PAPER

FUEL LIFE CYCLE ANALYSIS FOR DIFFERENT TYPES OF VEHICLES IN THE CANARY ISLANDS

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Abstract

The electrification of the automotive fleet is unstoppable over the world as well as the development and implementation of renewable energies. However, island regions are usually characterized by an intensive use of oil-derivate as primary energy sources in land transport but also, in the electricity production. Thus the introduction of the electromobility as instrument to reduce the emissions and improve the energy efficiency in land transport is diminished in these isolated regions. The shortage of renewable energy sources is due, among other reasons, to scarcity of terrain and the security requirements of small sized electric system. In this paper the fuel life cycle assessment is evaluated for a set of different power-train vehicles in the Canary Islands (Spain) scenarios. The results reveal that the current intensive use of oil-derivate fuels for electricity generation produce lower but similar $CO_{2\text{-eq}}$ emission than conventional cars in Tenerife. However, an increment of renewable energy share and to a lesser extent the charging management strategy not only reduces significantly the emissions, but also increase energy efficiency of plug-in electric vehicles in island regions.

1. Overview

The EU is leading the race towards a more sustainable energy model [1], [2]. In recent years, Spain has aligned itself with the European roadmap by developing regulations such as the climate change law and energy transition, that lead to the development of energy plans such as the PNIEC [3], [4]. In line with the roadmap set by Spain, the Canary Islands (Spain) has made progress in the energy transition and marks its own roadmap with the aim of advancing the total decarbonisation of the region for the year 2040, througt the PTECan [5]. From a technological point of view, the maturity reached by renewable technologies such as wind and photovoltaic, together with the emergence of technologies such as hydrogen and batteries, give hope to reach the marked quotas. These latest storage technologies will not only be key to the challenge of changing the electrical mix but will also play a decisive role in the shift towards electromobility [6].

Nowadays, transport is one of the highest energy demanding sector worldwide, within road transportation is the one with the greatest weight in final energy consumption (approx. 21%). Moreover, the intensive use of fossil fuels in land transport generates a 24% of the total CO_2 emissios from fuel combustion according to the International Energy Agency [7]. In addition, energy consumption in this sector is growing considerably, especially with developing economies [8]. The European Union (EU) has revealed its interest in this area, promoting new objectives for the reduction of CO_2 emissions and promoting low or zero emission vehicles [9]. From technical point of view, improving vehicle consumption and minimizing the impacts of demand growth in the transport sector, are crucial aspects to meet the objectives proposed by the EU. In example, some regulatory requirements impact manufacturers to significantly reduce the emissions of their fleets sold below 95 g.CO2/km by imposing penalties for non-compliance [10]. Although, the Internal Combustion Engine Vehicles, (ICEV) will dominate the market in the coming years, automakers are offering new sustainable products, such us, using Liquefied Petroleum Gas (LPG) or hybrid electric vehicles (HEV). Nowadays, Plug-in Electric Vehicles (PEV) are emerging solution to reduce both energy consumption and greenhouse gas (GHG) emissions. Conversely, Fuel Cell Electric Vehicles (FCEV) seems an alternative on the market in the mid-term.

The need to implement road transportation alternatives is more urgent the greater the dependence on fossil fuels. The EU has placed special interest in the case of isolated regions, since they are not only more vulnerable to the effects of climate change, but also import the majority of resources (energy or not) they consume. The Canary Islands are a case study with various peculiarities, as they constitute the most populous region (over two million inhabitants) and with the highest GDP of the outermost regions of the EU [11]. A total of 13.340 $t.CO_{2\text{-eq}}$ was emitted in the archipelago in 2019, being transport responsible for more than 40% of emissions. From the energy perspective, the archipelago stands out for relying on almost 97% of fossil fuels as a primary energy source [12]. Due to the great external energy dependence and the use of petroleum derivatives in the production of electricity, there is a debate about whether the PEVs are the best alternative to mitigate total emissions in transport. Despite the existence of energy policies in favor of renewables, in recent years only 16% of renewable penetration has been achieved on average in the Canary Islands in the last 2019 [13]–[15]. However, the Canary Islands are inmerse in a quick energy transformation the last two years. In order to compliance with the total descarbonization in 2040, an ambisious plan is deployed that implies the installation of an average of 300 MW of reneables per year [16]. Additionally, it is projected a set of electrical interconnections between islands as well as the reinforcement of the electrical grids to achieve a more robust electric system [17]. To deal with electricity surplus (derivated from a massive renewable instalation) a set of energy storage devices are projected in the islands, such as pumping-hydro, batteries and hydrogen [16], [18]–[22]. These transformation has a direct effect on PEV, due to the majority of their recharges could come from renewables, thus improving both energy efficiency and emissions.

This work aims to evaluate the different technological alternatives of land transport in terms of energy consumption and GHG emissions in the Canary Islands. To achieve this, a methodology of the Well to the Wheels (WtW) framed within the analysis of the life cycle of the fuel in transport is deployed. Finally, a series of scenarios (2020 and 2030) for each island system in the canarian archipelago are evaluated, taking a database of more than a 500 light-duty vehciles model and variants of different technologies, fuels and segments. Thus, this work contributes to the existing literature verifying whether PEV are a decisive solution to reduce emissions in isolated systems spit of the high dependence on oil in their electrical production. The electricity mix transformation towards renewable is the key to boost the potential benefits in terms of energy efficiency and emission reducer of PEVs in islands. The results obtained from this case study can be applied in other similar situations and, its importance lies, in the fact that it is a solution proposed in numerous energy transition plans.

The rest of the paper is estructured as follows: Methods section describes the well-to-whells methodology and presents a brief literature review. Furthermore, the detailed scenarios proposed and the recent vehicles sales to built the car inventory are shown. In the Results section the main figures derived from the case study are detailed. The final section presents the concluding remarks and some policy implications

2. Methods

This section is structured as follows: first, the WtW methodology and literature review is addressed. Second, the Canary Islands energy context is described and the energy scenarios for the Well to Tank (WtT) and Well to Plug (WtP) in present and mid-term (2030) are proposed. Finally, we expose the Canary Island car market sales in order built a car inventory and design the Tank to Wheel (TtW) or Plug to Wheels (PtW) part.

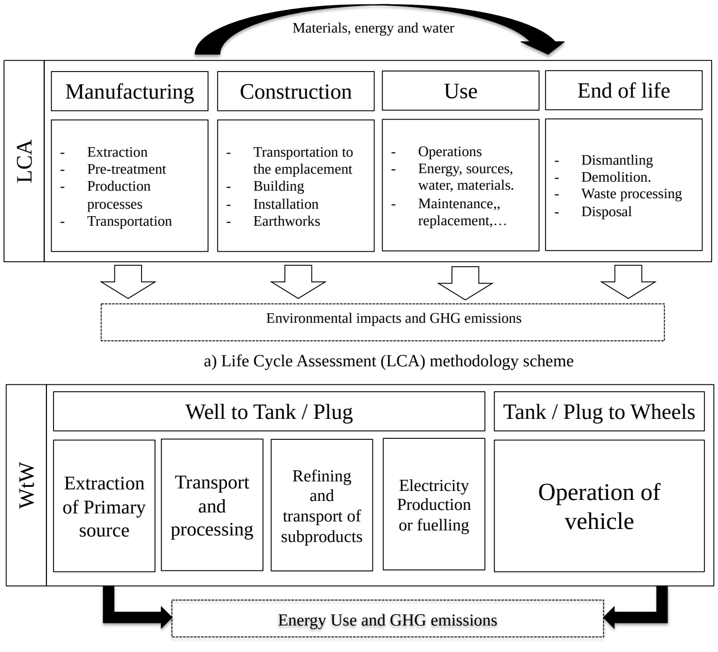
2.1. Background of LCA and WtW for transport fuel and vehicles

This work aims to evaluate the impact of different power-train technology vehicles in terms of energy consumption and emisions in the Canary Island energy context on present and mid-term (2030). To do that, this work bases on WtW methodology, widely developed in the literature. On the one hand, LCA is a widely used methodology that takes into account the entire environmental footprint of a defined product. This assessment process includes since sources required for the production process –water, energy, materials, etc– to the energy, the resources used during the lifespan of the product and finally the consideration of a second-life of the product or post-treatment performed when it becomes obsolete. However, this methodology is extremely complex to implement, mainly due to the lack of information available or simply not shared by stakeholders from the industry corporations [23].

There exist a large number of reports and papers presented by governments, administrations, companies and academics that's try to clarify the impacts of the vehicles to the environment. In example, Hawkins et al. (2013) perform a LCA that tries to compare the impacts of Battery Electric Vehicles (BEV) versus the conventional ones [24]. The authors conclude, "The global warming potential is about twice on an BEV production than an ICEV". They also affirm, "the environmental performance of BEVs is critically dependent on the combination of the vehicle and electricity production impacts as well as key factors such as energy use and battery and vehicle lifetimes". Additionally, the authors indicate, "it is counterproductive to promote BEVs in areas where electricity is primarily produced from lignite, coal, or even heavy oil combustion". Other recent study, perform a LCA of an BEV and ICEV in Italy revealing that although the electricity were generated by fossil fuel plants, the BEV reduce the impacts in terms of air acidification, photochemical oxidant formation and also GHG emissions [25].

Apart from the electricity mix composition, the battery packs manufacturing seems to be one of the most important factors that increase the global warming potential impacts of the EVs in the LCA. To reduce the gap between the results of WtW analysis and the complete LCA method, an recent article propose a new hybrid methodology [26]. It takes into account both the battery manufacturing and the WtW fuel consumption. According to their results, the GHG savings are around 10-13% lower in the EVs in comparison to the ICEV assuming the EU average mix of 2009. Other studies have been focused on the emissions of Li-Ion batteries manufacturing, situating between a 52 to 291 kg CO2/kWh [27]. More recently assessments reveals results between 26.6 to 253 kg CO2/kWh [28]. More recent papers, shows that the manufacturing of a 24kWh battery could consumes around 80GJ of energy, that is around 9 hundred times the energy capacity of the battery [29]. Both, the battery usage and to provide a second-life is also important in the whole LCA evaluation, concluding that a soft use of the battery has 42 to 50% less impacts per km than intensive use [30]. Additionally, after its use in the vehicle, the battery life can be expanded around 1.8 to 3.3 years as peak shaving or load shifting, however it strongly depends on the electricity generation mix and the efficiency losses in the battery.

On the other hand, WtW is defined as a specific LCA broadly used for transport fuels and vehicles (see Figure 1). These methodology is usually divided in two stages: (i) Well-to-Tank (WtT) or Well-to-Plug (WtP), that includes since the primary source extraction, the transport, the processing to elaborate fuel subproducts and the transport of the subproducts to the station. It also include the transformation to electricity up to the electric vehicle supply equipment; (ii) Tank-to-Wheels (TtW) or Plug-to-Wheels (PtW), includes the vehicle operation which is unique for each vehicle mode, but similar between different vehicle powertrain technologies. These methodologies quantify the energy use and the GHG emissions, since the well of extraction of the main sources to the wheels of the vehicle [31].



a) Life Cycle Assessment (LCA) methodology scheme

b) Well to Wheels (WtW) methodology Scheme

Figure 1: LCA and WtW methodology Schemes

All studies emphasizes that the strongest benefits of PEV lie in the potential energy efficiency a low GHG emissions empowered by an intensive renewable mix scenario. The major of studies performed in vehicles evaluate the fuel LCA, or in other words, the assessment of the WtW of different vehicle technologies. The European Commission performs –though the Join Research Center (JRC) – an assessment of WtW of future automotive fuels and powertrains in the European context [31].They concluded that the possible hybridization of the conventional engine technologies could provide further energy and GHG emission benefits. Additionally, Liquifed Petroleum Gas (LPG) provides a small WtW emissions saving compared to gasoline and diesel. Respect the PEV while electric propulsion on the vehicle is efficient, the overall energy use and GHG emissions depend critically on the source of the electricity used. A recent study from the University of Michigan compares a 143 countries and examining the WtW assuming different electricity mixes. The authors conclude that 52 countries are under the threshold of the ICEV fuel economy –51mpg equivalent–, it means that in countries like China, India and several African countries– is better drive a ICEV than a BEV. These countries are characterized by an intensive use of oil-derivates fuels and coal in their electricity mixes. In the rest of countries, the use of EVs improves the fuel economy, highlighting countries such as Iceland, Paraguay or Norway [32].

In accordance to the LCA literature presented, the transportation of fossil fuels gains relevance when remote locations requires to be supplied. The efficiency and the GHG equivalent emissions of PEV are highly dependent on the renewable share that composes the mix. The charging efficiency and management could play an important role in the reduction of the impacts of WtW. Thus, our contribution inside this literature is analyzing the special case of islanded regions. It meets many of the characteristics described above: (i) remote area to transport the fuel by tankers (97% of external energy dependence from oil); (ii) isolated electric power systems, characterized by difficulties in renewable introduction and high electricity losses from the grid (16% renewable in average) (iii) different mobility routines from island inhabitants, that covers less kilometres per day than continental users, that could affects on the charging patterns of PEVs and (iv) special car market where Sport-Utility Vehicles (SUV) domains the newly car registration for the last years. The results of this analysis can be potentially relevant in order to perform policy or investment decisions basing environmental awareness as a basic pillar.

2.2. The Canary Islands Energy Context.

The primary energy supply in the Canary Islands currently depends on petroleum-derived fuels over 97% in 2019 [12]. Starting from this unfavorable situation, the energy transition in the islands seems like a daunting task until achieve the full descarbonization in 2040, according to the PTECan [5]. The majority of the consumptions are located in transport sector, in which, land transport respresent the 34% of the final consumptions in 2019. At present, the ICEV domains the power-train techonologies, being the share of electric car sales around 2.5% of total new registration in the islands in 2020. Although, the electrification of the consumptions is one of the key to move to renewable energies, todays electric sector in the islands only represent the 20% of the final energy consumption. From this percentage, just 16% belonged from renewable sources during 2020. The rest of the electricity production is completed by conventional power plants fuelled by oil-derivate fuels (specifically fuel oil and diesel oil). This results in a high rate of emissions from the electricity system, which stands at 0.56 t.CO_2/MWh in 2020 (more than four times higher than that of the Spanish continental system). The great peculiarity of the Canary Islands is that it is composed of 6 isolated electrical systems, differentiated in sizes and characteristics according to the uniqueness of each of the islands (see Figure 2).

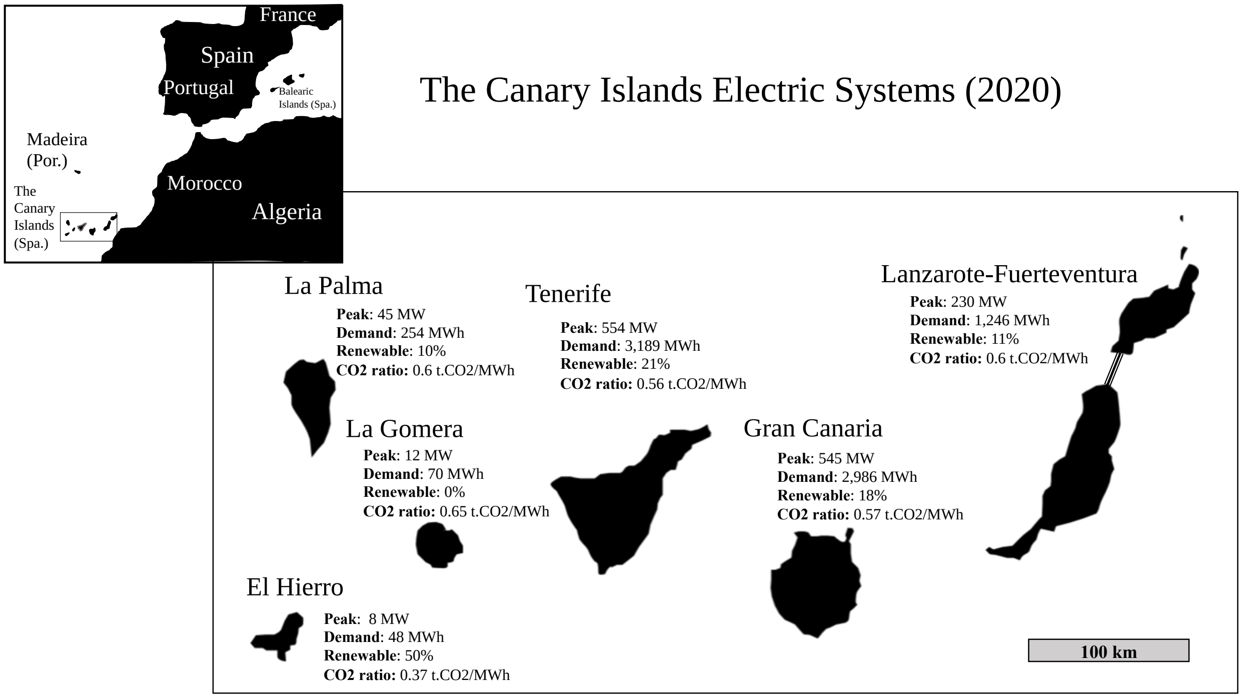


Figure 2: The Canary Islands Electric Systems (2020)

The islands' electricity generation plants is made up of the following technologies (see table 1) [12], [33]. The table contains the technologies net power installed per islands, the number of generator of each type, the fuel and the range of efficiency on beginning of 2020.

Table 1: Electricity Generation plants in the Canary Islands by technologies (2020)

Power Plant	Net Power (MW)[1]	Nº Generators [1]	Fuel[1]	Efficiency[2]	Emission Rate (t.CO2/MWh)
Tenerife					
Steam Turbine (ST)	223	4	Fuel oil	0.34 - 0.35	0.9
Combined Cycles (CC)	443	2	Gas oil	0.44 - 0.47	0.6
Diesel Engines (DE)	67	5	Fuel oil	0.45 – 0.46	0.68
Open-Cycle Gas Turbine (GT)	237	8	Gas oil	0.26 - 0.26	1.12
Wind Power (WP)	196	-	-	-	-
Photovoltaics (PV)	107	-	-	-	-
Total Tenerife	**1,273**	**-**	**-**	**-**	**-**
Gran Canaria					
Steam Turbine (ST)	257	4	Fuel oil	0.35 - 0.36	0.9
Combined Cycles (CC)	443	2	Gas oil	0.45 - 0.47	0.6
Diesel Engines (DE)	67	5	Fuel oil	0.44 – 0.44	0.68
Open-Cycle Gas Turbine (GT)	147	5	Gas oil	0.20 - 0.21	1.12
Wind Power (WP)	159	-	-	-	-
Photovoltaics (PV)	41	-	-	-	-
Total Gran Canaria	**1,114**	**-**	**-**	**-**	**-**
Fuerteventura + Lanzarote					
Diesel Engines (DE)	108+135	10 + 10	Fuel oil	0.40 – 0.40	0.68
Open-Cycle Gas Turbine (GT)	51+52	2 + 2	Gas oil	0.17 – 0.18	1.12
Wind Power (WP)	29+22	-	-	-	-
Photovoltaics (PV)	12+7	-	-	-	-
Total Lanzarote-Fuerteventura	**416**	**-**	**-**	**-**	
La Palma					
Diesel Engines (DE)	75	10	Fuel oil	0.39 – 0.39	0.68
Open-Cycle Gas Turbine (GT)	21	1	Gas oil	0.22 – 0.25	1.12
Wind Power (WP)	7	-	-	-	-
Photovoltaics (PV)	4	-	-	-	-
Total La Palma	**107**	**-**	**-**	**-**	
La Gomera					
Diesel Engines (DE)	19	9	Diesel oil	0.39 – 0.39	0.68
Total La Gomera	**19**	**-**	**-**	**-**	**-**
El Hierro					
Diesel Engines (DE)	11	-	Diesel oil	0.38 - 0.39	0.68
Wind Power (WP)	11	-	-	-	-
Pumping-Hydro Storage (PHS)	11	-	-	0.55 – 0.70	-
Total El Hierro	**33**		**-**	**-**	**-**
Total Islas Canarias	**2,962**		**-**	**-**	

Own elaboration. External information sources: [1] Anuario Energético de Canarias 2019; [2] RD 738/2015 , de 31 de julio, por el que se regula la actividad de producción de energía eléctrica y el procedimiento de despacho en los sistemas eléctricos de los territorios no peninsulares.

Both in the data presented in figure 1 and in table 1, the renewable mix by island and the size of the system varies considerably. The islands with the highest share of renewables are El Hierro and Tenerife, with 50% and 21% respectively. The quantitative leap in renewable energy in the former is due to the installation of a large-scale energy storage facility, in this case, a Pumping-Hydro Storage (PHS) plant called Gorona del Viento. For the rest of the islands, the renewable participation varies between the 21% to 10%. Nowadays in these systems there are not installed massive energy storage and the energy surplus starting to be a big barrier for the renewable deployment due to the economical losses that supposes to the private companies.

In the short-term, a total of 256 MW are on processing of application to built before 2024 (98 MW of PV and 158 MW of wind farms) [13]–[15]. Furthermore, two more interconnections between islands are planned to built: Tenerife-La Gomera (2024) and Fuerteventura-Lanzarote-Gran Canaria (2030) in mid-term [5]. These two connections are developed to ensure the robustnest of the electrical grids. However, a renewable share leap requires a massive energy storage backup in order to recover surplus energy from renewable sources and return this energy sustituing the conventional backups (such us gas turbines, the most pollutants and ineficients). Nowadays, there is just one PHS planning to built in Gran Canaria, called Chira-Soria (200 MWh and nearly 2.5 GWh of storage capacity). This power plant will allow the future Gran Canaria-Lanzarote-Fuerteventura system surpass the 50% of renewables in the mix. Tenerife, La Gomera and La Palma have also the potential to allocate PHS technology, however, there are not specific zones selected to built it up today. Another possibility is to install lithium-ion battery packs from second-life cycle BEV or new ones. Regional goverments has tried to promote hybrid renewable plant with batteries as backup for renewable overprodutction in their subsidies calls for projects [13]–[15]. This technology has the advantage that it not requires a long built project such us hydrogen or PHS, instead, batteries are modular and the installation is faster than the others.

2.3. Canary Islands Car Market. Vehicles Inventory

The car fleet in the Canary Islands is one of the oldest in Spain and Europe, with an average of 13.1 years old (12.1 in Spain), this is direcly influenced by one of the lowest income per cápita in Spain [34], [35]. Furthermore, the size of the fleet is nearly 1.5 million, thus implies one of the highest rate of vehicle per inhabitant (0.67) in Europe [36].

The sales trend in the Canary Islands has always penalized diesel (always being below 20% of sales historically). This is an interesting feature when compared to the rest of Spain (where diesel sales have been above 40%), caused majorly by the low tax policies gasoline. Since 2019, gasoline heads the sales instead of diesel cars, with 89% versus 10% of diesel for private users' newly registered cars. From these two ICEV power-trains, around th 9% of the fleet is hybrid (both mid and full-hybrid). The PEVs only represented around 1% and the LPG less than 1[36]. The trend for the coming years is a decrease in diesel until reaching a residual value, while the share of gasoline vehicles will decrease as the sales of technologies such as PEVs, and alternative fuels such as LPG or the inclusion of hydrogen increase.

From the point of view of the recently registered vehicle segment, there has been a notable increase in sales of SUVs which accounted for 30% of sales in 2015 to grow to 47% of sales in 2020 in the Canary archipelago. These vehicles are less aerodynamic, heavier and therefore less efficient. This figures are worrying, being much higher than those of European sales in 2019 (a 27% share) [36]. For the rest of the segments in Canaries, urban vehicles were established at 4%, compact at 36%, 3% for MPV, 2% for minivans and 2% for sedans and the rest for sport-cars, microcars. and luxury segment.

A total of 57,668 cars has been registered since 2019, however, some of them are imported pre-owned premium cars from Europe, thus just 54,985 are newly car sales in Canarian archipelago [37]. In order to perform this analysis, we have selected newly registered cars homologated with Worldwide harmonized Light vehicle Test Procedure (WLTP) mandatory from the beginning of 2019. It is defined as a global harmonized standard for determining the levels of consumption, pollutants and CO_2 emissions and electric range from light-duty vehicles. Though data mining, the newly car registration database has been filtered and grouped to built or car inventory (see Table 2). In the table, the car inventory is divided into car segment and technology showing Top 5 (Brand, Model and Power) and total sample.

Table 2: Car Inventory by Tecnology and Segment

Tecnología	ICEV - Gasoline	ICEV -Diesel	ICEV -LPG	mHEV	HEV	PHEVs	BEV
A - Segment: Micro-cars and Urban Cars Sample: 1,919	1,657 Kia Rio 84CV, Kia Picanto 84CV, Kia Rio 100 CV, Fiat 500 69CV, Toyota Aygo 72CV	-	5 Fiat 500 69CV, Renault Twingo 75CV	114 Kia Rio 100CV, Suzuki Ignis 83CV, Fiat 500 70CV, Kia Rio 120CV	54 Suzuki Ignis 83CV, Fiat 500 69CV	-	95 VW-eUP 61kW, Seat Mii, Mini Cooper SE 135kW, Renault Zoe 51kW, Renault Zoe 72CV, Smart Q Fortour 41kW.
B & C- Segment: Subcompacts, Compacts and Mid-Size. Sample: 17,413	15,525 Dacia Sandero 90CV, VW Polo 95CV, Seat Ibiza 95CV, Seat Ibiza 116CV, Dacia Sandero 73CV,…	389 Dacia Sandero 95CV, Seat Leon 116CV, BMW Serie1 116D 116CV, BMW 118D	86 Dacia Sandero 90CV, Dacia Sandero 101CV, Opel Corsa-E 90CV, Renault Clio 101CV, Ford Fiesta 97CV	276 Mazda 2 90CV, VW Golf 110CV, Kia Ceed 120CV, Homda Jazz 98CV,	944 Toyota Yaris Hybrid 73CV, Toyota Corolla 98CV, Honda Jazz 102CV, Toyota	7 Seat Leon 150CV, Citroën C5 Aircross 181CV, Mercedez Benz B250E 88CV	186 VW ID3 PRO 150kW, VW eGolf 100kW, Nissan Leaf 40kWh 110kW, BMWi3 125kW, Opel

		150CV, Seat Ibiza 95CV.		Ford Fiesta 125CV	Corolla 152CV, Toyota Yaris Hybrid 92CV		e-Corsa 100kW
D & E - Segment: Large cars and family cars. Sample: 681	493 Skoda Kodiak 150CV, Renault Scenic 140CV, VW Touran 150CV, Skoda Scala 116CV, Mercedez Benz CLA180 136CV.	177 Renault Megane SportTourer 116CV, Citroën C-Elysée BlueHDI 102CV, BMW Serie3 318D 150CV, Skoda Octavia 116CV, Skoda Octavia 150CV.	18 Dacia Lodgy 109CV, Dacia Logan MCV 90CV, Dacia Logan MCV, Renault Scenic 112CV.	32 BMW Serie3 320D 190CV, Skoda Octavia 150CV, Audi A5 Sportback 190CV, Audi A5 Sportback 150CV, Audi A5 Coupe 190CV.	262 Toyota Prius Plus 99CV, Infinity 306CV, Mercedes Benz C200 184CV, Totota Camry 178CV, Toyota Prius 98CV	30 BMW 225XE iPerformance 136CV, BMW Serie3 330E 184CV, Seat Leon ST 150CV, Volvo S60 TwinEngine 303CV, Mercedez Benz CLA250 E 160CV	3 Tesla Model S, Tesla Model 3
J-Segment: AllRoad cars, Crossovers and SUVs Sample: 25,647	21,211 Nissan Qashqai 140CV, VW T-Roc 116 CV, Seat Arona 116CV, Hyundai Kona 120CV, VW T-Cross 116CV.	943 VW Tiguan 150CV, Dacia Duster 116CV, BMW X1 SDrive 18D, 150CV, Nissan Qashqai 116CV, Land Rover Range Rover Evoque 150 CV.	336 Dacia Duster 114CV, Renault Captur 101CV, Dacia Duster 101CV	947 Ford Puma 125CV, Mazda CX-30 122 CV, Hyundai Tucson 116CV, Lexus UX 250h 152CV, BEM X3 XDrive 20D 190CV	1,712 Toyota C-HR 98CV, Toyota Rav4 178CV, Hyundai Kona 105CV, Toyota C-HR 152CV, Kia Niro 105CV	240 Volvo XC-40 180CV, Mitsubishi Outlander PHEV Kaiteki 135CV, Kia Niro 105CV, Volvo XC60 T8 Twin Engine 303CV, Mini Countryman Cooper SE A 136CV.	238 Hyundai Kona 150kW, Kia Niro 150kW, Audi E-Tron 50, 230kW, Mercedez Benz EQC400 4Matic, 145kW, Peugeot 2008 GE 100kW.
M-Segment: Multi-purpose vans, cargo vans and mini vans. Sample: 863	511 Ford Toruneo Courier 100CV, Dacia Dokker 131CV.	316 Peugeot Rifter GTLine 102CV, Dacia Dokker 75CV, VW Caddy 102CV, Renault Trafic 120CV, Ford Transit Custom 131CV	32 Dacia Dokker 109CV	-	-	-	4 Nissan E-NV200.

2.4. WtW modelling

The methodology scheme is showed in Figure 3. First, an assessment of TtW and TtP prosseses is detailed (figure3a). The modelling of the WtW analysis is performed in python. For each pathway from WtT or WtP we have executed a Monte Carlo experiment for each vehicle path and later, we will combine this simulation with the scenarios proposed for the different Canary Island systems in 2020 and an estimate for 2030. For future scenarios, data from all island electrical systems have been collected and it has been simulated that renewable penetration will be achieved in 2030 taking into account the planning of the region. In addition, the origin of fossil fuels (countries of origin, distances, imported quantities and ships) has been compiled to simulate pathways for both conventional vehicles (diesel and gasoline) and PEVs.

For each step on the pathways we determine the relative energy consumption and the emissions (if the process allocates any emissions). Later, as we have collected on section above, the car inventory contains the energy consumption and emissions for the Canary Island newly registrations car fleet (figure 3b). Finally, the summarize of the results are shown in terms of Energy Consumption (MJ/100km) and Total Emissions ($CO_{2\text{-eq}}$/km). For the ICEVs the results are disaggregated by segments. In the case of PEV (includes PHEVs and BEVs), the results depends on multiple conditions for the electric power systems (such us renewable penetration, or renewable capacity installed). In order to assess a high detailed scenarios, we have considered the emissions by island system (six different systems at present and four systems in 2030). Likewise, for PEVs the same previously used vehicle segments have been considered.

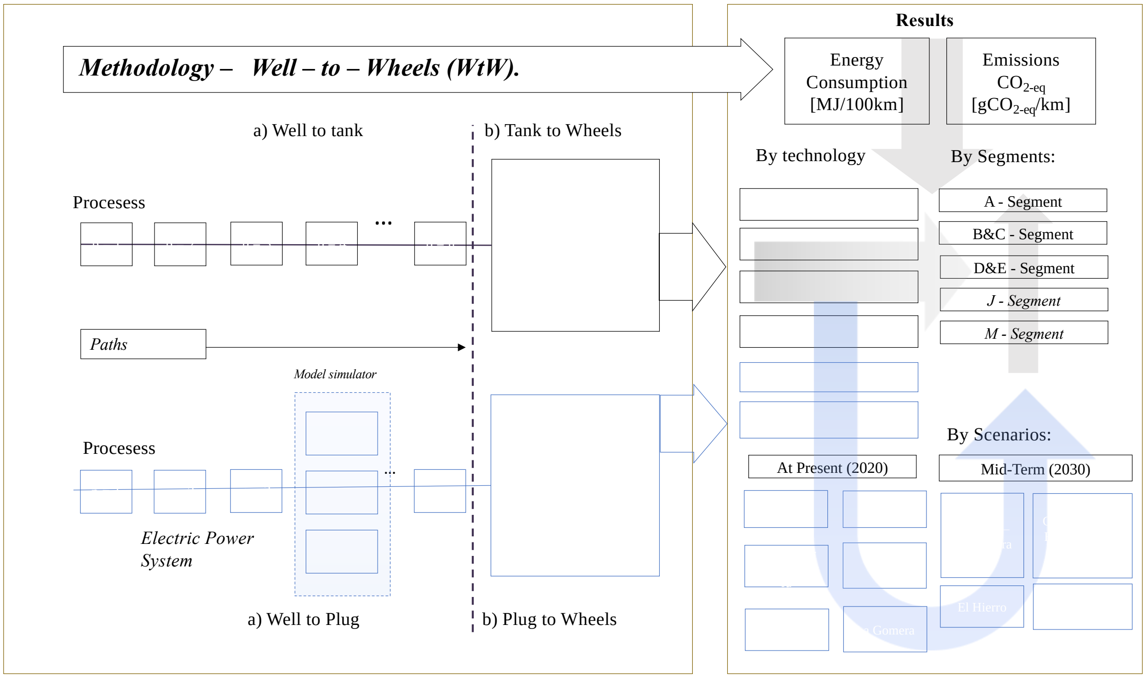


Figure 3: Methodology Scheme

Figure 4, details the energy pathways for each vehicle and the processes covered from the well of the energy source to the wheels of the vehicles. The main energy source for the Canary Islands is oil (remember that oil represents the 97% of the primary enegy sources in Canaries). The extraction of hydrocarbons occurs in a mix of more than 20 producing countries (Figure 4, n=1). Among the most representative are Nigeria (20%), Mexico (15%), Saudi Arabia (10%), Kazakhstan (8%), Iraq (6%), the United States (6%) and Brazil (5%). The energy consumption for the extraction, flaring and venting (Figure 4, n = 1) for oil is in average yield that is between 92.7% and 94.3% and is responsible for an emission source that is around 3.75 - 4.75 g.CO2 / MJ [31]

The transport is carried out by sea though oil tankers (Figure 4, n=2), which have load capacities from 60,000 to 160,000 tones of crude. The energy consumption is nearly around 49 to 51 tones of fuel per day [38]. Additionally, Table 3 details the distance routes to continental Spain and the energy efficiency in transport measured in relative energy lossed respect energy contained in the cargo.

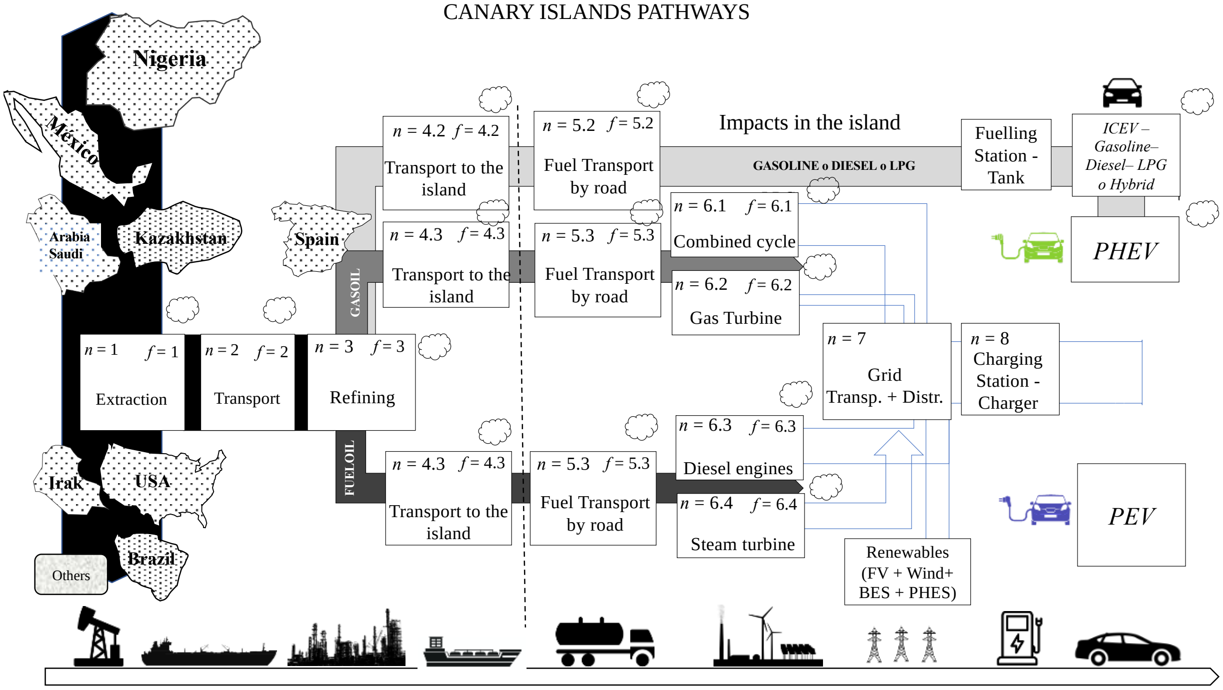


Figure 4: Energy Pathways

The oil refining process (Figure 4, n=3), is performed usually in Spanish refineries that feed the majority of the fuel consumption in the Canarian archipelago [12]. The oil refining efficiencies and CO_2 emissions per fuel products from Spanish facilities are not opening accessible mainly due to confidential and lack of transparency from this industry.[1] Crude oil from several countries in the world is refined mostly in Spanish territory in one of the 8 refineries currently operating.[2] According to the IEA and taking the average production of oil derivatives for the last decade (2007-2017) of a barrel of oil, the following products are obtained: (i) between 3.7 and 4.1% of LPG; (ii) between 44.2% and 47.0% gasoline; (iii) between 26.1 and 29.5% diesel or diesel fuel; (iv) between 2.5 and 4.2% fuel.[3] These values vary each year, depending on the type of crude oil, the demand for products, the specificities of the refinery itself, etc. For each petroleum product, the energy efficiency of the process (n = 3.1,…, 3.4) and the associated emissions (f = 3.1,…, 3.5) will vary. According to Han et al., (2015), both the efficiencies and the GHG emissions of the refining of petroleum products have been taken for the European refineries included in the study [39].

Once the products are obtained, they are transported to the Canary Islands in specific tankers. To calculate the efficiency of the process, the calculation was simplified using the energy data of the diesel and the consumption and characteristics of the ships [38]. The tanker efficiency to transport the oil-derivates products from Iberian Spain to the Canary Islands is around 99.5% and pollutes between 0.6 – 0.4 g.CO2 / MJ_{fuel}.

Table 3: Inventory main source imports

	Main source share	**Distance**	**Efficiency in transport MJ/MJ$_{fuel}$**		**g.CO2-eq /MJ in transport**	
Country	**%**	**(km)**	**Min (%)**	**Max (%)**	**Min (%)**	**Max (%)**
Nigeria	20	6,000	0.4	1.3	0.3	1
Mexico	15	9,000	0.7	1.9	0.5	1.4
Arabia Saudi	10	4,000	0.3	0.8	0.2	0.6
Kazakhstan	8	9,000	0.7	1.9	0.5	1.3
Iraq	6	5,500	0.4	1.2	0.3	0.8
USA	6	9,000	0.7	1.9	1.4	1.3

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[1] The energy efficiency and emissions usually depends on the technology development and type of refinery composition, the measures and investment in energy efficiency, the type of crude that is distillated, the output products produced, the environmental requirements from national legislation, the location of the plant, the climate, the seasons, the planning and optimization of each processes, the implementation of energy management system, etc.

[2] Santa Cruz de Tenerife refinery has been discarded because it is in a shutdown state and pending dismantling.

[3] For the year 2015 in Spain, the distribution in mass fraction of the products was 43.1% of diesel, 14.8% of kerosene, 13.6% of gasoline, 6.3% of fuel oil and 2.6% of LPG and 19.6% of the rest of the products.

Brazil	5	6,500	0.5	1,4	0.3	1
Other countries*	30	9,000*	0.7	1.9	0.5	1.3

Once the product reaches the corresponding island, the fuel is discharged and stored. Therefore, all emissions from this downstream process related to the movement and processing of fuels are considered indirect-local. In the process (n = 5.1, ... 5.3), both the efficiencies and the emissions of the diesel and fuel oil storage are calculated. This process generally consumes steam, as these products must be kept at adequate temperatures. Subsequently, in road transport, efficiencies of between 99.6% and 99.9% are obtained for diesel and gasoline, and between 99.5% and 99.7% for LPG. Finally, the fuel arrives at the service station, where it is distributed to the different ICEVs. This completes the process from the well to the tank.

Table 4: Inventory of the refining processes of energy efficiency and GHG emissions per subproduct

	Energy portion from 1 TOE (%)	Energy Efficiency (%) associated to the refining of product	CO2-eq Emissions associated to the refining of product (g.CO2eq/MJ_{fuel})
	Max/Min	Max/Min.	Max/Min
Gasoline	44.2 – 47.0	92.2 - 89.3	9.0 – 8.0
Diesel – Gasoil	26.1 – 29.5	95.6 - 93.1	13.0 – 9.0
Fuel oil	2.5 – 4.2	96.2 - 95.0	28.0 – 3.2
LPG	3.7 – 4.1	94.0 – 96.0	4.0 – 3.6

The electricity is produced by a mix of technologies which depends on the schedule time, the renewable installed and the electric power systems of each island. Figure 5, shows the electricity mix by technologies considered in this work. Depending on the electricity mix the emission rate (t.CO_{2-eq}/MWh) could varies (see Table 5) according to emission rate by techonologies [40].

Table 5: Emission rate by scenarios

	Average 2020	2030 PTECan
Tenerife	0.558	-
La Gomera	0.68	-
Tenerife-La Gomera	-	0.199
Gran Canaria	0.572	-
Lanzarote-Fuerteventura	0.603	-
Gran Canaria – Lanzarote - Fuerteventura	-	0.208
La Palma	0.597	0.213
El Hierro	0.377	0.19

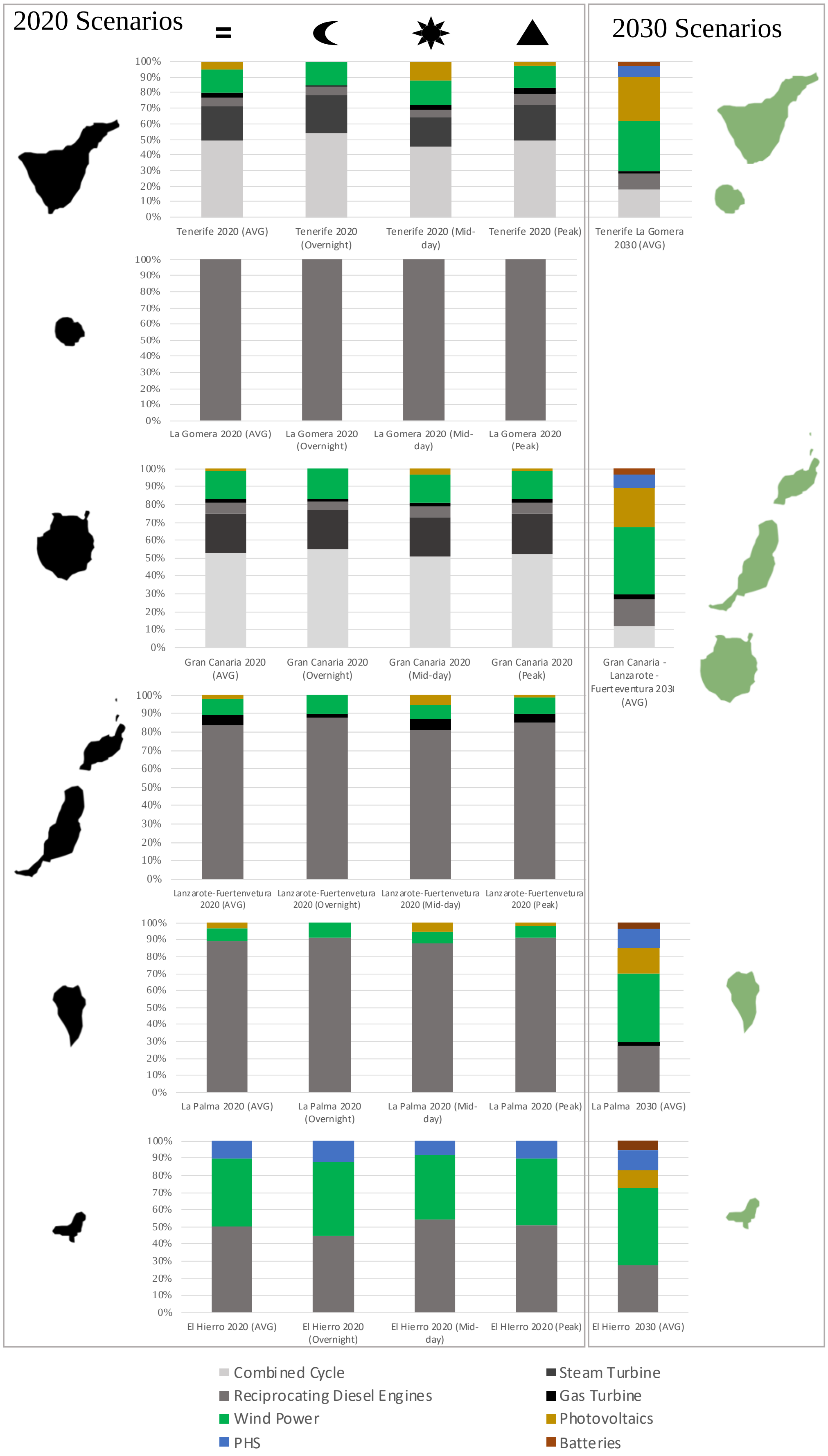

Figure 5: Energy Mixes in the Canary Islands

To calculate the WtW enegy consumption per km covered by a car we have developed the following formulas:

$$WtW_{energy\ consumption} = \left(\sum_{n=1}^{n} \left(1 + WtT_{n\ ,Total\ expended\ enegy}\right) \right) \cdot TtW_{car\ consumption}$$

where, *n*, represents the step number (see Figure 4), $WtW_{\text{energy consumption}}$ is the total energy consumed from the well to the wheels of the cars for each distance unit covered (measured in MJ/100km). WtT or WtP (for PEVs) total expended energy is the total energy expended per fuel or electricity transported to the refuelling station of charging station. Finally, TtW car consumption is the WLTP homologated expresed in MJ per 100km [31].

In terms of WtW emissions, the summatory of the emission sources involved from the wells to the wheels are considered. From the WtT or WtP the emission for each focus (n=1,…,7) should multiply by the total energy consumed from this step.

$$WtW_{GHG\ emissions} = \left(\sum_{f=1}^{f} \left(1 + ntW_{f\ ,}\right) \cdot\ WtT_{GHG,f} \right) + TtW_{GHG\ emissions}$$

where, *f*, is the emission focus number (asociated with a step), $WtW_{\text{GHG emissions}}$, is the total emisisons derivated from the well to the wheels of the vehcicle per distance covered (in g.$CO_{2\text{-eq}}$ /km). $WtT_{\text{GHG, f}}$ is the emissions for each *f* step (measured in g.$CO_{2\text{-eq}}$/MJ). Finally, ntW_f is the energy consumed from the wheels to the emission focus, *f* and the $TtW_{\text{GHG emissions}}$ is the WLTP homologated expresed in g.CO_2 per 100km.

3. Results

The results will be presented as follows: i) WtW results for conventional (gasoline, diesel and LPG) and hybrid (mHEV and HEV) vehicles. ii) WtW results for PEVs for current scenarios by island systems; iii) WtW results for PEVs in future energy scenarios according to PTECan (2030) and finally, iv) discussion and policy implications are detailed.

3.1. Well-to-Wheels Resutls for Internal Combustion Engine and Hybrids cars

First, Table 6 shows the energy consumption and direct emissions from exhaust pipe (between parenthesis) of the car inventory (sales of new vehicles in the Canary Islands in the 2019-2020 period). This table is the result of the collection and data mining of a sample of 47,795 vehicles in which the figures of the European WLTP homologation cycle have been taken into account. The vehicles have been classified and quantified by brand, model, power and power-train technology (as shown in table 2). The result of consumption and the average emissions of the fleet expressed in MJ/100km and in g.$CO_{2\text{-eq}}$/km respectively, are shown in table 6. The main results to be highlighted are the following:

- Gasoline, diesel and LPG vehicles are the most inefficent and pollutant light-duty conventional vehicles. As for LPG vehicles, they stand out for their high emissions in general. However, the figures improves both segmets D, E and J (SUVs) for LPG as alternative fuel.
- Hybridization seems the most feasible solution to reduce emissions from ICEVs. Light hybridization (mHEVs) reduces emissions by only 3% (5% its energy consumption) compared to gasoline ICEVs, however, full-hybridization (HEVs) reduces vehicle emissions by 18% (20% for energy consumption). Hybridization appears to be a potential solution for reducing energy consumption and direct emissions for these heavier vehicles.
- From the average fleet for ICEV, we can deduce that HEVs are the vehicles with the lowest energy consumption per distance traveled (167.4 MJ / 100km), thus being the case for most small and compact segments (A, B, C) and for SUVs (segment J). In general, HEV fleet pollutes less than the rest of conventional power-train technologies.
- Finally, the energy consumption and emissions of the average segment fleets by technology are hampered by the high portion of the J segment (SUVs) in vehicle sales in the Canary Islands (accounting for more than 40% for all power-train technologies).

Table 6: Car Inventory TtW by ICEV Tecnology and Segment (energy consumtpion in MJ/100km and tailpipe g.CO$_{2\text{-}eq}$/km emissions)

Power-train Tecnology	ICEV - Gasoline	ICEV - Diesel	ICEV -LPG	mHEV	HEV
Average fleet	**211.2 (132.3)**	**214.1 (137.0)**	**222.4 (143.0)**	**202.0 (128.7)**	**167.4 (105.3)**
A - Segment: Micro-cars and Urban Cars	188.6 (118.2)	-	380.4 (244.5)	174.0 (113.4)	163.6 (103.4)
B & C- Segment: Subcompacts, Compacts and Mid-Size.	198.0 (124.1)	168.0 (112.5)	263.8 (169.5)	181.7 (113.8)	155.0 (97.5)
D & E - Segment: Large cars and family cars.	219.2 (137.4)	177.6 (121.5)	208.0 (133.6)	205.5 (131.6)	212.2 (132.3)
J-Segment: AllRoad cars, Crossovers and SUVs	222.4 (139.4)	224.7 (147.8)	208.2 (133.8)	212.2 (136.0)	167.3 (105.4)
M-Segment: Multi-purpose vans, cargo vans and mini vans.	208.40 (130.6)	234.2 (146.2)	244.1 (156.9)	-	238.1 (158.7)

Once the emissions from the TtW (specific to the vehicle itself) have been shown, Table 7 details the energy consumption and the total emissions (table 7, between parenthesis) for the entire life cycle of the fuel from the WtW. Here are some highlights are shown below:

- The diesel vehicle fleet is revealed as the most polluting in terms of total GHG emissions throughout the cycle. However, they rank lower in terms of energy consumption per distance traveled, requiring less energy than those powered by gasoline and LPG. However, they rank lower in terms of energy consumption per distance traveled, requiring less energy than those powered by gasoline and LPG. This is because the TtW life cycle is more efficient, but more intense in GHG emissions.
- The life cycle of LPG for the sales fleet in the Canary Islands is below diesel and above gasoline in terms of GHG emissions. This technology reveals promising results in the longer and heavier vehicle segments such as the D, E and J (SUVs). In these segments, the reduction of emissions is around 10%.
- Hybridization remains the most feasible option for vehicles that use fossil fuels. Within this alternative, the cycle for vehicles with total hybridization stands out, where energy consumption and emissions are reduced by 21% compared to ICEV gasoline and 25% respect diesel. HEVs lead the reduction of emissions and consumption in all segments, except for vans.
- Finally, the mHEVs turns out to be quite useful in segments A, B, and C (smaller cars). It is striking how emissions soar in the heavy vehicle segments (where emissions and consumption rise above gasoline or diesel vehicles). This phenomenon is motivated by the very light hybridizations of high-performance vehicles or heavy weighing SUVs, achieving ECO labels to benefit from freedom of movement and savings in registration taxes. There is much discussion in the sector, because it does not seem logical that a gasoline ICEV with low consumption and emissions has mobility restrictions and yet an mHEV - SUV that doubles consumption and emissions can benefit from all the advantages related to the ECO label.

Table 7: WtW by Tecnology and Segment (energy consumtpion in MJ/100km and total g.CO$_{2\text{-}eq}$/km emissions)

Power-train Tecnology	ICEV - Gasoline	ICEV - Diesel	ICEV - LPG	mHEV	HEV
Average fleet	**244.5 (165.7)**	**241.8 (175.5)**	**253.1 (171.4)**	**233.8 (160.6)**	**193.7 (131.7)**
A - Segment: Micro-cars and Urban Cars	218.4 (148.1)	-	434.2 (287.7)	201.4 (136.9)	189.4 (129.3)
B & C- Segment: Subcompacts, Compacts and Mid-Size.	229.2 (155.4)	189.8 (142.6)	301.1 (199.5)	210.3 (142.5)	179.4 (122.0)
D & E - Segment: Large cars and family cars.	253.7 (172.0)	231.6 (158.4)	237.4 (157.3)	237.9 (164.1)	245.6 (165.8)

J-Segment: AllRoad cars, Crossovers and SUVs	257.5 (174.5)	255.3 (188.5)	237.6 (157.4)	245.7 (169.5)	193.7 (131.9)
M-Segment: Multi-purpose vans, cargo vans and mini vans.	241.2 (163.5)	263.0 (188.1)	278.6 (184.6)	-	275.6 (196.3)

3.2. Well-to-Wheels Resutls for Plug-In Eltectric Vehicles for current scenarios.

As can be expected, the life cycle of fuels for PEVs (PHEV, REEV and BEV) is highly determined by the generation technologies of the electrical system where they recharge their batteries. At this point, we analyze the current scenarios for each of the island systems that comprise the Canary Islands.

On the one hand, Table 8 shows the energy consumption and direct emissions (only for PHEVs) from the plug to the wheels, that is, the one marked by the WLTP homologation cycle corresponding to the actual sales (2019-2021) of this type of cars in the Canary Islands. The most prominent data in the table is reflected in the very low consumption and emissions by PEVs compared to ICEVs. By way of comparison, the average BEV is three times more efficient than any ICEV, except the HEV. It is important to note that BEVs do not emit directly, therefore, they reduce pollution in urban areas (where combustion vehicles consume and pollute more). On contrary, PHEVs pollute locally when battery level falls. In general, BEVs & REEV have the best figures in respect to PHEV, requiring half of energy for moving without emitting GHG.

Table 8: PtW by PEVs Technology and Segment (energy consumtpion in MJ/100km and pipetail g.$CO_{2\text{-eq}}$/km)

Power-train Tecnology	PHEVs	BEV & REEV
Average car fleet	**143.6 (41.8)**	**64.55 (0)**
A - Segment: Micro-cars and Urban Cars	-	59.9 (0)
B & C- Segment: Subcompacts, Compacts and Mid-Size.	116.0 (26.5)	63.7 (0)
D & E - Segment: Large cars and family cars.	125.7 (39.0)	60.6 (0)
J-Segment: AllRoad cars, Crossovers and SUVs	146.7 (42.6)	66.6 (0)
M-Segment: Multi-purpose vans, cargo vans and mini vans.	-	92.8 (0)

In the current scenarios (see Table 9), in the larger islands such as Tenerife, Gran Canaria and the Lanzarote-Fuerteventura system for the BEV fleet, in general the emissions are lower in all the electrical systems with respect to the ICEVs. For example, the electricity mix to which the batteries were recharged during 2020 in Tenerife, caused a 25% reduction in emissions with respect to the fleet of gasoline cars. The BEVs improve in emissions to the HEVs in general for the Tenerife and Gran Canaria systems, however, they are similar to those of the HEVs in the Lanzarote-Fuerteventura system (less benefited by renewables).

The opposite happens with energy consumption and WtW emissions in the case of PHEVs. This type of vehicle worsens all the numbers for all large electrical island power systems (except El Hierro). For the most favorable case, in Tenerife, the PHEV fleet emits 13% more than a gasoline ICEV. This is mainly due to the fact that PHEVs do not enjoy good energy efficiency both in their operation with the combustion engine and with their electric powertrain (for the latter, it shows figures much higher than the consumption by full BEVs). Despite these results and as we will see later (in future energy scenarios), PHEVs show their best behavior when they benefit from a power grid with a high penetration of renewable energies (with more than 35%, it begins to emit less than ICEVs).

Table 9: Car consumption and emission for PEVs WtW by segment and big island systems.

	Tenerife		Gran Canaria		Lanzarote - Fuerteventura	
Technology	PHEV MJ/100km (g.CO2/km)	BEV & REEV MJ/100km (g.CO2/km)	PHEV MJ/100km (g.CO2/km)	BEV & REEV MJ/100km (g.CO2/km)	PHEV MJ/100km (g.CO2/km)	BEV & REEV MJ/100km (g.CO2/km)
Average fleet	**264.1 (202.6)**	**154.5 (123.0)**	**254.9 (202.7)**	**147.0 (123.0)**	**289.9 (218.7)**	**175.6 (136.1)**
A - Segment: Micro-cars and Urban Cars	-	143.5 (114.1)	-	136.5 (114.1)	-	163.1 (126.3)
B & C- Segment: Subcompacts, Compacts and Mid-Size.	224.2 (171.8)	152.5 (121.3)	215.8 (171.9)	145.1 (121.3)	248.0 (186.6)	173.3 (134.3)
D & E - Segment: Large cars and family cars.	230.1 (178.3)	145.1 (115.4)	222.1 (178.3)	138.1 (115.5)	252.4 (192.2)	165.0 (127.8)
J-Segment: AllRoad cars, Crossovers and SUVs	269.5 (206.6)	159.6 (126.9)	260.1 (206.6)	151.8 (126.9)	295.8 (222.9)	181.3 (140.4)
M-Segment: Multi-purpose vans, cargo vans and mini vans.	-	222.2 (176.7)	-	211.4 (176.8)	-	252.5 (195.6)

On the other hand, in small electrical systems (La Palma, La Gomera and El Hierro) the numbers are disparate given the great differences between energy models of these islands (see Table 10). La Palma shows similar figures to the cases of Lanzarote-Fuerteventura. On the other hand, La Gomera, which currently has a 99.7% conventional electricity mix (from burning diesel oil in reciprocating diesel engines) shows the worst figures in terms of GHG emissions of all the scenarios studied. The average emissions for the BEV fleet on this island are 8% higher than those of ICEVs and up to 31% higher than HEVs. All the contrary occurs in the smallest system of the archipelago (El Hierro), where the penetration of renewable energies reaches 50%. In this system, the BEV fleet reduces GHG emissions by 60% compared to gasoline ICEV and its energy consumption for the WtW cycle by 54%. Furethermore, The island of El Hierro is the only one in which PHEVs benefit both in energy consumption and emissions compared to conventional ones, showing similar figures to HEVs.

Table 10: Car consumption and emission for PEVs WtW by segment and small island systems.

	La Palma		La Gomera		El Hierro	
Technology	PHEV MJ/100km (g.CO2/km)	BEV & REEV MJ/100km (g.CO2/km)	PHEV MJ/100km (g.CO2/km)	BEV & REEV MJ/100km (g.CO2/km)	PHEV MJ/100km (g.CO2/km)	BEV & REEV MJ/100km (g.CO2/km)
Average fleet	**289.1 (215.7)**	**175.0 (133.6)**	**330.6 (287.1)**	**208.9 (192.0)**	**211.1 (138.9)**	**111.2 (70.9)**
A - Segment: Micro-cars and Urban Cars	-	162.4 (124.0)	-	193.9 (178.2)	-	103.3 (65.9)
B & C- Segment:	247.3 (183.9)	172.6 (131.8)	285.4 (249.6)	206.1 (189.4)	175.5 (113.2)	109.8 (70.0)

Subcompacts, Compacts and Mid-Size.						
D & E - Segment: Large cars and family cars.	251.7 (189.4)	164.3 (125.5)	287.7 (251.4)	196.2 (180.3)	184.2 (123.2)	104.5 (66.6)
J-Segment: AllRoad cars, Crossovers and SUVs	294.9 (219.9)	180.6 (137.9)	337.3 (292.8)	215.6 (198.2)	215.5 (141.7)	114.8 (73.2)
M-Segment: Multi-purpose vans, cargo vans and mini vans.	-	251.5 (192.1)	-	300.3 (275.9)	-	159.9 (102.0)

3.3. Well-to-Wheels Resutls for Plug-In Electric Vehicles for Future Energy Transition Scenarios.

The transition to a decarbonized mix is one of the most important remains that will take place throughout this century. The Canary Islands are not alien to this transformation and have an ambitious project to decarbonise the islands in 2040. The PTECan in its preliminary documents proposes to integrate an intermediate objective in 2030 of at least 70% renewable in the Canary Islands.

In 2030, a set of infrastructures will be executed, chaging the panorama of the electrical systems previously considered, such as the interconnections between Tenerife-La Gomera (2025) or Gran Canaria with Lanzarote and Fuerteventura. In addition to the integration of large-scale energy storage such as the PHS of Chira-Soria in Gran Canaria (2030).

The most relevant resutls (see Table 11) for these scenarios related to the PEVs fleet considered in this study are detailed below:

- In all the scenarios considered, the energy consumptions of the WtW cycle notably improve those of the ICEV (which remain stable as they cannot benefit from a quantitative leap in the improvement of their processes).
- PHEVs are around 105 g.CO$_{2\text{-eq}}$, which significantly improves the best conventional technology (HEVs) by 20% and differs by more than 40% from diesel.
- For BEVs, the improvements in terms of emissions throughout the cycle increase drastically, reaching reductions of 69% compared to gasoline, 71% compared to diesel and 60% compared to HEVs.
- In respect to WtW energy consumption, a BEV in 2030 will require a 60% less energy in comparisson to an average ICEV.

Table 11 : Car consumption and emission for PEVs WtW by segment in 2030' Future island systems.

	Tenerife – La Gomera		Gran Canaria–Fuerteventura – Lanzarote		La Palma		El Hiero	
Technology	PHEV MJ/100km (g.CO2/km)	BEV & REEV MJ/100km (g.CO2/km)	PHEV MJ/100km (g.CO2/k8m)	BEV & REEV MJ/100km (g.CO2/km)	PHEV MJ/100km (g.CO2/km)	BEV & REEV MJ/100km (g.CO2/km)	PHEV MJ/100km (g.CO2/km)	BEV & REEV MJ/100km (g.CO2/km)
Average fleet	**191.8 (104.6)**	**95.6 (42.9)**	**192.7 (105.9)**	**96.3 (43.9)**	**194.5 (108.4)**	**97.7 (46.0)**	**192.4 (100.9)**	**96.0 (39.9)**
A – Segment: Micro-cars and Urban Cars	-	88.7 (39.8)	-	89.4 (40.7)	-	90.7 (42.7)	-	89.1 (37.1)
B & C-Segment: Subcompacts, Compacts and Mid-Size.	157.8 (81.7)	94.3 (42.3)	158.7 (82.8)	95.0 (43.3)	160.3 (85.1)	96.4 (45.3)	158.3 (78.3)	94.7 (39.4)

D & E - Segment: Large cars and family cars.	167.6 (93.5)	89.7 (40.3)	168.4 (94.6)	90.5 (41.2)	169.9 (96.7)	91.8 (43.2)	168.1 (90.4)	90.1 (37.5)
J-Segment: AllRoad cars, Crossovers and SUVs	195.8 (106.7)	98.7 (44.3)	196.8 (107.9)	99.4 (45.3)	198.6 (110.5)	100.9 (47.5)	196.4 (103.0)	99.1 (41.2)
M-Segment: Multi-purpose vans, cargo vans and mini vans.	-	137.3 (61.7)	-	138.4 (63.1)	-	140.5 (66.1)	-	138.0 (57.4)

3.4. Discussion and Policy Implications

The results of this article are critical from the point of view of promoting technologies in a region as unique as the Canary archipelago. Today, the policies to promote alternative propulsion technologies for light transport dedicated to the private consumer are determined by national policies. However, these policies are biased by an energy situation in mainland Spain that differs greatly from the island regions.

In general, PEVs technologies are promoted via direct subsidy to the purchase, currently they can cover between 4,500 and 9,000 euros per vehicle (provided that a series of conditions are met) and and the tax exemption for purchases in the Canary Islands (for ICEVs the tax rate is between 9.5 to 13.5%). These policies that have been in place since 2010, fails if we compare it to the sales forecasts that were to be produced for 2020 [41]. For example, according to the study of the implementation of the electric vehicle in the Canary Islands prepared in 2013, by 2020 there would be a total of 37,589 BEV of which about 29,089 would be passenger cars. The reality in 2020 is that Canaries accumulate a total of about 1,875 BEV, only 6% of the estimated forecast. The question is what has been failed to correctly promote alternative technologies to the traditional ICEV.

The results of this study may shed light on certain technologies that should not be promoted at the moment, given the electricity mix of which the islands are comprised (see Figure 6, the summary of results). For example, the introduction of PHEVs would only be recommended on the island of El Hierro since 50% of the mix is reached with renewable energies. On the other hand, it would be interesting to discourage heavy and inefficient vehicles such as those in the J segment (SUVs, SUVs and pickups and crossovers). Although it is true that they had always been popular on the islands given the orography and agricultural activity in certain areas of the islands, the change in urban consumer behavior towards SUVs puts the climate goals at risk.

The ECO labeling for low energy efficiency and high emissions mHEVs or the ZERO labeling for PHEVs with similar characteristics is in a certain way a contradiction to achieve the objectives of decarbonization in Canarian archipelago. Given the results of this study, the full-HEV seems to have an excellent performance in all vehicle segments and they turn out to be very competitive in terms of energy consumption and emissions. In addition, HEVs have the approval of the consumer (representing almost 8% of sales). On the other hand, with regard to alternative fuels, it seems that the use of LPG stands out in the segment D, E and J (SUVs), being the figures in terms of emissions and energy consumption much lower than gasoline, diesel and even some HEV. Therefore, the use of this fuel for vehicles in these segments should be promoted.

As general conclusions on energy policy, we recommend promoting the use of BEV in all island electrical systems (except La Gomera). As an alternative to the combustion vehicle, the use of full-HEVs should be promoted via tax reduction. We recommend the use of alternative fuels to gasoline and diesel such as LPG, especially in segments D, E and J. Conversely, we do not recommend promoting mHEVs given their low emission and consumption reduction. Finally, the promotion of PHEVs as vehicles should only be carried out in systems where recharging is assured with at least 35% renewable energy.

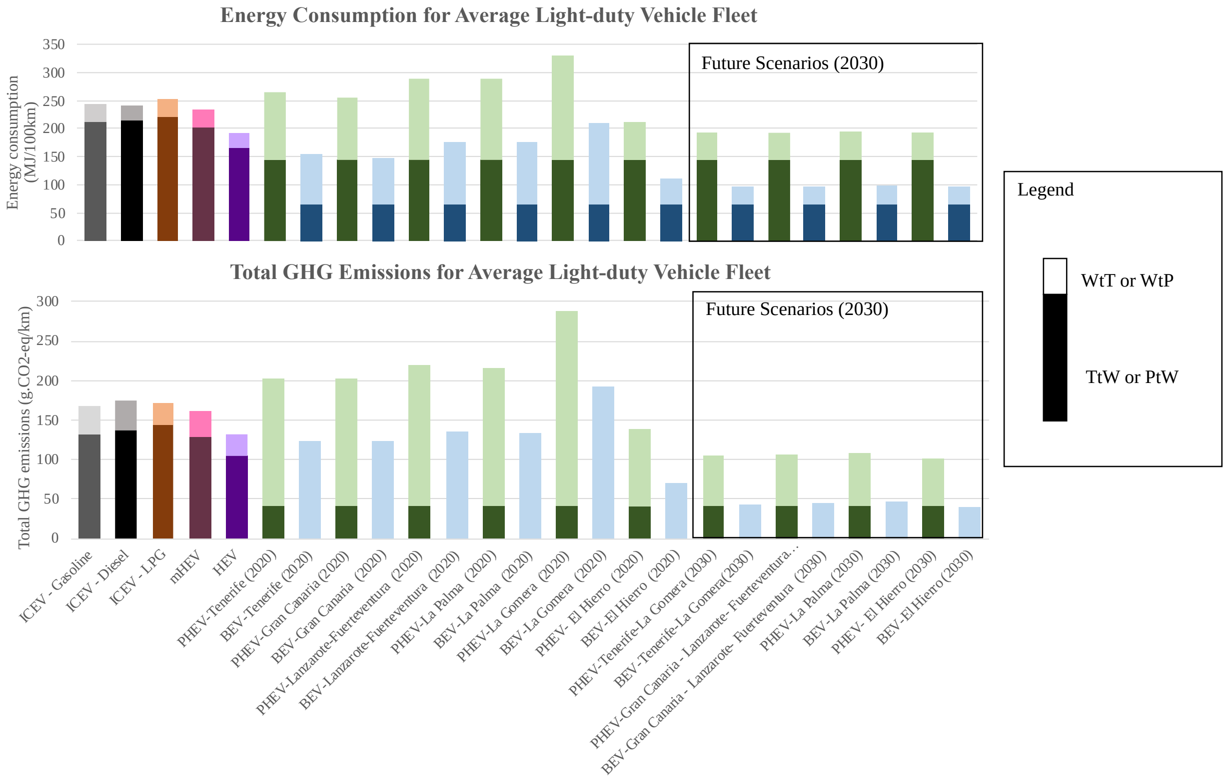

Figure 6: Energy Consumption for Average Light-Duty Vehicle Fleet in the Canary Islands

4. Conclusions

Road transportation is one of the most polloting sectors worldwide. To cope with the environmental commintments, the goberments should boost policies focusing on altenative green solutions. In the Canary Islands the situation is critical due to the intense use of petroleum derivatives that has led to 97% energy dependence in 2019. Thus, the advantages of the PEVs as mitigator of equivalent emissions is partially lost. The results shows that the impact on the environment of PEVs depends significantly on how cleanest is or electricity production. Additionally, in some scenarios, BEVs could be similar or more pollutant than some ICEVs. The alternative of PHEV requires cleanest mixes (more than 35% of renewable energy in the mix) to improve the equivalent emissions of ICEVs. However it is important to note that PEVs does not pollute locally, reducing dangerous gases in cities. Finally, the BEVs becames the best solutions achieving reducions about 70% in $CO_{2\text{-eq}}$ in 2030 scenarios.

Future research on this study should focus on how charging management influence the WtW impacts on these island systems, in order to promote initiatives on PEVs that use smarter charging strategies.

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