business and development of smart grids and the streamlining of environmental policies and government incentive systems.

Despite the major constraints associated with electric vehicles, the Portuguese government has, in recent years, become involved with the concept of sustainable mobility, which combines the promotion of new vehicle technologies (hybrid, electric, plug-in, fuel cell) and energy sources (biodiesel, electricity, natural gas, among others), the development of new mobility management tools and the promotion of behavioral change in driving as well as the use of new mobility alternatives.

Of course, this would explain the increased acceptance of Portuguese operators regarding electric vehicles. However, there have been no sales of conventional hybrids (HEV) in Portugal, even considering different degrees of electrification of the propulsion system (HEV and PHEV). HEV prices are higher than conventional options (ICE) [3] and while fuel savings could reach around 30%, the lack of any purchase support for this type of vehicle negatively impacts its penetration into fleet renewal. On the other hand, although there is plug-in support (PHEV), this type of vehicle does not exist in the heavy-duty passenger segment.

Although the penetration level of alternative propulsion technologies in the heavy-duty passenger transport sector is very reduced, this work studies the real operational impacts of a BEV bus under different driving and topographic context, analyzing its energy impacts.

2. Methodology

To fulfil the goal of estimating the impacts of an increased number of EV (electric vehicles) on the operation and maintenance of passenger buses in Portugal, data was obtained from bus operators, under real operating conditions, in locations with specific characteristics (altitude, topography, driving context, etc.), as well as data from official sources and manufacturers.

By contacting operators, it was possible to obtain data on energy consumption, overall and per km, charging times and some feedback about using electric vehicles within a passenger transport context. Information on the penetration of these vehicles in Portugal was obtained from official sources, namely ACAP (Portuguese Automobile Trade Association), and directly from bus manufacturers.

2.1. Description of the fleet of heavy-duty passenger BEVs

The scenario of vehicles with a higher rate of electrification (PHEV, and purely electric – battery (BEV) and fuel cells (FCV)) is very different and still have a very low impact. Only the BEV represent about 2.74% of new vehicle sales in 2019 [10]. However, in the last 4 years, growth in this segment has been slow, as shown in Table 1.

TABLE 1: Sales in Portugal: impact of electrification – Caetano BEV [10]

Brand	2006		2007		2008		2009		2010		2011		2012	
	Qtd	2006	Qtd	2007	Qtd	2008	Qtd	2009	Qtd	2010	Qtd	2011	Qtd	2012
Scania	49	18,28%	89	26,10%	73	20,98%	50	15,11%	15	15,46%	15	8,43%	9	7,50%
Volvo	35	13,06%	47	13,78%	84	24,14%	100	30,21%	42	43,30%	32	17,98%	26	21,67%
Iveco	5	1,87%	10	2,93%	33	9,48%	33	9,97%	0	0,00%	6	3,37%	1	0,83%
MAN	115	42,91%	167	48,97%	119	34,20%	111	33,53%	24	24,74%	70	39,33%	18	15,00%
Caetano BEV	0	0,00%	0	0,00%	0	0,00%	0	0,00%	0	0,00%	0	0,00%	0	0,00%
Mercedes	64	23,88%	28	8,21%	39	11,21%	37	11,18%	16	16,49%	55	30,90%	66	55,00%
Total	268	100,00%	341	100,00%	348	100,00%	331	100,00%	97	100,00%	178	100,00%	120	100,00%

Brand	2013		2014		2015		2016		2017		2018		2019	
	Qt	2013	Qt	2014	Qt	2015	Qt	2016	Qt	2017	Qt	2018	Qt	2019
Scania	13	11,11%	9	6,29%	8	4,97%	30	13,27%	29	12,45%	35	9,80%	30	8,22%
Volvo	27	23,08%	29	20,28%	39	24,22%	64	28,32%	50	21,46%	26	7,28%	25	6,85%
Iveco	1	0,85%	1	0,70%	1	0,62%	2	0,88%	1	0,43%	0	0,00%	0	0,00%
MAN	38	32,48%	28	19,58%	31	19,25%	57	25,22%	61	26,18%	159	44,54%	228	62,47%
Caetano BEV	0	0,00%	0	0,00%	0	0,00%	1	0,44%	0	0,00%	25	7,00%	10	2,74%
Mercedes	38	32,48%	76	53,15%	82	50,93%	72	31,86%	92	39,48%	112	31,37%	72	19,73%
Total	117	100,00%	143	100,00%	161	100,00%	226	100,00%	233	100,00%	357	100,00%	365	100,00%

This growth seems to imply the start of a new stage in the acceptance and penetration of these vehicles (BEV) in the market. However, there are various uncertainties regarding their penetration due to the interaction process among manufacturers (technological characteristics and costs), consumers (in terms of acceptance) and governments (BEV purchase incentives). Nevertheless, it may be stated that these results are a consequence of concerted efforts by the automobile industry and decision makers. Official data reveals that 16 BEV vehicles were registered until September 2019 (Table 2).

TABLE 2: Automobile market per type of fuel/energy (2019 ACAP) [10]

		September 2019				January - September 2019			
		Passenger Light-duty	Light commercial	Heavy-duty commercial	Heavy-duty passenger	Passenger Light-duty	Light commercial	Heavy-duty commercial	Heavy-duty passenger
	Gasoline	6 752	12			87 326	58		
	% Gasoline	46,4%	0,4%			50,2%	0,2%		
	Diesel	5 738	2 681	733	14	69 328	27 953	3 811	312
	% Diesel	39,4%	98,9%	99,9%	41,2%	39,8%	99,3%	98,9%	60,6%
	Electric	685	15		6	5 422	130		16
	% Electric	4,7%	0,6%		17,6%	3,1%	0,5%		3,1%
Plug-i	Electric/Gasoline	440				2 758			
	%Electric/Gasoline	3,0%				1,6%			
	Electric/Diesel	31				528			
	%Electric/Diesel	0,2%				0,3%			
Hybrid Electric	Gasoline/Hybrid	691				6 322			
	% Gasoline/Hybrid	4,7%				3,6%			
	Diesel/Hybrid	79				400		9	
	%Diesel/Hybrid	0,5%				0,2%		0,2%	
Hybrid Non Electric	Gasoline/CNG						7		
	% Gasoline/CNG						0,0%		
	Gasoline/LNG								
	% Gasoline/LNG								
	Gasoline/LPG	142				1 922			
	% Gasoline/LPG	1,0%				1,1%			
	Diesel/LNG							2	
	% Diesel/LNG							0,1%	
	CNG		2		14	18	8	16	187
	% CNG		0,1%		41,2%	0,0%	0,0%	0,4%	36,3%
	LNG			1				17	
	% LNG			0,1%				0,4%	
	Total	14 558	2 710	734	34	174 024	28 156	3 855	515

3. Results

Energy use data was obtained from real operating conditions in Madeira island, whose studied cases reveal different driving and topography scenarios, with distinct challenges for implementing electric vehicles.

3.1. Aerobus Route - SAM (Madeira)

The Aerobus route run by SAM is 52 km long (both ways), and has a maximum altitude difference of 331 m. The Aerobus route connects Praia Formosa to the Cristiano Ronaldo Airport and back again to Praia Formosa. Figure 5 presents the battery state of charge (SOC, in percentage of available battery charge), travelled kilometres and altitude, obtained at specific points along the bus route, after a full charge.

It was found that with current battery capacity the bus performs only one two-way trip to the airport, which ends at Praia Formosa with a 39% SOC level. On the return to the station, a distance of about 2 km, it uses another 12% and reaches the station with a 27% charge. Table 3 summarises energy consumption during the route and electricity regeneration by the braking system.

A complete two-way trip (54 km) of the Aerobus route has a total consumption of 55.18 kWh and a specific consumption of 1.02 kWh/km. During the trip, energy regeneration occurs on two sections, which increases the autonomy by 15%.

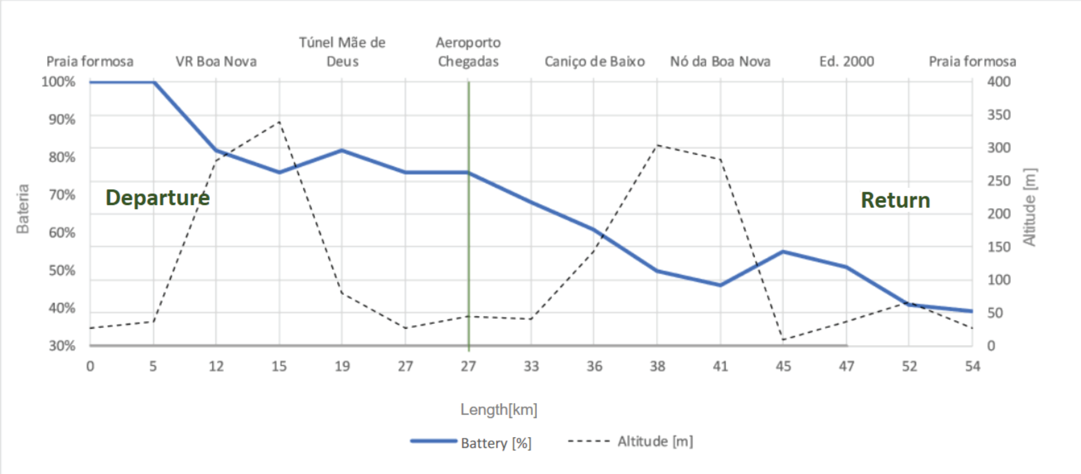

Figure 5: Distance, altitude and battery SOC level – Aerobus Route

Table 3: Energy consumption, battery status and regeneration – Aerobus Route

Trip		Battery Status	Energy Regeneration	Consumption (kWh)	Specific Consumption (kWh/km)
P. Formosa - Aeroporto		76%	6%	55,18	1,02
Aeroporto - P. Formosa		39%	9%		
Empty	Estação - P. Formosa	100%	-	10,86	2,71
	P. Formosa - Estação	27%	-		

3.2. Monte 21 - Horários do Funchal

The Monte 21 route run by Horários do Funchal is 14 km long and has an altitude difference of 620 m. Figure 6 shows the battery SOC level, travelled kilometers and altitude, obtained at specific points along the bus route, after a full charge, operating in the Monte 21 route that links Praça da Autonomia to Largo da Fonte.

It was found that with this battery the bus made two complete two-way trips to Largo da Fonte, of approximately 14 km each, ending at Praça da Autonomia with 50% SOC level. On the return to the station, over a distance of about 4 km, it uses 12% of the battery energy and reaches the destination with 38% SOC level. Table 4 summarises energy consumption during the route and electricity regeneration by the braking system.

Two complete two-way trips on the Monte 21 route results in a total consumption of 38.71 kWh and a specific consumption of 1.43 kWh/km. There is electricity regeneration on the trips in the Monte-Centre direction, which increases the autonomy by 27%.

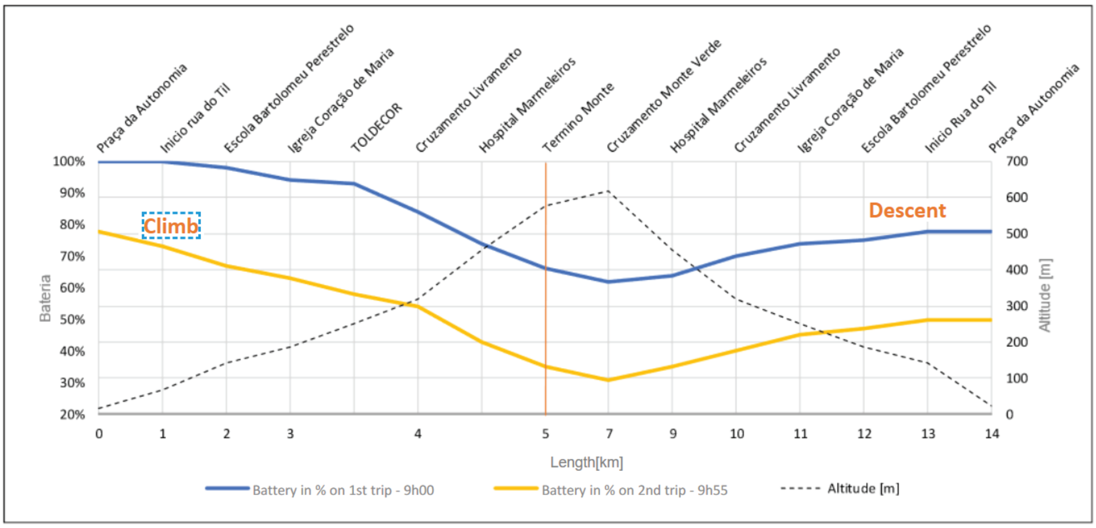

Figure 6: Distance, altitude and battery SOC level – Monte 21 Route

TABLE 4: Energy consumption, battery status and regeneration – Monte 21 Route

Trip	Way	Battery Status	Energy Regeneration	Consumption (kWh)	Specific Consumption (kWh/km)
1st Trip (9h00)	Centro - Monte	66%	-	38,71	1,43
	Monte - Centro	78%	12%		
2nd Trip (9h55)	Centro - Monte	35%	-		
	Monte - Centro	50%	15%		
Empty	Estação - Centro	100%	-	9,29	1,33
	Centro - Estação	38%	-		

3.3. Nazaré 45 - Horários do Funchal

The Nazaré route run by Horários do Funchal is 10 km long and has an altitude difference of 204 m. Figure 7 presents the battery SOC level, travelled kilometers and altitude, obtained at specific points along the bus route, during a full charge, on the Nazaré 45 route, which connects Marina Shopping, in the centre of Funchal, to Rotunda do Amparo.

The battery capacity allowed the bus to perform three complete two-way trips (30 km), to Nazaré, ending at Marina Shopping with a 49% battery SOC level. On the return to the station, at a distance of about 4 km, it used another 15% and reached the destination with 34% SOC level. In this case, the bus would have sufficient battery charge to make more trips. Table 4 summarises energy consumption on the route and electricity regeneration by the braking system.

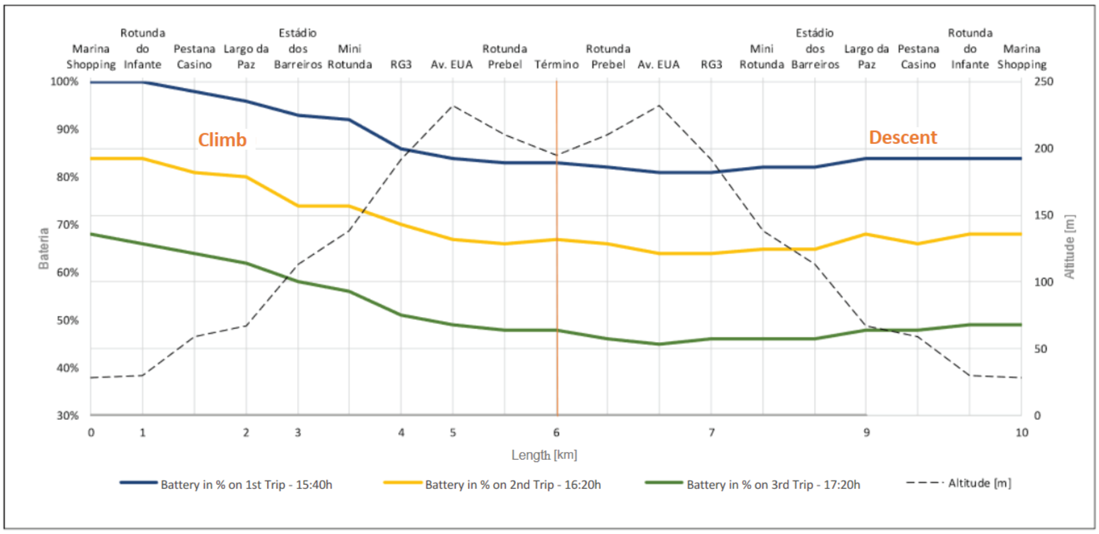

Figure 7: Distance, altitude and battery SOC level – Nazaré 45 Route

Table 5: Energy consumption, battery status and regeneration – Nazaré 45 Route

Trip	Way	Battery Status	Energy Regeneration	Consumption kWh	Specific Consumption (kWh/km)
1st Trip (15h40)	Centro - Nazaré	83%	-	49,45	1,65
	Nazaré - Centro	84%	1%		
2nd Trip (16h20)	Centro - Nazaré	67%	-		
	Nazaré - Centro	68%	1%		
3rd Trip (17h20)	Centro - Nazaré	48%	-		
	Nazaré - Centro	49%	1%		
Empty	Estação - Centro	100%	-	12,61	1,80
	Centro - Estação	34%	-		

Three complete two-way trips on the Nazaré 45 route results in a total consumption of 49.45 kWh and a specific consumption of 1.65 kWh/km. Due to the moderate gradient, there is little regeneration of electricity, which occurs only in one period during the trips in the Nazaré-Centre direction, with a 3% increase in autonomy.

4. Conclusions

The transportation sector still depends on a high proportion of fossil fuels. Limited reserves of fossil fuels and their environmental impact have boosted the development of alternative solutions, especially in road passenger transport. Currently, HEV, PHEV and BEV are the most feasible alternative to conventional vehicles (ICE), despite the technical difficulties and uncertainties about their acceptance, which still persist.

This work presents an analysis of implementing electric vehicles in Portugal, with emphasis on heavy-duty passenger vehicles. It was found that the electric heavy-duty passenger market has only started 4 years ago and is slowly increasing with 16 new vehicles registered this year. Conventional hybrid technology (HEV) is currently not used in Portuguese market, partly due to the lack of government incentives, contrary to the situation in other European markets where a large range of options are offered by the main automobile manufacturers. On the other hand, the main manufacturers of large vehicles do not include the PHEV system in their product line (which allows access to incentives

Since electric vehicles are the option with the greatest growth, this study also covered the performance of these vehicles within an operation context, by monitoring routes with distinct driving and topography scenarios.

It was found that electric vehicles (BEV) performed well on the indicated routes, run by the operators in a real scenario test, with energy consumptions ranging from 0.91 to 1.65 kWh/km. On the other hand, battery capacity was a proven limitation in some routes such that, in acquiring BEV, it will be necessary to implement higher battery capacity and to select a fast charging infrastructure allowing the vehicles to operate nearly continuously.

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