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TRABAJO FIN DE GRADO

HOW DIFFERENT SCENARIOS TOWARDS LESS POLLUTING MOBILITY IMPACT IN SPAIN AT A MICRO AND MACRO LEVEL

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A mi familia y amigos, por los ánimos que me han dado, empujándome cuando más lo necesitaba y demostrándome que, con esfuerzo se puede conseguir grandes cosas.

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CÓMO DISTINTOS ESCENARIOS HACIA UNA MOVILIDAD MENOS CONTAMINANTE IMPACTAN A NIVEL MICRO Y MACRO EN ESPAÑA

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RESUMEN DEL PROYECTO

1. INTRODUCCIÓN

La movilidad es uno de los elementos vitales en las ciudades pues es lo que mantiene los centros urbanos en funcionamiento. Asimismo, también es uno de los elementos más perjudiciales actualmente, pues la movilidad contribuye negativamente al problema de contaminación y dependencia energética existente tanto en España como en Europa. Según la EEA [1], (Agencia Europea del Medio Ambiente) alrededor del 12% de las emisiones totales de CO_2 de la UE son causadas por las partículas contaminantes de los vehículos. En el caso de España, esa situación no mejora en absoluto. Según el Ministerio de Transición Ecológica [5], el sector del transporte genera aproximadamente el 27% de los gases de efecto invernadero (GEI) emitidos en España y más del 40% de las emisiones totales de óxido de nitrógeno.

La Unión Europea, consciente de la importancia de estos problemas, ha desarrollado una hoja de ruta para descarbonizar el sector del transporte. Se espera que este sector reduzca sus emisiones de gases de efecto invernadero (GEI) en la UE en un 60% para 2050 en comparación con los niveles de 1990 [2]. Con ese fin, desde 2007, se está legislando el transporte por carretera, estableciendo los estándares de emisiones para los vehículos matriculados nuevos, entre otras medidas. (El Capítulo 2 estudia en profundidad tanto las regulaciones a nivel local como europeo). Se espera que el cumplimiento de estos compromisos europeos sobre el cambio climático requiera la descarbonización parcial o completa de la flota de automóviles. Como resultado, hay una tendencia acelerada hacia soluciones más limpias a la vez que viables rentablemente en el sector del transporte.

Aun siendo común en la Unión Europea, el objetivo de descarbonizar el transporte para reducir la contaminación, no existe una estrategia clara o uniforme a nivel europeo o nacional sobre el camino a seguir para conseguirlo. Cada país apuesta por una tecnología diferente, por ejemplo, Alemania apuesta por la electricidad y el hidrógeno para descarbonizar su flota, mientras que Francia apuesta por el gas natural y los combustibles biometano. Esta tesis tiene como objetivo principal proponer diferentes estrategias hacia una movilidad de baja contaminación, así como medir su impacto en la economía a nivel micro y macro en España.

Para ello, en el análisis realizado se ha distinguido entre dos niveles: Micro y Macro. Ambos niveles incluyen escenarios que simulan diferentes evoluciones de las características propias de los vehículos y sus tecnologías (La evolución de los costos de combustible, rendimientos, consumos medios, precios de compra ...), así como factores nacionales (tasa de interés, costos de infraestructura ...).

El análisis micro tiene como objetivo responder desde la perspectiva del consumidor qué tipo de vehículo se ajusta mejor a él, dependiendo del año de compra, los kilómetros recorridos por año y la composición del hogar (si tiene uno o dos vehículos). Mientras que el análisis Macro pretende responder la pregunta, ¿cuál es la mejor estrategia para tomar como hoja de ruta para el país?

Los resultados extraídos del análisis realizado en ambos niveles señalan que, además de los factores económicos, los factores ambientales juegan un papel clave en como se debe descarbonizar la flota.

2. METODOLOGÍA

Para poder realizar estos análisis, se necesita un estudio previo de la composición actual de la flota, así como de su evolución histórica, y las características principales de cada una de las tecnologías. Por esta razón, antes de realizar estos análisis, y poder extraer conclusiones, se investigó a cerca de:

1. Reglamento sobre el sector del transporte a nivel local y europeo, así como la definición de las normas actuales sobre vehículos (*Capítulo 2*).
2. Investigación profunda de los diferentes tipos de vehículos (*Capítulo 3*).
   a) Cómo funciona su motor, analizando sus principales ventajas y desventajas.
   b) Infraestructuras actuales en España, y un análisis de si es factible o no implementar cada tecnología en un futuro próximo.

    c) Costo de las infraestructuras requeridas y asentar las bases de cómo deben penetrar dichas infraestructuras a medida que aumenta la flota de los vehículos poco contaminantes.
    d) Precios de catálogo de los 10 coches más vendidos en 2019 para cada tipo de combustible.
    e) Precios de catálogo de los 5 vehículos hatchback más vendidos en 2019 por tipo de combustible.
    f) Precios históricos del combustible en España de cada una de las tecnologías.
    g) Análisis de sus costos de mantenimiento, incluyendo los costos del seguro.
    h) Gases de efecto invernadero emitidos por tipo de vehículo (CO_2, NO_x y PM_x).
3. Análisis de la composición actual de la flota española, así como un Pronóstico de la evolución del parque, utilizando una herramienta Excel proporcionada por el OVEMS (*Capítulo 4*).

El objetivo principal de esta tesis es analizar cómo diferentes escenarios hacia una movilidad menos contaminante impactan en la economía española a nivel micro (desde la perspectiva del consumidor) y macro (estrategia nacional). Para ello, se han llevado a cabo los dos análisis. Ambos análisis tienen muchas cosas en común, debido a que se centran en extraer conclusiones de cada escenario basándose principalmente en factores económicos y medioambientales. Además, dentro de cada escenario, se han generado a su vez 27 subescenarios distintos, donde se ha ido jugando con las distintas variables del modelo y viendo su impacto en el coste total (costos de combustible en la bomba, precios de compra y consumo promedio).

Debido a la imposibilidad de analizar cada uno de los subescenarios en detalle, ni tampoco predecir que como evolucionarán las variables en el futuro, el alcance de esta tesis queda limitado a los subescenarios extremos. Es decir, de entre los 27 subescenarios del estudio, se han tomado aquellos donde se producen los máximos y mínimos costos, lo que permite pensar, que el valor real se producirá entre dichos valores. A estos subescenarios se han llamado Business as usual (costo máximo) y ruta de descarbonización (costo mínimo). En todos los gráficos presentados en esta tesis, se muestran dos líneas por cada tipo de vehículo, representando el coste máximo (business as usual) y el coste mínimo (ruta de descarbonización) que pueden tomar. La Tabla 1 muestra las características de estos escenarios (los Apéndices B y C muestran en detalle cómo se ha seleccionado como subescenarios estudiados)

Table 1: Características de los escenarios Decarbonization path and Business as Usual (Own source)

	Min. (Decarbonization Path)			**Max. (Business as Usual)**		
	CONSUMO	COSTE DE COMBUSTIBLE	PRECIO DE COMPRA	CONSUMO	COSTE DE COMBUSTIBLE	PRECIO DE COMPRA
Gasolina	-1% por año	Cte	Cte	Cte	+1% por año	+1% por año
Diesel	-1% por año	Cte	Cte	Cte	+1% por año	+1% por año
BEV	-1.5% por año	-1% por año	-30% en 2050	Cte	Cte	-1 % por año
PHEV*	-1.5 % por año (electricidad) -1% por año (gasolina)	-1% per year (electricidad) cte (gasolina)	-30% en 2050	Cte	Cte (electricidad) + 1 % por año (gasolina)	-1 % por año
CNG	-1% por año	-1% por año	-1% por año	Cte	Cte	Cte
LPG	-1% por año	-1% por año	-1% por año	Cte	Cte	Cte

* Debido a que los vehículos híbridos enchufables PHEV puede funcionar con carburantes convencionales y con electricidad, en ambos escenarios se han tomado los valores extremos de la gasolina y la electricidad.

Microanálisis: Este análisis tiene como objetivo encontrar qué tipo de vehículo se ajusta mejor a cada usuario en función de sus características. Para lograrlo, se han desarrollado los siguientes sub-análisis:

1. <u>Costo según el año de compra:</u> Debido a que las nuevas tecnologías evolucionan a un ritmo frenético; Es interesante estudiar cuándo es más conveniente cambiar de vehículo. Además, este sub-análisis ha estudiado el costo total de un vehículo a lo largo de toda su vida útil dependiendo del año de compra, si el vehículo recorre 10,000 kilómetros, 15,000 kilómetros y 20,000 kilómetros, para una esperanza de vida de 12 y 15 años.
2. <u>Costo dependiendo de los kilómetros recorridos:</u> En España, el promedio de kilómetros recorridos al año por vehículo es de alrededor de 13,000 km. Sin embargo, los kilómetros recorridos por muchos conductores están muy alejados de esa cifra. Por ello, se ha analizado el coste total de un vehículo comprado en

2020, 2025 y 2030 con una esperanza de vida de 15 años en función de los kilómetros que recorra.

3. <u>Costo para un hogar en 2020:</u> Actualmente, los vehículos eléctricos (BEV) presentan limitaciones en relación a su baja autonomía al recorrer distancias de más de 20.000 kilómetros. Además de la baja autonomía, la falta de infraestructuras para la carga de estos vehículos, complica poder viajar largas distancias. Por lo tanto, en caso de que una persona / hogar quiera hacer en 2020, más de 20,000 kilómetros necesitarían dos vehículos (BEV + Gasolina). El vehículo de gasolina recorrerá los kilómetros en carreteras mientras que el eléctrico lo hará en vías urbanas. En este análisis, se compara tener un coche eléctrico y otro de gasolina, con tener un vehículo o dos vehículos iguales de las otras tecnologías.

Para calcular los costos por vehículo se ha utilizado la siguiente fórmula:

$$\begin{aligned} Coste\ Total\ \text{año}_{i,j} = {} & Precio\ de\ compra_{(si\ i=y),j} + Coste\ de\ mantenimiento_{i-y,j} + km\ recorridos_i \\ & * Consumos\ medio_{y.j} * Coste\ de\ combustible_{i,j} * Efecto\ de\ antig\text{ü}edad_{i-y} \end{aligned} \tag{1}$$

$$Coste\ total_j = \sum_{i=1}^{x} Coste\ Total\ \text{año}_i \tag{2}$$

i: Año analizado
j: Tipo de vehículo analizado (Tecnología)
y: Año de compra
x: Esperanza de vida

Macroanálisis: Para la realización de este análisis, se ha utilizado la herramienta Excel proporcionada por el OVEMS (Observatorio del vehículo eléctrico y movilidad sostenible de ICAI) que genera previsiones de la evolución de la flota española. Desde el Observatorio, se han generado 4 escenarios de la flota.

1. <u>Escenario base</u>: En este escenario se produce una penetración progresiva de las nuevas tecnologías poco contaminantes, llegando a 2 millones de vehículos eléctricos en 2030.
2. <u>Escenario eléctrico</u>: Este escenario simula una electrificación completa de la flota. En 2050, todos los vehículos vendidos son eléctricos (PHEV + BEV).

3. Escenario de gas: En este escenario, la flota española es gasificada. Como ocurre en el escenario eléctrico, en 2050 todos los vehículos vendidos serán GLP o GNC.
4. Escenario convencional de ICE: Este escenario supone que no hay cambios en la composición de la flota. Todos los vehículos funcionarán con gasolina o Diesel.

Este análisis considera todos los costos fijos y variables de la flota española. De hecho, a medida que llegan al mercado los vehículos con tecnologías alternativas, se requiere una inversión para la construcción de una red de infraestructuras acorde al parque. Por eso se ha llevado a cabo un subanálisis del coste de Infraestructuras requerido en cada escenario.

Debido a que este análisis pretende ser utilizado para diseñar estrategias nacionales hacia una tecnología poco contaminante, las emisiones de efecto juegan un papel principal en la ejecución de esta tesis. De hecho, se ha establecido el precio que costaría reducir una kt. de CO_2, NO_X y PM, reemplazando el escenario convencional de ICE por los otros escenarios.

Para calcular los costos totales de la flota, se ha utilizado la siguiente fórmula:

$$\begin{aligned} Coste\ Total\ año_i = & \sum_{j=1}^{6} Precio\ de\ compra_{i,j} * Vehículos\ vendidos_{i,j} \\ & + \sum_{j=1}^{6} \sum_{y=1990}^{i} Coste\ de\ mantenimiento_{i-y,j} + \sum_{j=1}^{6} Coste\ de\ infraestructuras_{i,j} \\ & + \sum_{j=1}^{6} \sum_{y=1990}^{i} Consumos\ _{y,j} * Coste\ de\ combustible_{i,j} * km\ viajados_{i,j} \\ & * Efecto\ de\ antigüedad_{i-y,j} \end{aligned}$$

$$Coste\ Total = \sum_{i=2020}^{2050} Coste\ Total\ año_i$$

i: Año analizado
j: Tipo de vehículo (Tecnología)
y: Año de compra

3. RESULTADOS Y CONCLUSIONES

Según lo explicado anteriormente sobre esta tesis, se ha realizado una estimación de los costos y las emisiones de los vehículos tanto a nivel micro (un vehículo) como macro (flota española). Dichos análisis, se encuentran desarrollados y explicados en detalle en el Capítulo 5, como conclusión se ha obtenido qué tecnología es la óptima según el año de compra, los kilómetros recorridos y la esperanza de vida. Los resultados obtenidos de los análisis micro y macro se presentan detalladamente en el Apéndice D.

Además, se ha obtenido el costo de reemplazar un vehículo convencional por una alternativa eléctrica o de gas en términos de reducción de emisiones (Tabla 2). El signo menos significa el gasto extra que costaría reducir 1 t. de emisiones.

Table 2: Costo de reemplazar un vehículo convencional por una alternativa eléctrica o de gas en términos de reducción de emisiones (Elaboración propia)

		CO_2 (€/kg)	**NO_X (€/kg)**	**PM (€/kg)**
ELECTRIFICACIÓN DE LA FLOTA	**Gasolina Min**	-0,224	-0,33	-0,02
	Gasolina Max	-0,240	-0,35	-0,02
	Diesel Min	-0,35	-0,03	-0,003
	Diesel Max	-0,59	-0,05	-0,01
GASIFICACIÓN DE LA FLOTA	**Gasolina Min**	0,55	0,39	0,02
	Gasolina Max	11,80	0,58	0,19
	Diesel Min	0,61	0,43	0,02
	Diesel Max	12,07	0,60	0,19

Por último, se presentan las tres estrategias diferentes estudiada que podrían tomarse a nivel macro/nacional(escenario gas, electricidad y base) y sus ventajas.

1. **Escenario de gas:** Es la alternativa más barata al escenario convencional. De hecho, podría ahorrarse en promedio entre 5.157,5 y 7.354,69 millones de euros al año, dependiendo del subescenario (Business as usual o ruta de descarbonización). Con respecto a las emisiones, si la flota fuese gasificada contando del momento actual hasta el 2050, se habrían reducido 277.96 kt. de NOx y 1.03 kt. de PM. En cambio, las emisiones de CO_2 habrían aumentado en 27.865,69 kt. lo que permite pensar que gasificar la flota no es la manera óptima de conseguir "Emisiones-Cero".
2. **Escenario eléctrico:** Es la estrategia más cara que se podría tomar. Sin embargo, es donde se produce la mayor reducción de emisiones. Si se compara este escenario con el escenario Gas, el escenario Eléctrico sería entre 15.067,75 y 15.912,84 millones de euros más caro al año, pero se estarían reduciendo403,85 kt. de CO_2, 12,74 kt. de NO_x y 0.21 kt. al año, lo que hace que, a pesar de ser el

escenario con mayores costes, es en el que se produce una mayor descarbonización de la flota.

3. **Escenario base:** este escenario propone una introducción gradual de los combustibles alternativos. Probablemente, y especialmente hasta que un combustible termine por despegar y revolucionar el mercado, la flota española evolucionará de manera similar a este escenario, en el que todas las tecnologías alternativas irán poco a poco introduciéndose. Como se explica en el análisis del coste de las infraestructuras necesarias (punto 5.2.5.1 del trabajo), es mejor hacer un "all in" a una sola tecnología, ya que ayudaría a reducir muchos costos, y aumentarían las economías de escala. Por lo tanto, a pesar de ser el escenario más realista, ni económica ni medioambientalmente es el escenario óptimo.

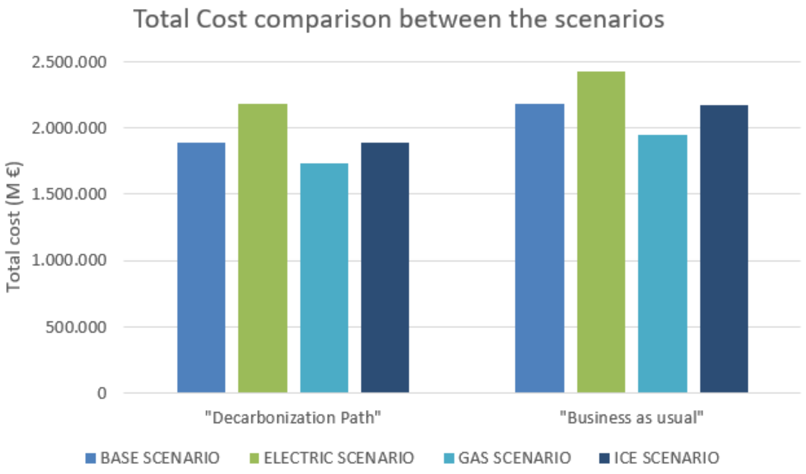

Figure 1:Comparación del coste total entre escenarios (Elaboración propia)

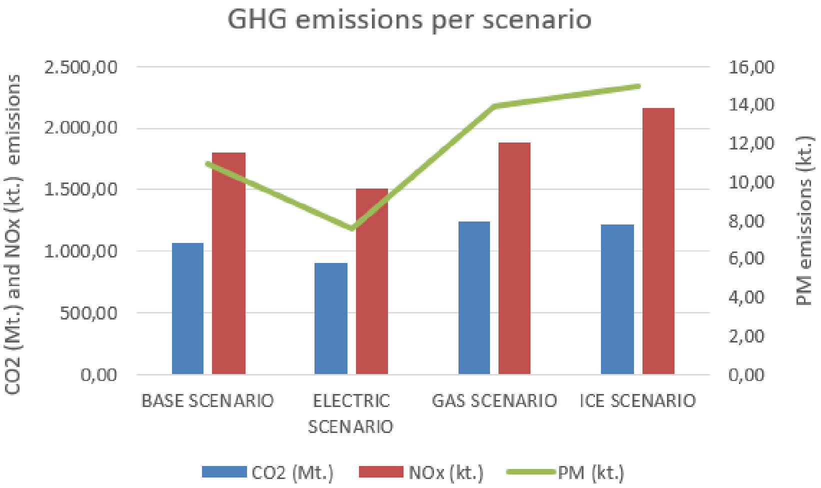

Figure 2:Emisiones Efecto Invernadero por escenario (Elaboración propia)

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EXECUTIVE SUMMARY

1. INTRODUCTION

Mobility is the lifeblood of our cities, and what keeps our urban centers functioning, it is also one of the main contributors to these issues. Likewise, it is also one of the most damaging elements at present, as mobility contributes negatively to the problem of pollution and energy dependency existing both in Spain and in Europe. According to the EEA [1], (European Environment Agency) for around 12% of the total EU CO_2 emissions are caused by the vehicle's polluting particles and in the case of Spain, that situation doesn't improve at all. According to the Ministry for the Ecological Transition [5], the transport sector generates approximately 27% of the greenhouse gases (GHG) emitted in Spain and more than 40% of the total nitrogen oxide emissions.

The European Union aware of importance of these facts, has developed a roadmap to decarbonize the transport sector. This sector is expected to reduce his greenhouse gas (GHG) emissions in the EU by 60% by 2050 compared to 1990 levels [2]. To that end, since 2007, road transport is being legislated, setting the emissions standards for new vehicles, among other measures. (Chapter 2 dives deeply into local and European regulations). Compliance with these European commitments on climate change is expected to require partial or complete decarbonization of passenger car fleet. As a result, there is an accelerating shift toward cleaner, as well as cost-efficient solutions in the transportation sector.

Although the objective of decarbonizing transport to reduce pollution is a common objective in the European Union, there is no clear or uniform strategy at European or national level on the way forward to achieve it. Each country is betting in one different technology, for instance, Germany bets on Electricity and Hydrogen to decarbonize its fleet, while France bets on Natural Gas and Bio-methane fuels. This senior thesis aims to propose different strategies towards low polluting mobility as well as its impact on the economy at a micro and macro level in Spain. To that end, the analysis carried out has distinguished by two levels, the Micro, and the Macro analysis. Both analyses include several scenarios that simulate different forecasts of vehicle factors (evolution of fuel costs, yields, consumption, purchase prices ...), as well as national factors (interest rate, costs of infrastructure ...)

The Micro analysis aims to answer from a consumer perspective which vehicle type works better for him, depending on the purchase year, the kilometers covered per year, and the number of vehicles per household (one or two). While the Macro analysis intends to answer the question, which is the best strategy to take as a roadmap for the country. The results obtained from the analysis carried out at both levels indicate that, in addition to economic factors, environmental factors play a key role to decarbonize the Spanish Fleet.

2. METHODOLOGY

To perform these analyses, it is needed an exhaustive study of the current composition of the fleet, as well as of each of the low-pollution technologies. For this reason, prior performing these analyzes, an exhaustive research was carried out of:

1. Regulation on Transport sector at a local and European level, as well as defining current vehicles Standards (*Chapter 2*).
2. Deep research of the different types of vehicles (*Chapter 3*).
    a. How works its engine, analyzing its main advantages and disadvantages.
    b. Current infrastructures in Spain, and an analysis whether is feasible or not to implement each technology in the near future.
    c. Cost of infrastructures required and set the bases of how these infrastructures will penetrate.
    d. Purchase prices of the top 10 most sold vehicles on 2019 per fuel type.
    e. Purchase prices of the top 5 most sold hatchback vehicles on 2019 per fuel type.
    f. Historical fuel prices at pump in Spain of each of the technologies.
    g. Analysis of its maintaining costs, including Insurance costs.
    h. GHG Emissions per vehicle type (CO_2, NO_x and PM_x).
3. Analysis of the current Spanish fleet composition, as well as a Park evolution Forecast, using an Excel tool from the OVEMS (*Chapter 4*).

The main purpose of this thesis is analyzing how different scenarios towards less polluting mobility impact in Spain at a micro (from the consumer perspective), and macro level (National strategy) on the economy. To that end, it has been carried out the two analyses. Both analyzes have many things in common, due to are centered on drawing conclusions from each scenario based mainly on economic and pollutant factors. In addition, within each scenario, 27 sub-scenarios have been also generated, where the different variables of the model were modified (fuel costs at pump, purchase prices, and average consumption).

Since it is impossible to analyze all the results in depth neither to predict what will happen in the future, the scope of this thesis is limited to extreme sub-scenarios. Among the 27 sub-scenarios, it has been taken those where the maximum and the minimum cost occurred. These sub-scenarios have been called Business as usual (maximum cost) and decarbonization path (minimum cost). In all the graphs presented in this thesis, two lines are shown for each type of vehicle, representing the maximum cost (business as usual) and the minimum cost (decarbonization route) that they can take. *Table 3* shows the characteristics of this scenarios (Appendix B and C shows in detail how has been selected as the sub-scenarios studied)

Table 3: Characteristics of the Decarbonization path and Business as Usual sub-scenarios (Own source)

	Min. (Decarbonization Path)			**Max. (Business as Usual)**		
	CONSUMPTION	FUEL COST	PURCHASE PRICE	CONSUMPTION	FUEL COST	PURCHASE PRICE
Gasoline	-1% per year	Const	Const	Const	+1% per year	+1% per year
Diesel	-1% per year	Const	Const	Const	+1% per year	+1% per year
BEV	-1.5% per year	-1% per year	-30% in 2050	Const	Const	-1 % per year
PHEV*	-1.5 % per year (electricity) -1% per year (gasoline)	-1% per year (electricity) const (gasoline)	-30% in 2050	Const	Const (electricity) + 1 % per year (gasoline)	-1 % per year
CNG	-1% per year	-1% per year	-1% per year	Const	Const	Const
LPG	-1% per year	-1% per year	-1% per year	Const	Const	Const

* Due to PHEV can run using conventional carburant and electricity, in both scenarios the extreme values of both gasoline and electricity have been taken.

Micro analysis: This analysis aims to find which fuel alternative technology works better for a determined driver. To achieve it, it has been developed three sub-analysis:

1. Cost depending on the Purchase year: As new technologies evolve at a frenetic pace; it is interesting to study when it is most convenient to trade-in your passenger car. Moreover, the cost depending on the purchase year has been analyzed for many scenarios, covering 10,000 kilometers, 15,000 kilometers and 20,000 kilometers, as well as for a life expectancy of 12 and 15 years.
2. Cost depending on the kilometers covered: In Spain, the average kilometers per vehicle is around 13,000 km. However, there are many drivers whose kilometers covered are far from the average. Furthermore, it has been analyzed for a vehicle purchased in 2020, 2025 and 2030 with a life expectancy of 15 years.
3. Cost for a Household in 2020: It is aware of the current limitations of BEV when it comes to cover more than 20,000 kilometers, due to their low range makes really difficult being able to travel long distances. Hence, in case a person/household want to cover in 2020 more than 20,000 kilometers would need two vehicles (BEV + Gasoline). In this analysis, has been compared having this pair of vehicles with having just one vehicle and with having two vehicles of the other technologies.

For calculating the costs per vehicles has been used the following formula:

$$Total\ Cost\ year_{i,j} = Purchase\ price_{(if\ i=y),j}\ + Manteinance\ cost_{i-y,j}\ + km\ covered_i \\ * Consumption_{y.j} * fuel\ cost_{i,j} * antiquity\ effect_{i-y} \tag{3}$$

$$Total\ Cost\ _j = \sum_{i=1}^{x} Infrastructure\ cost_i \tag{4}$$

i: Year analyzed
j: Vehicle type analyzed
y: Purchase Year
x: Life expectancy

Macro analysis: For the accomplishment of this analysis, it has been used the Excel tool that OVEMS to generate forecast evolutions of the Spanish fleet. From the Observatory, they have generated 4 scenarios of the fleet.

- Base scenario: In this scenario it is produced a progressive penetration of the low alternative's technologies, reaching 2 millions of electric vehicles in 2030.
- Electric scenario: This scenario simulates an electrification of the fleet. In 2050, all vehicles sold will be electric (PHEV+BEV).
- Gas scenario: In this scenario, the Spanish fleet is gasified. As in the electric scenario, in 2050 all the vehicles sold are LPG or CNG.
- ICE conventional scenario: This scenario supposes that there is no change in the fleet composition. All the vehicles are run by gasoline or diesel.

This analysis considers all fixed and variables costs of the Spanish fleet. Indeed, as low polluting vehicles hit the market, it is required an investment for building a refueling infrastructures network. Because of that it has been also carried out a sub-analysis of the Infrastructures cost required.

Due to this analysis aims to be used for designing National strategies towards low polluting technology, Green House emissions are one of the main players of the analysis. Indeed, it has set the price that would cost reducing one kt. of CO_2, NO_x and PM, replacing ICE conventional scenario by the other scenarios.

For calculating the total costs of the fleet, it has been used the following formula:

$$\begin{aligned} Total\ Cost\ year_i = {} & \sum_{j=1}^{6} Purchase\ price_{i,j} * vehicles\ sold_{i,j} \\ & + \sum_{j=1}^{6} \sum_{y=1990}^{i} Manteinance\ cost_{i-y,j} + \sum_{j=1}^{6} Infrastructure\ cost_{i,j} \\ & + \sum_{j=1}^{6} \sum_{y=1990}^{i} Consumtion\ _{y,j} * fuel\ cost_{i,j} * km\ covered_{i,j} * Yield_{i-y,j} \end{aligned} \tag{5}$$

$$Total\ Cost = \sum_{i=2020}^{2050} Total\ cost\ year_i \tag{6}$$

i: Year analyzed
j: Vehicle type
y: Purchase Year

3. CONCLUSIONS AND RESULTS

As previously explained on this thesis, an estimate of the costs and emissions has been made of the vehicles at both the micro (vehicle) and macro levels (Spanish fleet). Within the micro-level analyzes that have been carried out, it has been obtained which technology is the optimum depending on the year of purchase, the kilometers traveled and the life expectancy. The results obtained from the micro analyzes are presented in detail in Appendix D.

Moreover, it has been obtained the cost of replacing a conventional vehicle by an electric or gas alternative in terms of emissions reduction (*Table 4*). The minus sign means that for reducing 1 t. of emissions is required an extra expense.

Table 4:Cost of replacing an ICE vehicle in terms of GHG emissions (Own source)

		CO_2 (€/kg)	**NO_X (€/kg)**	**PM (€/kg)**
ELECTRIFY THE VEHICLE FLEET	**Gasoline Min**	-0,224	-0,33	-0,02
	Gasoline Max	-0,240	-0,35	-0,02
	Diesel Min	-0,35	-0,03	-0,003
	Diesel Max	-0,59	-0,05	-0,01
GAS VEHICLE FLEET	**Gasoline Min**	0,55	0,39	0,02
	Gasoline Max	11,80	0,58	0,19
	Diesel Min	0,61	0,43	0,02
	Diesel Max	12,07	0,60	0,19

Last, it will been studied the three different strategies that could be taken at a macro level (Gas, Electric and Base scenario) to the current situation (ICE conventional scenarios, and its advantages.

1. **Gas scenario:** It is the cheapest alternative to the conventional scenario. Indeed, it could be saved on average between 5.157,5 and 7.354,69 million Euros per year, depending on the sub-scenario (Business as usual or Decarbonization path). Regarding the emissions, if the fleet would be gasified, from now until 2050, it would be cut 277.96 and 1.03 kt. of NO_X and PM, respectively. However, CO_2 emissions are increased in 27.865,69 kt. which let us think that Gasification the gas is not the optimum way to Decarbonize the fleet.
2. **Electric scenario:** It is the most expensive strategy that could be taken. However, it is produced the biggest reduction in emissions. If it is compared to

this scenario with the Gas scenario, the Electric scenario would be between 15.067,75 and 15.912,84 million Euros more expensive per year than the Gas scenario. Regarding the emission, there is a huge difference between Gas and Electric scenarios, due to it could be cut by 11.403,85 kt. of CO_2, 12.74 kt. of NO_x and 0.21 kt. the emission per year.

3. **Base scenario:** This scenario proposes a gradual introduction of all alternative fuels. Probably, and especially until one fuel alternative takes off and hits the market, the Spanish fleet will evolve in a way similar to this scenario, introducing all fuel alternatives. As it is presented in the infrastructure's analysis (section 5.2.5.1 of this senior thesis), it would be better to do an "all-in" to just one technology, it would help to reduce costs. Therefore, despite being the most suitable and realistic scenario, neither economically nor environmentally is the optimal scenario

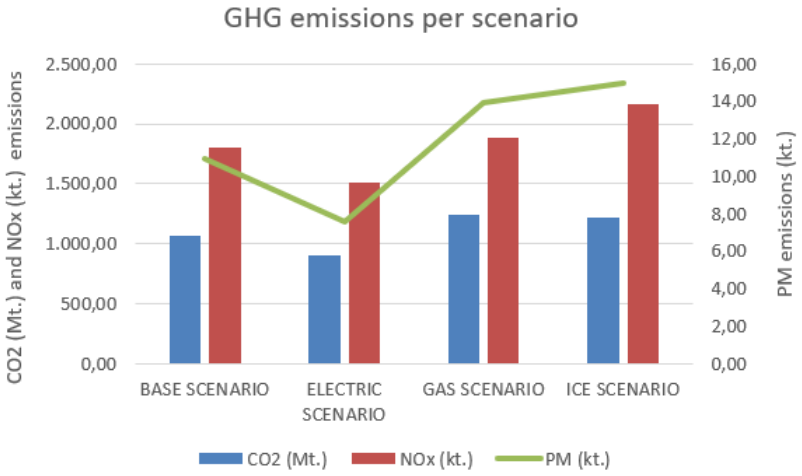

Figure 3: Green House Gases emissions per scenario (Own source)

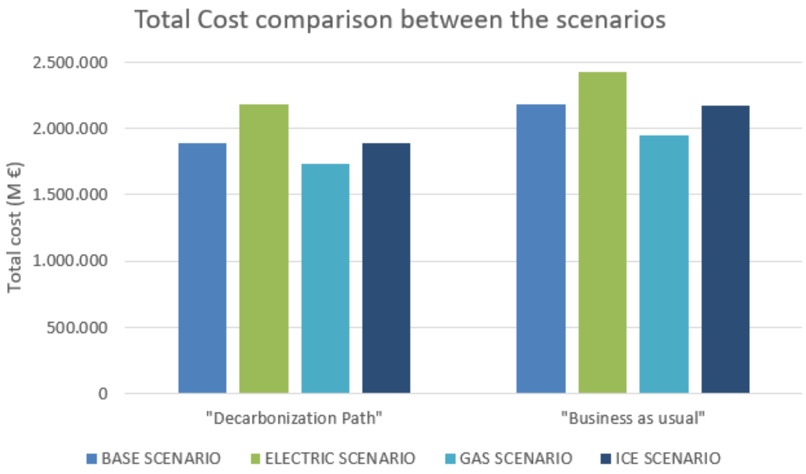

Figure 4:Total Cost comparison between the scenarios (Own source)

Abbreviations

EV	Electric vehicle
BEV	Battery Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
NGV	Natural Gas Vehicle
H2	Hydrogen Vehicle
LNG	Liquid Natural Gas
LPG	Liquefied Petroleum Gas
GHG	Greenhouse Gas
H2V	Hybrid Vehicle
T2W	Tank to Wheel
W2T	Well to tank
W2W	Well to Wheel
ICE	Internal Combustion Engine
PNIEC	National Integrated Energy and Climate Plan
OVEMS	Electric vehicle observatory and sustainable mobility
IIT	Institute for Technological Research
EC	European Commission
EU	European Union
DGT	Directorate General of Traffic
ACEA	European Association of Automobile Manufacturers
GDP	Gross Domestic Product
DAFI	Directive on the deployment of alternative fuels infrastructure
PM	Particle Matter

EEA	European Environment Agency
NPV	Net Present Value
AELEC	Association of Electric Power Companies
SDG	Sustainable Development Goals
S&P	Standard & Poor's
GFC	Global Financial Crisis
UN	United Nations
EAFO	European Alternative Fuel Observatory

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CHAPTER 1: INTRODUCTION

Nowadays, it is well known that pollution is one of the most important topics related to the population's health and safety worldwide. Despite the fact that mobility is the lifeblood of our cities, what keeps our urban centers functioning, it is also one of the main factors which is causing this issue. According to the EEA [1], (European Environment Agency) for around 12% of the total EU CO_2 emissions, is caused by the vehicle's polluting particles. The European Union is aware of this fact, and the decarbonization of transport is essential if they want to fulfill Europe's political commitments on climate change. The transport sector is expected to reduce his greenhouse gas (GHG) emissions in the EU by 60% by 2050 compared to 1990 levels [2]. Compliance with these commitments is expected to require a partially or complete decarbonization of the passenger car fleet. That is why today, new business models are introduced by companies from different sector such as Oil, Electric or Automobile, that are changing the way we view mobility systems, introducing new technological innovation in the form of different low-polluting fuels.

As it can be observed in the graph shown *(Figure 5)*, over the past few years, several low-polluting fuel alternatives have emerged. There is significant evidence of an upward trend in these fuels which suggests that in the medium-long run there might be a completely electric mobility. The purpose of this project is to analyze, from an academic point of view, how different strategies or scenarios towards less polluting mobility impact in the medium and long run in the Spanish economy at a micro (It will be analyzed all the cost associated with each of the technologies, taking into account both, fix and variable costs such as the price of fuels, its efficiency, its maintenance cost…) and a macro level (the impact in the GDP, evaluating the impact of the new park in each production sector, and in case there is time it will cover energy dependence…). In addition, one of the objectives of this work is to identify the most beneficial strategies in economic and sustainable terms the Government should implement. It will be achieved by carrying out a set of scenarios and comparing the business as usual results with those of decarbonization path (electric mobility). This decarbonization will be achieved by implementing low polluting fuels.

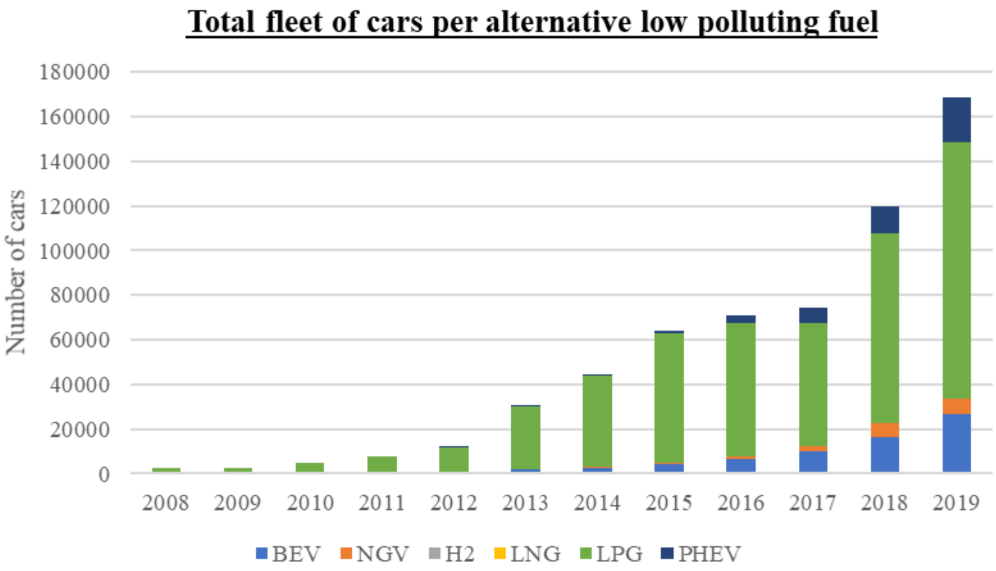

Figure 5:Total Spanish Fleet of cars per alternative low polluting fuel (Source: EAFO)

Among all the types of low polluting vehicles that exist, it has been chosen those that have been implemented with greater success during the last few years and there had been several researches. Therefore, the Spanish automobile fleet used in the scenarios will be made up of conventional, gasoline and diesel vehicles, as well as low-polluting fuel vehicles, including: BEV (battery electric vehicle), NGV (natural gas vehicle), PHEV (plug-in hybrid electric vehicle), LPG (liquefied petroleum gas). Even though more technologies have emerged over the last decade, it has been chosen the ones that seems easier to implement in Spain, mainly because of their current refueling network. Despite these will not have been considered in the scenarios, it will be discussed all their benefits and also a brief explanation about why they have not been introduced in the scenarios. These technologies are HEV (Hybrid Electric Vehicle), H2 (Hydrogen Vehicle) and LNG (Liquid Natural Gas Vehicle).

Among all the different alternatives of low polluting fuel, Electric Vehicles seems to be at this moment the most successful choice in which Governments and Companies are spending more amount of money developing it. This type of vehicle is receiving increasing attention due to their high fuel economy, low pollution emissions (CO_2, NO_x, PM_x) and reduction of the maintenance cost. These advantages versus the gasoline or diesel vehicles, combined with the increasing pollution problems are having most of the populated cities worldwide, suggest that EV can be an alternative to the conventional car and its progressive increase through next years. There are two main different types of vehicles considered as electric, Battery Electric Vehicles and Plug-in Hybrid Vehicles. Although the hybrid vehicle could be part of that family, HEV is not yet to be considered as a proper electric vehicle, due to uses two or more distinct types of power such as internal combustion engine to drive an electric generator that powers an electric motor. However, there is no doubt that it is still a good alternative during the transition to full electrification.

Even though Electric vehicles are considered by most as an emerging technology surrounded by success from its beginnings, this couldn’t be further from the truth. To understand the current moment in the evolution of the electric vehicle, it is important to remember its multiple failed attempts throughout history. The electrification of transportation systems began in the late 19th, including the emergence of EV. They became very popular in the cities of the United States, but its limited autonomy made the historic Ford triumph. At the end of the XX century, it was developed a new prototype of EV, and once again, it resulted in a failure. It was in 2009 when Tesla came up with a new electric model which has achieved that today the vast majority of brands already offer electric vehicles, and that within their short and medium term plans they propose to electrify their offer totally or partially.

Natural Gas Vehicle (NGV) is a low polluting alternative fuel vehicle which uses compressed natural gas or liquefied natural gas (LNG). Compared to the other low-pollution alternatives, although they are somewhat more polluting than electric vehicles, they are still a very good option for total decarbonization due to its high hydrogen/carbon index which causes it to produce less carbon dioxide per unit of energy delivered. Natural gas vehicles should not be confused with Autogas vehicles or LPG vehicles, powered by liquefied petroleum gas, mainly propane (C_3H_8), which is a fuel with a fundamentally different composition than the NGV uses.

1.1 *STATE OF THE ART*

Since the Electric Vehicle's resurgence, added to the climate crisis that is going through, have led many researchers from all around the world to study on this topic. And of course, the Institute for technological Research (Instituto de Investigación Tecnológica IIT) of ICAI has been part of these researches, especially his section of the electrical observatory (OVEMS). Over the last years, an analysis and dissemination of electric vehicle technology and sustainable mobility has been carried out from the observatory through reports on the state of the art and news on the EV and Sustainable Mobility aimed at the university sphere, the industry and institutions. The work carried out has included specialists from various fields within the Universidad Pontificia de Comillas (technology, economy and regulation, sociology, urban planning and air quality).

The field of study has also been varied, for the realization of this project, the previous investigations made by the university colleagues will be used as a basis. Specially, the thesis made by José González Pérez "Environmental and Economic Impact of EV" [3], where the author made a deep analysis of the environmental impact of the diesel and gasoline vehicles, generating scenarios until 2040. However, from an economic point of view, many information remains to be studied and discovered.

Moreover, for this thesis, due to the incorporation of the electric car in the study, will be of great importance to analyze the panorama of the electricity sector in Spain, and its evolution in the coming years. For this, the committee of experts for an ecological transition [4] has been taken into account, in which the professor of this university (ICAI) Pedro Linares has participated, his participation in this work was in the development and supervision of a model for Evaluation and design of sustainable energy policies.

1.2 MOTIVATION

In the transport sector, energy consumption is produced especially intensive, growing and singularly damaging to the environment. In our country it represents about 40% of the energy consumed. And according to the Ministry for the Ecological Transition [5], it generates approximately 27% of the greenhouse gases (GHG)[1] emitted in Spain *(figure 6)* and more than 40% of the total nitrogen oxide emissions *(figure 7)*. In addition, in the last year there was an increase of 1.7% of the total GHG emissions, due to mainly an increase of the emissions caused by road transport. Transport sector is formed by road transport which represent nearly three quarters of it (73%) and maritime and air transportation.

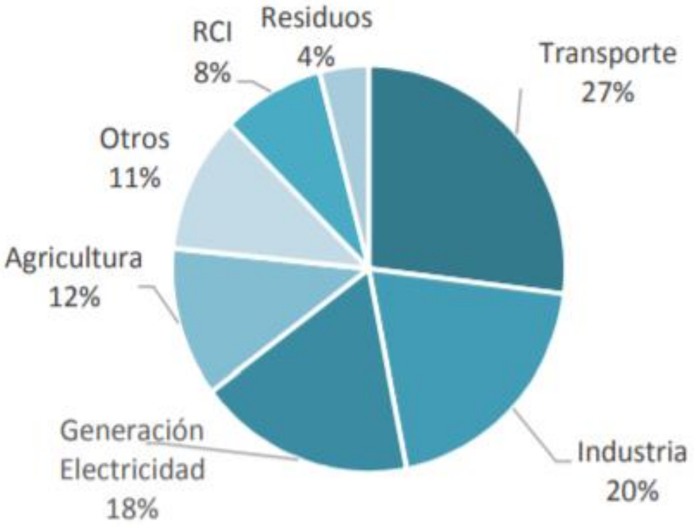

Figure 6: Emisions per-Sector (Source: Inventario Nacional de emisiones de Gases de Efecto Invernadero 2018 [31])

Within the road transport, in line with what the ministry has stated [5], it should be noted that most of the emissions are produced by passenger cars, representing around 30% of the

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[1] A greenhouse gas (GHG) is a gas that absorbs and emits radiant energy within the thermal infrared range. The primary greenhouse gases in Earth's atmosphere are water vapor (H2O), carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), and ozone (O3). Without greenhouse gases, the average temperature of Earth's surface would be about −18 °C (0 °F), rather than the present average of 15 °C (59 °F).

transport sector's emissions, which means around 12% of the total GHG emissions in the country.

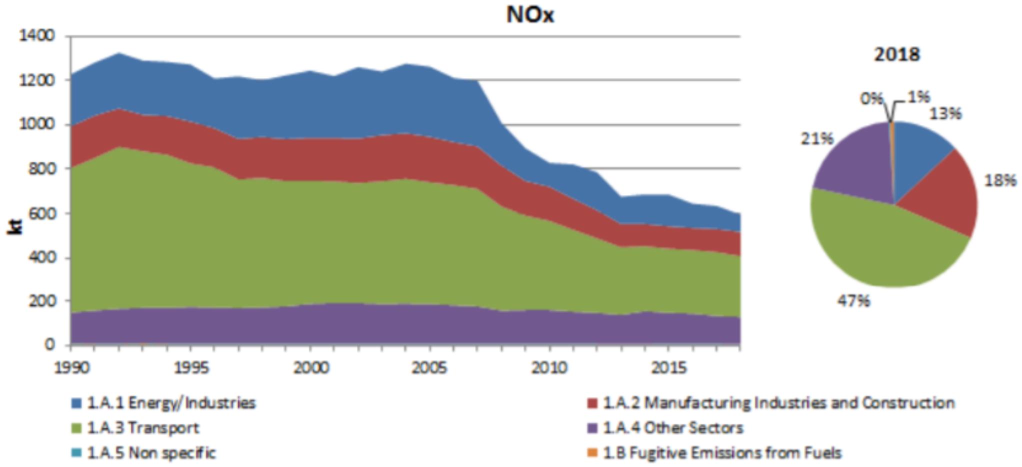


Figure 7:Evolution of NOX emissions by category and distribution in year 2018 (Source: IIR, Informative Inventory Report [30])

As previously was said, finding a solution to reduce emissions globally is one of the main objectives to be achieved on this decade. It is true that during the last decade there has been a lot of researches regarding to this topic. Nonetheless, many of these projects have been done with a previous economic interest and may have led to vias their conclusions. This project will be done to complete from an academic point of view the researches already done. In addition, it is yet to be done a rigorous analysis of the impact in the Spanish Economy.

1.3 MAIN PROJECT OBJETIVES

The present thesis is aimed at the analysis from an academic point of view, how different strategies towards less polluting mobility impact in the medium and long run at the Spanish economy at a micro and macro level. To answer that question, it will be required to analyze more concrete topics, specifying more tangible targets such as:

- Comparing the cost associated with the new park in each scenario, taking into account not only the average cost of manufacturing each type of vehicle but also the price of stablishing charging stations. (Macro level)
- Comparing the consumer total cost taking into account both fix and variable cost. To carry out this, the average consumption of each fuel, its efficiency and its cost associated will be calculated, which will give the vehicle total cost based on the kilometers traveled and its useful life.

Table 5: Comparison characteristics per fuel type (Source: Own source)

Fuel	**Price (€)**	**Average Consumption**	**Total cost (€/100km)**	**TTW CO2 (g/100km)**
Gasoline	17.006,40 €	5,509 l/100km	7,217	126,3
Diesel	26.838,20 €	4,75 l/100km	5,795	125
BEV*	30.703,43 €	15,25 kWh/100km	2,593	0
PHEV*	38.505,00 €	15,01 kWh/100km + 1,82 l/100km	4,936	54
GNC	21.339,00 €	3,648 kg/100km	3,247	120,2
GLP	14.457,20 €	6,527 l/100km	4,658	127

- Energy dependence, one of the main characteristics of the Spanish energy is its actual dependence on fossil imports like oil, coal or gas. During the last decade it was estimated to be around 73%, which is 20 % more than the European energy dependence average [6]. It will be commented the change produced regarding the energy dependence after the implementation of the low polluting fuels.

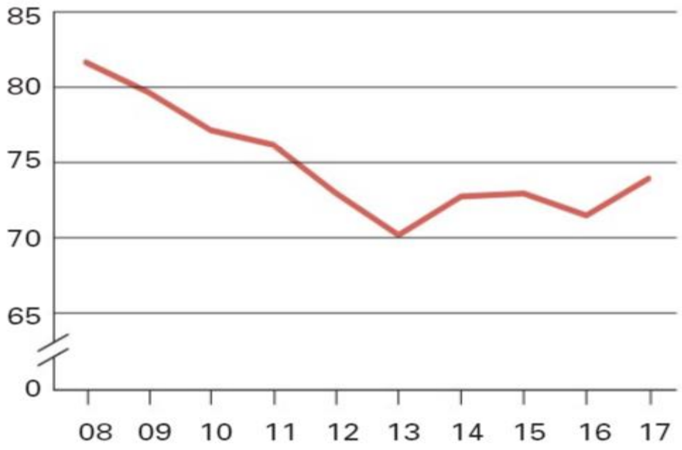


Figure 8: Energy dependence over the last decade (Source: INE [6])

- In addition, the scenarios carried out will allow to propose some viable fiscal policies apart from the actual ones, Tax exemptions, Purchase incentives and MOVEA plan.
- Even though calculation of the emissions is not the main purpose of this thesis, it will be also analyzed the GHG emissions per fuel type as well as its energy losses both tank to wheel and well to tank per fuel and an estimation of Well to Tank (W2T) emissions.

1.4 METHODOLOGY

In order to answer the research question posed, it will be used the inductive research approach, based on the data extracted from diverse sources consulted. The sources consulted include the material provided by the OVEMS Observatory, which includes many publications and research related to this topic, both nationally and internationally.

Regarding the search for literature review, apart from academic publications, use has been made of government publications, specially EU and National commissions, sector reports and other types of corporate reports.

To achieve all the previous objectives and answer the research question, two Excel tools will be used which allows to generate different scenarios. The first one, has been developed by the OVEMS, this tool allows simulations on the evolution of the passenger vehicles fleet. This tool will be used for analyzing the effect of implementing low polluting alternatives on the economy at a macro level. To achieve that, it will be carried-out different scenarios, in which it will be set different levels of low polluting alternatives implementation. The first scenario will be called the base scenario, it will represent a possible situation in which there will be 2 million of electric vehicles (BEV+PHEV) in 2030, taking place an electrification of the gradual fleet. In addition, it will be carried out three more scenarios in which in 2050 will be sold just electric vehicle, gas vehicle or petrol vehicles respectively. The generation of these 4 scenarios will allow to compare easily between them, drawing economic conclusion about which alternatives brings more benefits at a macro level. It will be assumed in all scenarios is that the number of Km traveled in Spain will remain constant. Although there may be a slightly increasing tendency of them, thanks to new business models such as carpooling by Blablacar, or carsharing implemented by Car to go and Emov among others, combined with the increase in urban population versus rural and the increase of the use of Public transport, suggest it is an accurate hypothesis.

The second tool has been designed to carry out analysis at a micro level. This tool allows to generate scenarios on the total cost of each type of vehicle throughout its useful life. This tool takes into account all the expenses associated with the purchase of the vehicle, from the purchase cost to the cost of fuel consumed or the vehicle maintenance. For this, the tool will generate many sub-scenarios, which will result in two opposite scenarios, one in which the Government does not give any type of aid to promote the introduction of less polluting alternatives "business as usual" these will be business as usual and the other scenario it would be the decarbonization path, in which the Government would invest money in aid to promote the vehicles with little pollution as if in the implementation of its refueling structure. This analysis will allow economic conclusions to be drawn at a micro level from the different alternatives.

1.5 RESOURCES

As it has been commented previously, to carry out this senior project, it will be used two Excel tools. The first one, developed by the OVEMS, allows the generation of various scenarios towards a less polluting mobility. Based on the results obtained, the impact of the possible strategies followed will be analyzed. The outputs obtained thanks to the use of this tool will allow to draw conclusions about what strategies should be implemented in the medium and long term. For a better understanding of this tool, its way of operation will be briefly explained. First of all, you have to define the long-term car strategy (2050), each scenario will involve a different strategy. The Excel tool has a sigmoid program, which will automatically calculate the number of vehicle registrations for each fuel each year. This sigmoidal will have 2 variables with which it can be modified. The year in which it is centered and its slope, depending of those values, it is possible to control whether the strategy followed is more or less aggressive. A decrease will make it similar to a step (*Figure 10*) while an increase in the slope will transform the sigmoid into a straight line (*Figure9*).The purpose of showing two samples scenarios is to demonstrate how the Excel tool works, changing the inputs generates different outputs and scenarios, rather than showing the analyzed ones.

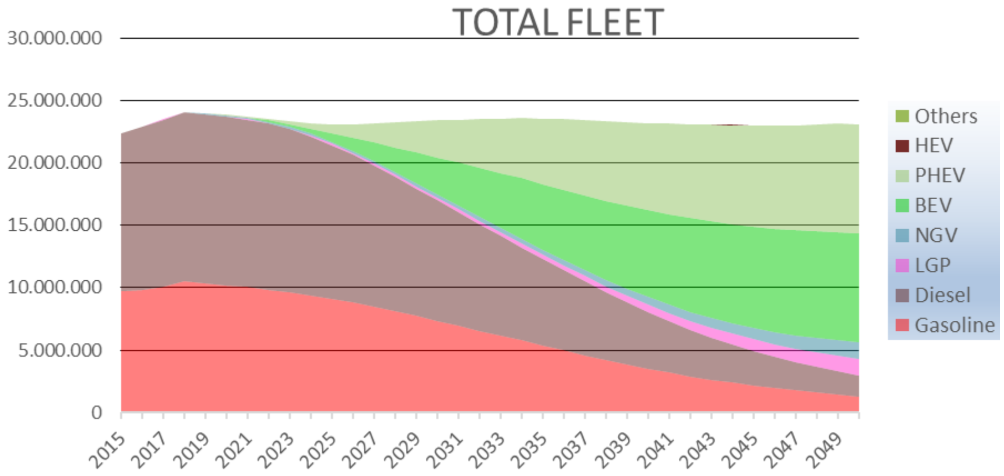


Figure 10: Sample Scenario showing Diminishing returns (Own source)

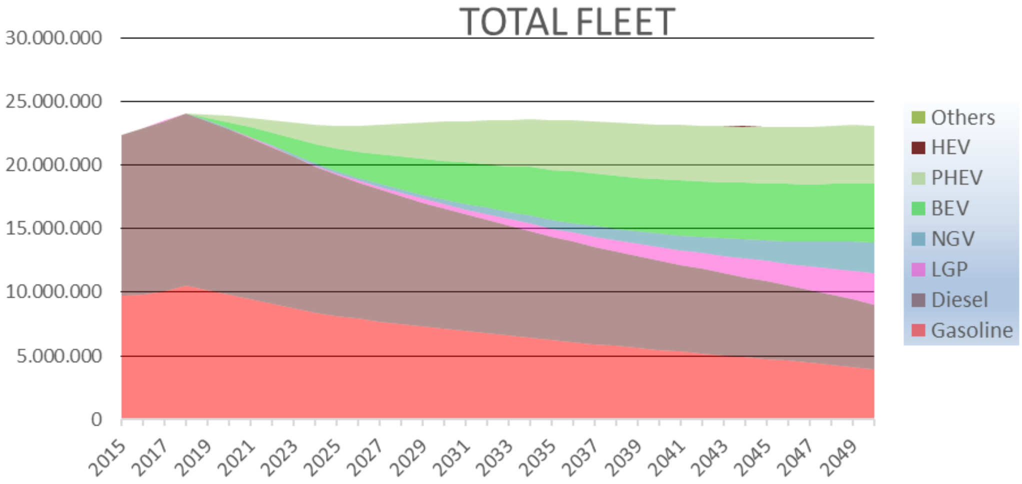


Figure 9:Sample straight-line Scenario (Own source)

The objective of this project is not to develop said tool, but to rely on it to analyze strategies. Therefore, its operation will not be explained in detail, but the inputs and outputs will be briefly explained.

Inputs:

- Types of low-recycling fuels (HEV, PHEV, BEV, NGV, LGP and others)
- Total number of Km traveled per year (assumption to be constant), it will be taken into account both the year of registration and the effect of antiquity.
- The percentage of long-term sales of each fuel (in 2050)
- Consumption ratios per fuel type and its evolution over the time.
- Emission ratios per fuel type and its evolution over the time.

Outputs per year:

- CO_2 emissions
- NO_x emissions
- Total energy consumption, distinguishing between tank to wheel (T2W), well to tank(W2T) and well to wheel Total fleet structure(W2W)
- Particles emissions PM_{10}
- Total fleet
- Total cost associated with the park

Regarding the second tool used in this project, its aim is to analyze the different fuel alternatives and measures its impact in the economy at a micro level. This tool simulate different scenarios about how will evolve the prices, consumptions, and efficiencies of each of the vehicle alternatives. Once again, it will be briefly explained which variables are used in the tool.

Inputs:

- Purchase price per vehicle type depending on the year

- Fuel cost depending on the year
- Average consumption depending on the purchase year and antiquity
- Maintenance cost per year, also including the vehicle insurance
- Life expectancy of the vehicle
- Real interest
- Km covered per year

Outputs:

- Total cost over vehicle’s life

Figure 11 shows a graph showing the two scenarios mentioned above. The business as usual scenario would correspond to the continuous lines (which is the maximum value since the package of aid provided would be minimal) while the dotted line would be the decarbonization route of road transport. This graph has been calculated for a life expectancy of the vehicle of 15 years and would have been purchased in 2025, that is, it would have given time for the possible aid package to have been implemented. It is one of the multiple simulations made at the Micro analysis. While *Figure 12* shows a graph which represents the Total cost of the Base Scenario, analyzed at the Macro level in chapter 5. It has been decided to show, to get an idea of the studies made at this project, and it will help to understand why it

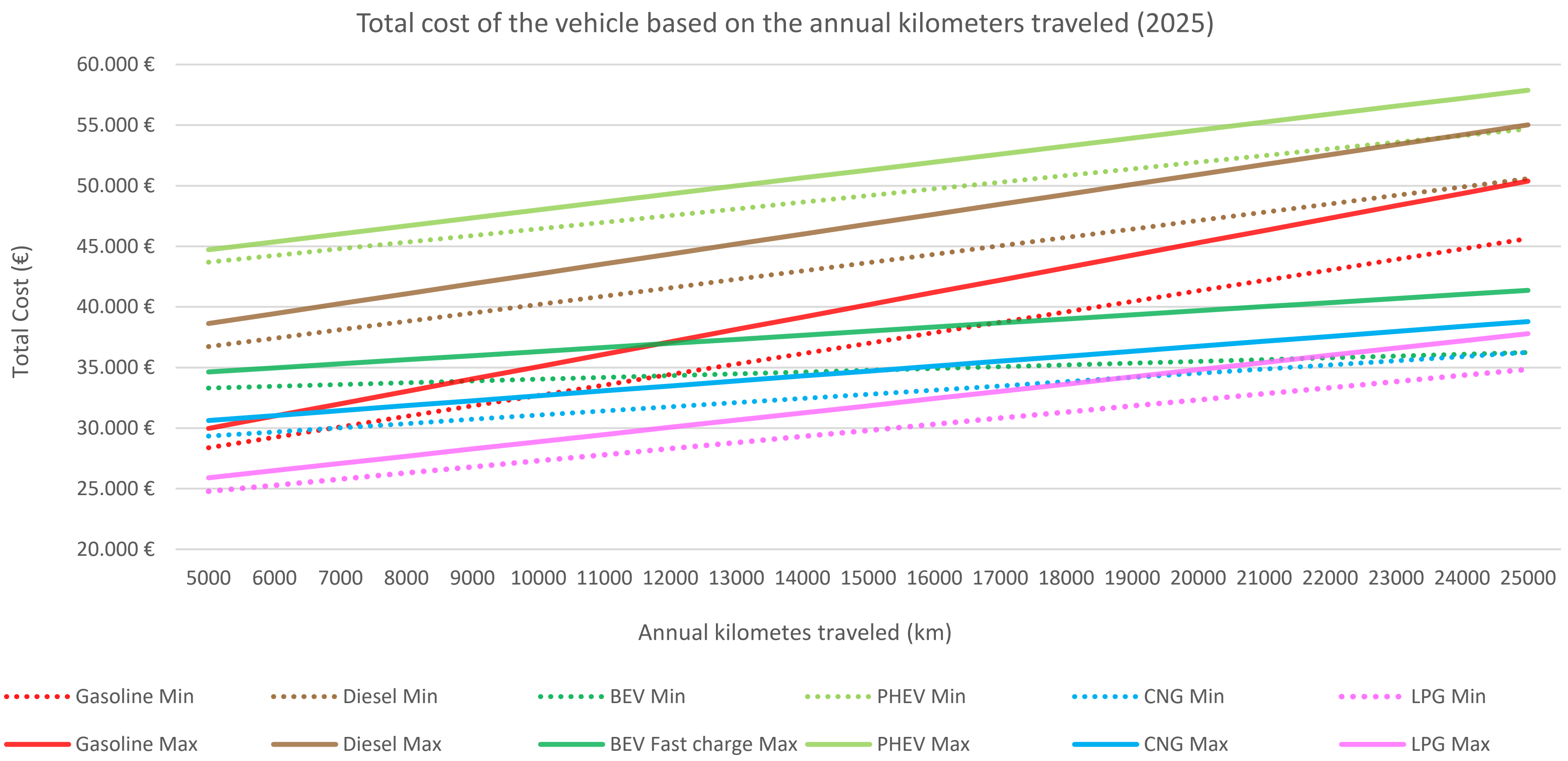


Figure 11: Total cost of a vehicle bought in 2025 and with a life expectancy of 15 years old (Own source)

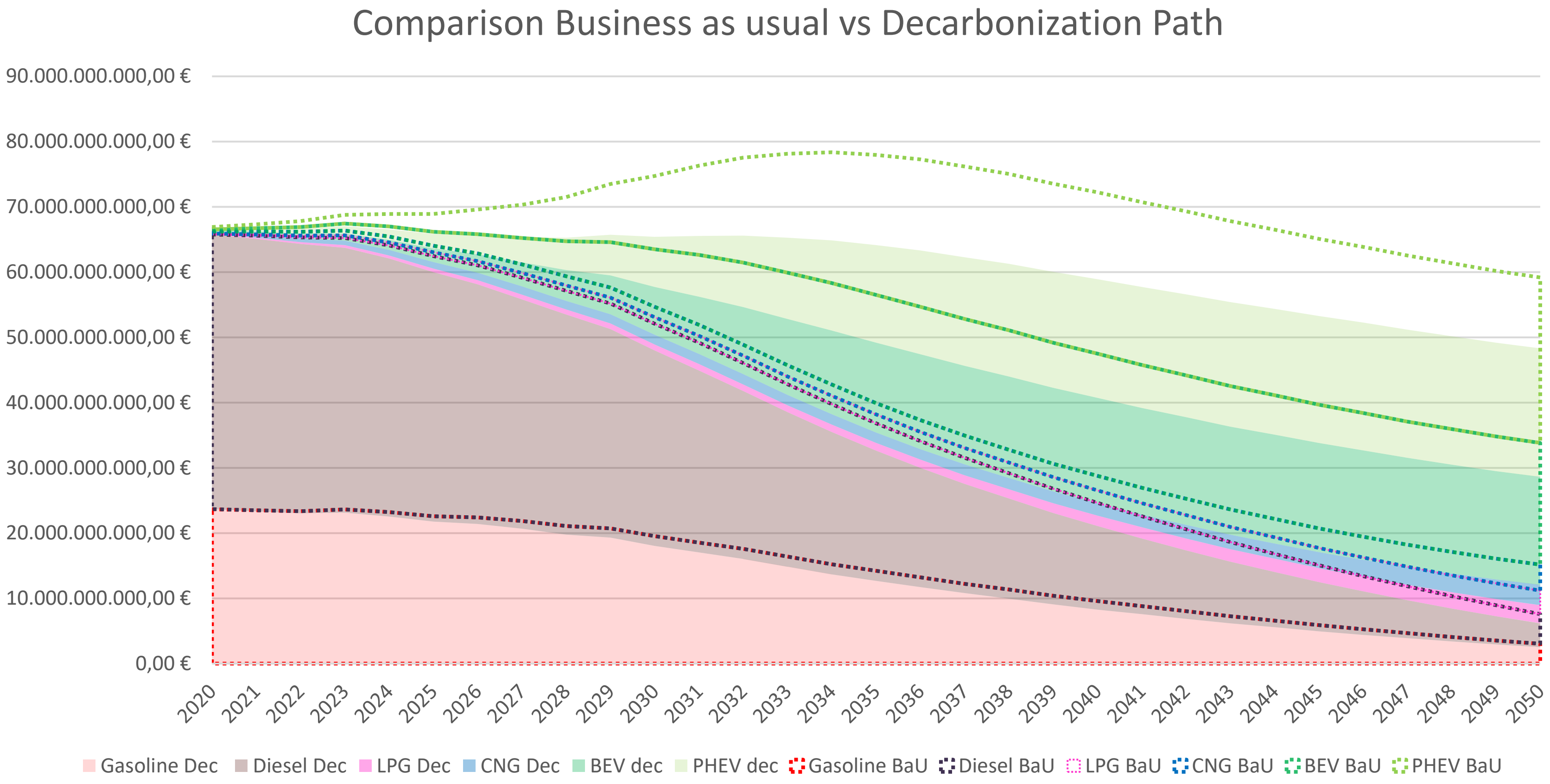


Figure 12: Total cost comparison Business as usual vs Decarbonization Path, base scenario (Own source)

CHAPTER 2: EMISSIONS REGULATIONS

Air pollution is a local as well as a global problem caused by the emission of certain substances that, either by themselves, or by those resulting from their chemical reactions, cause harmful effects on the environment and health.

As can be seen in *figure 14*, urban air pollution is a serious problem in many of the large Spanish cities. The intense and incessant traffic, together with factories that do not control their emissions, turns the air of the big cities not only from Spain, but from all over the world into real clouds of contamination. Sometimes even the pollutant levels can exceed the limits of safety for human health set by the WHO.

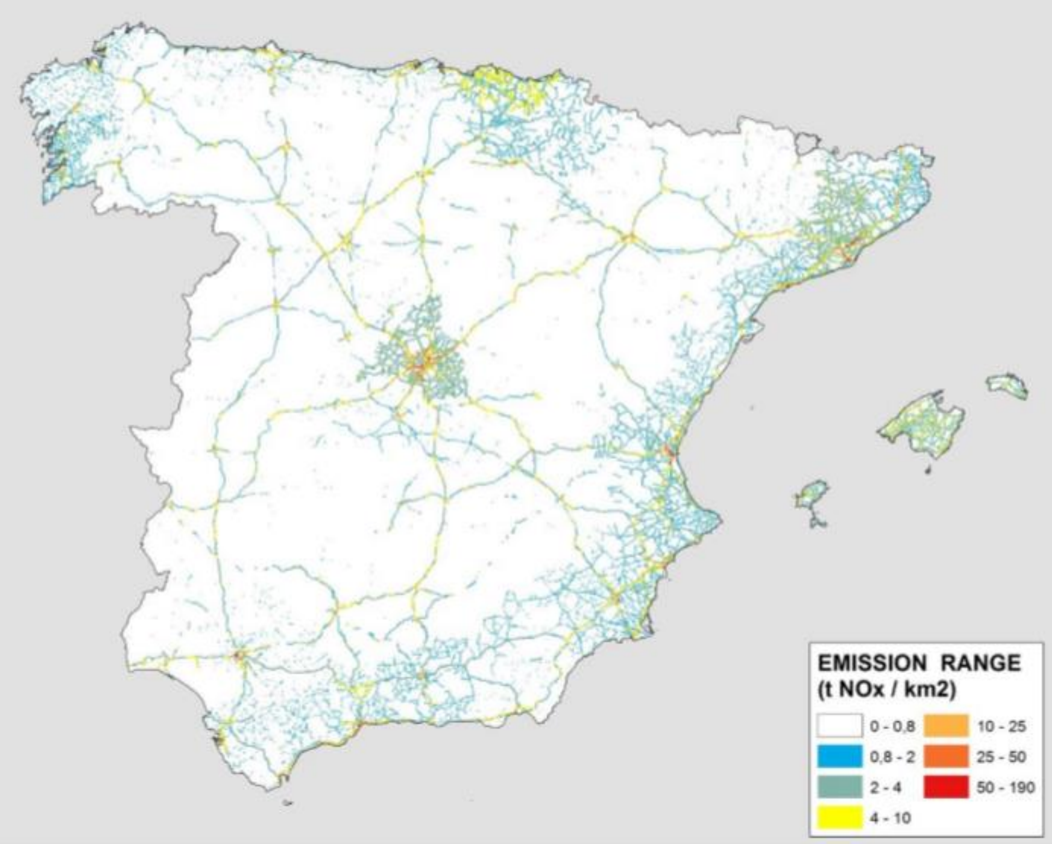


Figure 13: Road Transport Emissions spatial distribution in Spain (Source: [40])

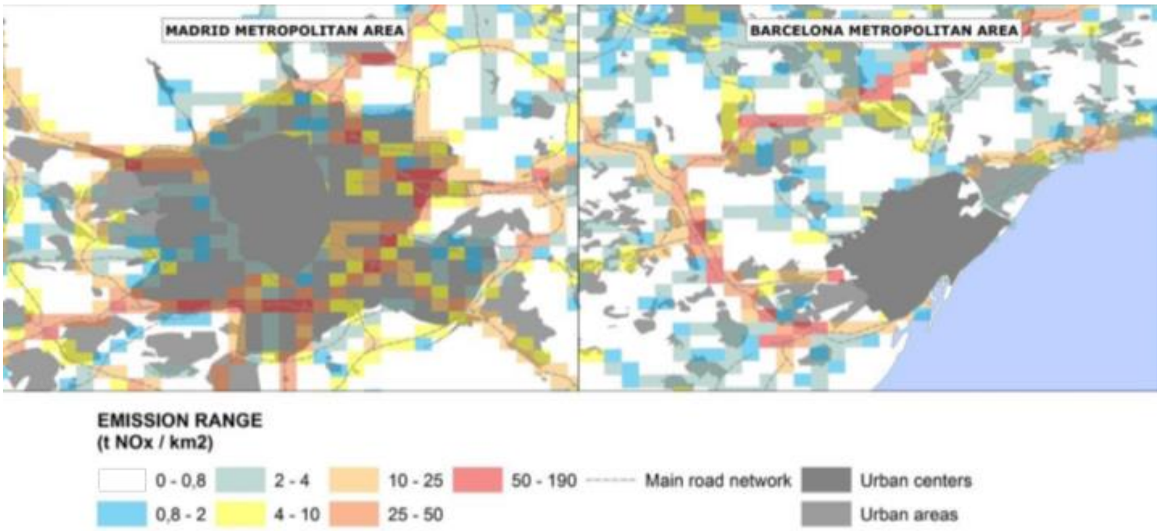


Figure 14:Road Transport Emissions spatial distribution in the two biggest cities of Spain (Source: Informative Inventory Report [33])

Europe, including also Spain, presents a problem in terms of pollution and energy dependence. For this reason, there has been a concern on the country for several decades to reduce the emissions associated with the fuel used in transport sector. According to the Ministry of Ecological Transition [7], Transport was responsible for 30.3 % of CO_2 equivalent emitted into the air in Spain. Road and domestic air transport are the biggest contributors to emissions, therefore it is a sector of major interest when seeking to reduce the emission of pollutants and greenhouse gases (GHG).

This concern was translated into the creation of different regulations which will be briefly explained in this study. At European level, two different types of norms can be distinguished:

a) Regulations: A "regulation" is a binding legislative act the European Union that becomes immediately enforceable as law in all member states simultaneously.

b) Directives: A "directive" is a legislative act that sets out a goal that all EU countries must achieve. However, it is up to the individual countries to devise their own laws on how to reach these goals.

Due to there are norms emitted by the European Union and also by the Spanish Government, it is convenient to analyze these policies first at the both levels, first at the European level and then focus on Spain as the country of application of this legislation. Firstly, it will be analyzed the set of regulations to improve air quality applied by European authorities since 2007, it was when European Commission started taking this issue seriously. The following table *(Table 2)* shows the measures adopted which affect directly to the transport sector, it will be explained their new restrictions, emphasizing those related to the "EURO Standards", which sets the maximum values of toxic pollutants emitted by each type of vehicle. The directive on the development of alternative fuels (DAFI) will also be analyzed, which highlights the enormous concern about the problem of energy dependence, both for economic and security reasons.

As mentioned before, the objective of this chapter is not to analyze in depth the directives related to vehicles, but to briefly introduce their existence and impact on this thesis. For this, this chapter has been based on the work done by my colleague José González Perez [3]a couple of years ago, updating and completing in case any of the directives were necessary.

Table 6:Summary of the main relevant European legislation on Road Transport (Source:European Union Law, Eur-Lex)

Norms	Year	Object
Regulation EC No 715/2007	2007	It stablishes the type approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information.
Directive 2008/50/EC	2008	It sets out measures for the assessment of ambient air quality in Member States as well as for obtaining information on ambient air quality in order to help combat air pollution and nuisance. The Directive

		aims at increasing cooperation between the Member States in reducing air pollution.
Regulation EC No 692/2008 implementing and amending Regulation EC No 715/2007	2008	Amends Regulation No 715/2007, referring to type-approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information.
Regulation EC No 443/2009	2009	Setting emission performance into 130 g of CO_2/km standards for new passenger cars as part of the Community's integrated approach to reduce CO_2 emissions from light-duty vehicles.
Regulation EC No 443/2009	2010	Specify components of motor vehicles using compressed natural gas (CNG) in their propulsion system and its maximum life.
Regulation EC No 510/2011	2011	Setting emission performance standards into 175 g of CO_2/km for new light commercial vehicles as part of the Union's integrated approach to reduce CO_2 emissions from light-duty vehicles.
Regulation EU No 253/2014 amending Regulation EC No 510/2011	2011	Define the modalities for reaching the 2020 target to reduce CO_2 emissions from new light commercial vehicles, setting into 147 g of CO_2/km.
Regulation EU No 333/2014 amending Regulation EC No 443/2009	2014	Define the modalities for reaching the 2020 target to reduce CO_2 emissions from new passenger cars, setting into 95 g of CO_2/km.
Directive 2014/94/EU (DAFI)	2014	On the deployment of alternative fuels infrastructure in order to minimize dependence on oil

		transportation and mitigate the environmental impact of transportation.
Regulation EU 2016/427 amending Regulation EC No 692/2008	2016	Regards emissions from light passenger and commercial vehicles (Euro 6)
Regulation EU 2018/956	2018	On the monitoring and reporting of CO_2 emissions from and fuel consumption of new heavy-duty vehicles
Regulation EU 2019/1242 amending Regulations EC No 595/2009 and EU 2018/956	2019	Setting CO_2 emission performance standards for new heavy-duty vehicles.
Regulation (EU) 2019/631 repealing Regulations (EC) No 443/2009 and (EU) No 510/2011	2019	Setting CO_2 emission performance standards for new passenger cars and for new light commercial vehicles. The targets are defined as a percentage reduction from the 2021 starting points, in the case of cars, 15% reduction from 2025 onwards and 37.5% reduction from 2030 onwards

2.1 DIRECTIVE ON THE DEPLOYMENT OF ALTERNATIVE FUELS INFRASTRUCTURE (DAFI)

Due to on this project are used some scenarios using low polluting alternatives, it is of great interest analyzing the Directive 2014/94/EU of the European Parliament and of the council of 22 October 2014 on the deployment of alternative fuels infrastructure, commonly known as DAFI. It establishes a common framework of measures for the deployment of alternative fuels infrastructure in the European Union in order to minimize dependence on oil and to mitigate the environmental impact of transport. This Directive sets out minimum requirements for the building-up of alternative fuels infrastructure, including recharging points for electric vehicles and refueling points for natural gas (LNG and CNG) and hydrogen, to be implemented by means of Member States' national policy frameworks, as well as common technical specifications for such recharging and refueling points, and user information requirements. As previously mentioned, being a directive requires a transposition into national regulations. In Spain, it was included in the National Action Framework (Marco de Acción Nacional), approved by the Council of Ministers in 2016.

Based on these premises, the directive determines that an adequate number of charging points for electric vehicles must have been guaranteed in 2020.

2.2 CO_2 EMISSIONS REGULATIONS

In this section, it will be analyzed the evolution of the regulations designed by the European Union regarding CO_2 emissions in passenger cars, light commercial vehicles and heavy-duty vehicles.

2.2.1 PASSENGER CARS:

Initially, the CO_2 emission limits were reached through agreements between the EU and the European Association of Automobile Manufacturers (ACEA). Along these lines, an agreement was announced in 1998 that sought to limit the average CO_2 emissions of new passenger cars to 140 g/km by 2008, which meant reducing emissions by 25%. This agreement was part of the European strategy to reduce emissions to 120 g/km in 2012. However, this way of proceeding was not as effective as thought at first, and the EU legislators modified the way to attack the problem, starting to use Regulations such as Regulation EC 443/2009 as the way of achieving the aforementioned objectives.

This Regulation set at 130 g of CO_2 / km the average emissions of new passenger cars from all manufacturers, through the improvement of technology of vehicle engines to be achieved in 2015. The results obtained thanks to this norm were much better than what it was expected, achieving a decrease from 160 g/km in 2006 to 132 g/km in 2012, reaching the goal 3 years earlier than expected.

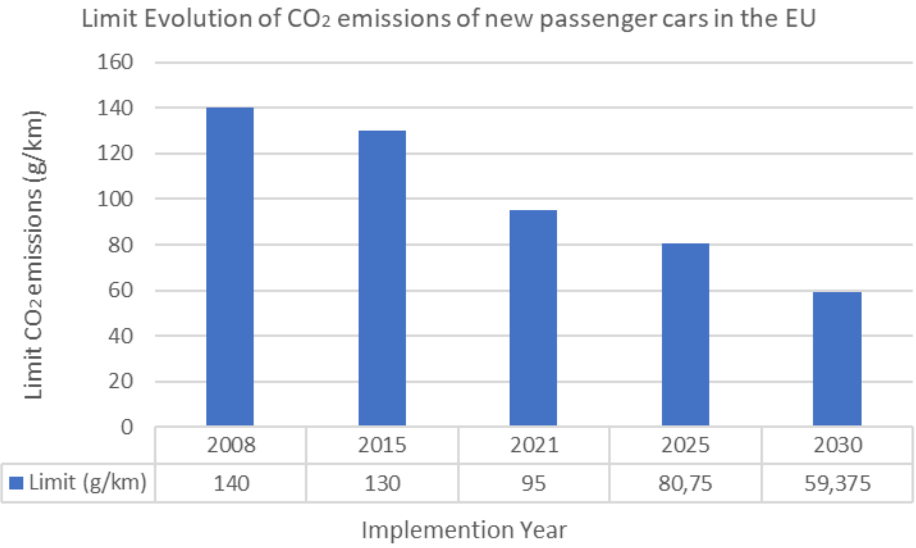
In view of the great effect of this regulation, and in line with the aim of reducing transport pollution, Regulation EC 333/2014 was formulated, which, modifying the 2009 Regulation, established a new limit of 95 g / km for the year 2020.

It is important to underline that compliance with the all these Regulations, is measured by the New European Driving Cycle (NEDC) driving model. This test was designed in the 1980s, and last updated in 1997. It is based on a first circuit load test, in which the aerodynamic resistance, rolling resistance and mechanical losses of the car are measured, and a subsequent laboratory test in which they are simulated different operating conditions of the vehicle in order to calculate the emissions produced.

This test system has been severely criticized due to the inability to simulate real operating conditions, resulting in measured emissions during the test which, according to the study "FROM LABORATORY TO ROAD: A 2015 update of official and real – world fuel consumption and CO2 values for Passenger cars in Europe" [8] of the International Council on Clean Transportation (ICCT), were in 2014 40% lower than the real ones. Another problem associated with this test is that, when it is carried out in the laboratory under stipulated and previously known conditions, it is not simulated the reality of driving, and encourages the creation of instruments that alter vehicle emissions under the test conditions. so they could be minimized. In this line, the scandal known as "Dieselgate" was uncovered in 2015, in which several manufacturers' Volkswagen Group included software in their models that detected the moment in which the vehicle was being subjected to Official emissions tests and then changed the engine controls to minimize emissions during the test. This meant that this company had tremendous losses, had to pay $ 17.5 billion as compensation to vehicle owners and dealers, and a fine of $ 4,300 million to the American government. Added to the huge stock market crash it suffered and the loss of prestige of the firm.

As a result, the European Commission (EC) presented a new legislative proposal that established the Worldwide Harmonized Light Test Procedure (WLTP) to replace of NEDC as the vehicle homologation procedure, it was introduced in September of that year. This global test determines harmonized standards for the pollution level, fuel consumption and CO_2 emissions of every type of passenger's cars, including also low polluting fuels alternatives.

In 2019, the European Union presented a new regulation Regulation (EU) 2019/6311 establishing a new reduction of 15% from 2025 onwards and 37.5% reduction from 2030 onwards on the emission performance standards for new passenger cars and for new light commercial vehicles.



	2008	2015	2021	2025	2030
Limit (g/km)	140	130	95	80,75	59,375

Figure 15:Limit Evolution of CO2 emissions of new passenger cars in the European Union (Own source)

2.2.2 LIGHT COMMERCIAL VEHICLES:

The regulations applied to the new light commercial vehicles (vans and trucks) are similar, in terms of form, to the regulations applied to passenger cars. In this case, regulation takes longer to be introduced. In 2011, Regulation EC 510/2011 was introduced, on it, the average emissions of new light commercial vehicles were set at 175 g of CO_2/km "through the improvement of vehicle technology", to be achieved in 2017 or before. As it happens to passenger cars, the measure was a success, reaching an average emission of 163.7 g of CO_2/km in 2017. In line with the reduction emissions trend, the European Commission established a new Regulation 253/2014, by which the new limit was set to 147 g of CO_2 / km for the year 2020, representing a reduction of nearly a 20% compared to the average emissions of the year 2012.

As mentioned in the section on passenger cars, and due to the achieved ambitious objectives, in November 2019 was announced a legislative proposal by the European Commission that seeks to reduce emissions from both passenger cars and light commercial vehicles by 15% by 2025 and by 37.5% by 2030. Thus, the maximum CO2 emissions would be limited to 125 g of CO2/km in 2025 and 92 g of CO2/km in 2030.

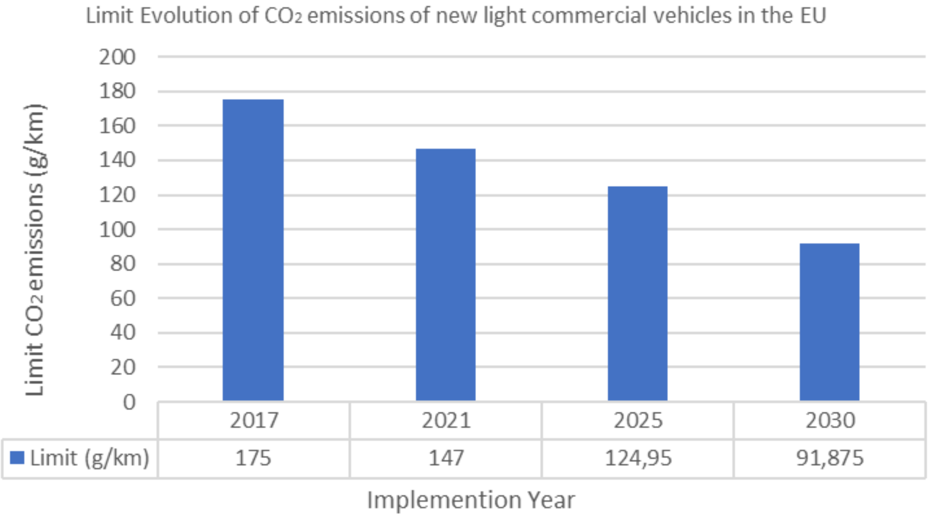


Figure 16:Limit Evolution of CO2 emissions of new light commercial vehicles in the European Union (Own source)

2.2.3 HEAVY-DUTY VEHICLES:

According to the European Commission [9] a quarter of the total amount of GHG produced by road transport, are responsible the trucks, buses, lorries and coaches. For this reason, they cannot be exempt from the legislation, and there has been also regulated at the European Level. Since the previous century, certain emissions of toxic pollutants have been controlled by regulations that have been gradually tightening (EURO Standards), but due to the lack of knowledge or controlling tools on that time, CO_2 was not part of those controls.

While cars are mass-produced and share most of their characteristics, sometimes even in different models, heavy vehicles are adapted to the specific needs and requirements of carriers, so each vehicle is different, making it difficult to measure emissions. In order to overcome these difficulties, the European commission developed in 2014 a simulation tool called Vehicle Energy Consumption Calculation Tool (VECTO), which has the support of manufacturers and is designed to calculate emissions based on vehicle specifications. The main advantage of this tool is that it manages to overcome the expensive road tests that all manufacturers opposed. This tool apart from analyzing five different emissions profiles for both buses and trucks, it also determines the power consumption of every relevant vehicle component.

In the words of the EC: “Monitoring, reporting and verification are the short-term priorities to close the knowledge gaps and create a reliable reference. In the medium term, the Commission will evaluate additional measures; for example, the definition of mandatory CO_2 limits for new heavy vehicles or the introduction of market mechanisms."

On 20 November 2017, a consultation was opened that offers citizens the opportunity to express their views on possible EU measures to reduce CO_2 emissions. Two years later, the European Union came up with a new regulation, Regulation (EU) 2019/1242 setting CO_2 emission standards for heavy-duty and a mechanism to incentivize the uptake of zero- and low-emission vehicles, in a technology-neutral way.

From 2025 on, manufacturers will have to meet the targets set a 15% reduction for the fleet-wide average CO2 emissions of their new lorries registered in a given calendar year. Stricter targets will start applying from 2030 on, which will be set a reduction of 30% compared to 2020 emissions.

2.3 EURO STANDARDS

As it happened with CO_2 emissions, there has been legislation since 1992 to limit emissions of toxic pollutants for passenger cars, light commercial vehicles and heavy-duty vehicles. They are known as Euro 1, 2, 3, 4, 5 and 6 for light commercial vehicles and passenger cars and Euro I, II, III, IV, V and VI for heavy vehicles. Since the launch of the Standards until now there has been carried out several updates, generally each 4 years. These updating has supposed a reduction in the limits for the emission of regulated pollutants: carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_X) and Particles (PM_x). It should be noted that until the year 2000, HC and NO_X were established at a common value to be evaluated separately from that year on.

Within each regulation, the specific pollutants to be reduced, the evaluation method and the limits for compliance vary for the different classes of vehicles and fuels used, differentiating diesel and gasoline passenger cars and light commercial vehicles from heavy-duty vehicles. Light commercial vehicles, Category N1, are further divided into three weight classes of less than 3.5 tons, are subcategories N1-I, N1- II and N1-III. This classification is based on the Reference Mass, defined as the mass of the vehicle in running order less the uniform mass of the driver of 75 kg, and increased by a uniform mass of 100 kg.

Table 7:Vehicles Category N1 - Weight classes (Source: TransportPolicy.net)

Class	Reference Mass, RW	
	Euro 1-2	**Euro 3,4,5,6**
I	RW ≤ 1250 kg	RW ≤ 1305 kg
II	1250 kg < RW ≤ 1700 kg	1305 kg < RW ≤ 1760 kg
III	1700 kg < RW	1760 kg < RW

For its part, the emissions regulation of heavy diesel motor vehicles, those dedicated to the transport of goods that exceed 3500 kg of PBV, although it evaluates the same pollutants as for the rest of diesel vehicles, the test procedures used and the way of measuring them are different, so they are not comparable.

In the following tables will be shown the emissions standards for each the mentioned categories. While for light commercial vehicles and passenger cars the emission limits are expressed in g/km, in the case of heavy vehicles they are expressed in g/kWh of energy produced by the engine.

Table 8: EU emission standards for passenger cars (Category M1) Source: Dieselnet [10]*

Stage	**Date**	**CO**	**HC**	**HC+NOx**	**NOx**	**PM**	**PN**
				g/km			#/km
Positive Ignition (Gasoline)							
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	-	-
Euro 2	1996.01	2.2	-	0.5	-	-	-
Euro 3	2000.01	2.30	0.20	-	0.15	-	-
Euro 4	2005.01	1.0	0.10	-	0.08	-	-
Euro 5	2009.09b	1.0	0.10d	-	0.06	0.005e,f	-
Euro 6	2014.09	1.0	0.10d	-	0.06	0.005e,f	6.0×1011 e,g
Compression Ignition (Diesel)							
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	0.14 (0.18)	-
Euro 2, IDI	1996.01	1.0	-	0.7	-	0.08	-
Euro 2, DI	1996.01a	1.0	-	0.9	-	0.10	-
Euro 3	2000.01	0.64	-	0.56	0.50	0.05	-
Euro 4	2005.01	0.50	-	0.30	0.25	0.025	-
Euro 5a	2009.09b	0.50	-	0.23	0.18	0.005f	-
Euro 5b	2011.09c	0.50	-	0.23	0.18	0.005f	6.0×1011
Euro 6	2014.09	0.50	-	0.17	0.08	0.005f	6.0×1011

** At the Euro 1..4 stages, passenger vehicles > 2,500 kg were type approved as Category N1 vehicles*
† Values in brackets are conformity of production (COP) limits
a. until 1999.09.30 (after that date DI engines must meet the IDI limits)
b. 2011.01 for all models
c. 2013.01 for all models
d. and NMHC = 0.068 g/km
e. applicable only to vehicles using DI engines
f. 0.0045 g/km using the PMP measurement procedure
g. 6.0×1012 1/km within first three years from Euro 6 effective dates

Table 9:EU emission standards for light commercial vehicles (Source:Dieselnet [10])

	Stage	**Date**	**CO**	**HC**	**HC+NOx**	**NOx**	**PM**	**PN**
					g/km			#/km
Positive Ignition (Gasoline)								
N_1, Class I ≤1305 kg	Euro 1	1994.10	2.72	-	0.97	-	-	-
	Euro 2	1997.01	2.2	-	0.50	-	-	-
	Euro 3	2000.01	2.3	0.20	-	0.15	-	-
	Euro 4	2005.01	1.0	0.10	-	0.08	-	-
	Euro 5	2009.09[b]	1.0	0.10[g]	-	0.06	0.005[e,f]	-
	Euro 6	2014.09	1.0	0.10[g]	-	0.06	0.005[e,f]	6.0×10^{11} [e,j]
N_1, Class II 1305-1760 kg	Euro 1	1994.10	5.17	-	1.40	-	-	-
	Euro 2	1998.01	4.0	-	0.65	-	-	-
	Euro 3	2001.01	4.17	0.25	-	0.18	-	-
	Euro 4	2006.01	1.81	0.13	-	0.10	-	-
	Euro 5	2010.09[c]	1.81	0.13[h]	-	0.075	0.005[e,f]	-
	Euro 6	2015.09	1.81	0.13[h]	-	0.075	0.005[e,f]	6.0×10^{11} [e,j]
N_1, Class III >1760 kg	Euro 1	1994.10	6.90	-	1.70	-	-	-
	Euro 2	1998.01	5.0	-	0.80	-	-	-
	Euro 3	2001.01	5.22	0.29	-	0.21	-	-
	Euro 4	2006.01	2.27	0.16	-	0.11	-	-
	Euro 5	2010.09[c]	2.27	0.16[i]	-	0.082	0.005[e,f]	-
	Euro 6	2015.09	2.27	0.16[i]	-	0.082	0.005[e,f]	6.0×10^{11} [e,j]
N_2	Euro 5	2010.09[c]	2.27	0.16[i]	-	0.082	0.005[e,f]	-
	Euro 6	2015.09	2.27	0.16[i]	-	0.082	0.005[e,f]	6.0×10^{11} [e,j]
Compression Ignition (Diesel)								
N_1, Class I ≤1305 kg	Euro 1	1994.10	2.72	-	0.97	-	0.14	-
	Euro 2 IDI	1997.01	1.0	-	0.70	-	0.08	-
	Euro 2 DI	1997.01[a]	1.0	-	0.90	-	0.10	-
	Euro 3	2000.01	0.64	-	0.56	0.50	0.05	-
	Euro 4	2005.01	0.50	-	0.30	0.25	0.025	-
	Euro 5a	2009.09[b]	0.50	-	0.23	0.18	0.005[f]	-
	Euro 5b	2011.09[d]	0.50	-	0.23	0.18	0.005[f]	6.0×10^{11}
	Euro 6	2014.09	0.50	-	0.17	0.08	0.005[f]	6.0×10^{11}

Category†	Stage	Date	CO	HC	HC+NOx	NOx	PM	PN
					g/km			#/km
N_1, Class II 1305-1760 kg	Euro 1	1994.10	5.17	-	1.40	-	0.19	-
	Euro 2 IDI	1998.01	1.25	-	1.0	-	0.12	-
	Euro 2 DI	1998.01[a]	1.25	-	1.30	-	0.14	-
	Euro 3	2001.01	0.80	-	0.72	0.65	0.07	-
	Euro 4	2006.01	0.63	-	0.39	0.33	0.04	-
	Euro 5a	2010.09[c]	0.63	-	0.295	0.235	0.005[f]	-
	Euro 5b	2011.09[d]	0.63	-	0.295	0.235	0.005[f]	6.0×10^{11}
	Euro 6	2015.09	0.63	-	0.195	0.105	0.005[f]	6.0×10^{11}
N_1, Class III >1760 kg	Euro 1	1994.10	6.90	-	1.70	-	0.25	-
	Euro 2 IDI	1998.01	1.5	-	1.20	-	0.17	-
	Euro 2 DI	1998.01[a]	1.5	-	1.60	-	0.20	-
	Euro 3	2001.01	0.95	-	0.86	0.78	0.10	-
	Euro 4	2006.01	0.74	-	0.46	0.39	0.06	-
	Euro 5a	2010.09[c]	0.74	-	0.350	0.280	0.005[f]	-
	Euro 5b	2011.09[d]	0.74	-	0.350	0.280	0.005[f]	6.0×10^{11}
	Euro 6	2015.09	0.74	-	0.215	0.125	0.005[f]	6.0×10^{11}
N_2	Euro 5a	2010.09[c]	0.74	-	0.350	0.280	0.005[f]	-
	Euro 5b	2011.09[d]	0.74	-	0.350	0.280	0.005[f]	6.0×10^{11}
	Euro 6	2015.09	0.74	-	0.215	0.125	0.005[f]	6.0×10^{11}

† For Euro 1/2 the Category N1 reference mass classes were Class I ≤ 1250 kg, Class II 1250-1700 kg, Class III > 1700 kg

a. until 1999.09.30 (after that date DI engines must meet the IDI limits)
b. 2011.01 for all models
c. 2012.01 for all models
d. 2013.01 for all models
e. applicable only to vehicles using DI engines
f. 0.0045 g/km using the PMP measurement procedure
g. and NMHC = 0.068 g/km
h. and NMHC = 0.090 g/km
i. and NMHC = 0.108 g/km
j. 6.0×1012 1/km within first three years from Euro 6 effective dates

Table 10:EU emission standards for heavy-duty CI (diesel) and PI engines: Transient testing (Source:Dieselnet [8])

Stage	**Date**	**Test**	**CO**	**NMHC**	**CH$_4$**[a]	**NOx**	**PM**[b]	**PN**
					g/kWh			*1/kWh*
Euro III	1999.10 EEV only	ETC	3.0	0.40	0.65	2.0	0.02	
	2000.10		5.45	0.78	1.6	5.0	0.16[c]	
Euro IV	2005.10		4.0	0.55	1.1	3.5	0.03	
Euro V	2008.10		4.0	0.55	1.1	2.0	0.03	
Euro VI	2013.01	WHTC	4.0	0.16[d]	0.5	0.46	0.01	6.0×10^{11}[e]

Table 11:EU emission standards for heavy-duty CI (diesel) engines: Steady-state testing (Source:Dieselnet [8])

Stage	**Date**	**Test**	**CO**	**HC**	**NOx**	**PM**	**PN**	**Smoke**
				g/kWh			1/kWh	1/m
Euro I	1992, ≤ 85 kW	ECE R-49	4.5	1.1	8.0	0.612		
	1992, > 85 kW		4.5	1.1	8.0	0.36		
Euro II	1996.10		4.0	1.1	7.0	0.25		
	1998.10		4.0	1.1	7.0	0.15		
Euro III	1999.10 EEV only	ESC & ELR	1.5	0.25	2.0	0.02		0.15
	2000.10		2.1	0.66	5.0	0.10a		0.8
Euro IV	2005.10		1.5	0.46	3.5	0.02		0.5
Euro V	2008.10		1.5	0.46	2.0	0.02		0.5
Euro VI	2013.01	WHSC	1.5	0.13	0.40	0.01	8.0×1011	

2.4 POLLUTANTS EMITTED BY VEHICLES

A number of different air pollutants and GHGs are emitted by road vehicles. In the words of the European Environment Agency [11] can be split into two groups: “those that are regulated under EU road transport legislation and those that presently are not.

1. The European Environment Agency include as 'regulated' pollutants:

a. Carbon dioxide (CO_2), which is the main product of fuel combustion in vehicle engines, along with water. CO_2 is the most significant GHG influencing climate change, posing a threat to public health and the environment.

b. Hydrocarbons (HCs), which are produced from either incomplete or partial combustion and which are toxic to human health. HCs, and particularly the volatile organic compounds (VOCs)[2], contribute to the formation of ground-level ozone and photochemical smog in the atmosphere. Ozone irritates the eyes, damages the lungs and aggravates respiratory problems.

c. Carbon monoxide (CO), a product of incomplete combustion, which occurs when the carbon in the fuel is only partially oxidized, forming CO and not CO_2. It is colorless and odorless but highly toxic. Direct exposure to CO reduces the flow of oxygen in the bloodstream and is particularly dangerous to people with heart disease. Like HCs, CO also contributes to the formation of ground-level ozone and smog.

d. Particulate matter (PM), which is a product of incomplete combustion and a complex mixture of both primary and secondary PM. 'Primary' PM is the fraction of PM that is emitted directly into the atmosphere, whereas 'secondary' PM forms in the atmosphere following the release of precursor gases (mainly sulfur dioxide (SO_2), nitrogen oxides (NO_X), ammonia (NH_3) and some VOCs). In terms of its potential to harm human health, PM is one of the most important pollutants, as it penetrates into sensitive regions of the respiratory system and can cause or aggravate cardiovascular and lung diseases and cancers.

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[2] Volatile organic compounds (VOCs) are organic chemicals that have a high vapor pressure at ordinary room temperature. Their high vapor pressure results from a low boiling point, which causes large numbers of molecules to evaporate or sublimate from the liquid or solid form of the compound and enter the surrounding air, a trait known as volatility.

   e. Nitrogen oxides (NO_X) (see also box on nitrogen emissions from motor vehicles), which constitute a group of different chemicals that are all formed by the reaction of nitrogen — the most abundant gas in air — with oxygen. NO_X comprises colorless nitric oxide (NO) and the reddish-brown, very toxic and reactive nitrogen dioxide (NO_2). NO_X emissions also lead to the subsequent formation of 'secondary' PM and ground-level ozone in the atmosphere, and cause harm to the environment by contributing to the acidification and eutrophication of waters and soils.

2. 'Non-regulated' pollutants are the ones emitted by vehicles that are not currently regulated by vehicle emission standards in the EU include: certain acidifying pollutants, such as NH_3 and SO_2 (although emissions of the latter are indirectly addressed via fuel quality legislation, which limits the amount of Sulphur permissible in fuels); certain carcinogenic and toxic organic pollutants, such as polycyclic aromatic hydrocarbons (PAHs), persistent organic pollutants (POPs), dioxins and furans; and heavy metals, such as lead, arsenic, cadmium, copper, chromium, mercury, nickel, selenium and zinc.

In addition, the report [11] makes another distinction between the types of emissions, in this case, it distinguishes according to the provenance of the emissions. Vehicles emissions can be categorized into three groups:

1. Exhaust emissions — the emissions produced primarily from the combustion of different petroleum products such as petrol, diesel, natural gas (NG) and liquefied petroleum gas (LPG). These fuels are mixtures of different hydrocarbons, i.e. compounds that contain hydrogen and carbon atoms. In a 'perfect' engine, oxygen in the air would react in a combustion process with all of the hydrogen in the fuel to form water and with all of the carbon in the fuel to form CO2, and the nitrogen in the air would remain unaffected. In reality, no combustion process is 'perfect'; thus, vehicle engines emit many different pollutants in addition to water and CO2. The

amount of each pollutant emitted is very dependent on the type of fuel used, e.g. whether a vehicle is diesel or petrol powered, and engine technology.

2. Abrasion emissions — the emissions produced from the mechanical abrasion and corrosion of vehicle parts. Abrasion is only important for PM emissions and emissions of some heavy metals. Significant levels of PM emissions can be generated from the mechanical abrasion of the vehicle's tires, brakes and clutch, the road surface wear or the corrosion of the chassis, bodywork and other vehicle components.
3. Evaporative emissions — the result of vapors escaping from the vehicle's fuel system. Evaporative emissions are important for only VOCs. Petrol fuel vapor contains a variety of different HCs, which can be emitted any time there is fuel in the tank, even when the vehicle is parked with its engine turned off.”

CHAPTER 3: TYPES OF VEHICLES PER FUEL

According to the Ministry for the Ecological Transition [3], transport sector generates approximately 27% of the greenhouse gases (GHG) emitted in Spain and more than 40% of the total nitrogen oxide emissions. In particular, passenger transport emitted 52 MteqCO2, 66% of the total transport sector, being private car the most polluting form of passenger transport.

The main problem in terms of emissions generated by the transport sector is that emissions occur in large urban centers at ground level, exposing large numbers of people to toxic effects. For example, 35% of the emissions of polluting elements are carried out on 5% of the surface and directly affects 60% of the Spanish population, causing, according to the European Environment Agency [12], 38,600 premature deaths attributable to $PM_{2.5}$, NO_2 and O_3 exposure in Spain in 2015.

Petroleum fuels are accused of being the main cause of transport pollution. Until now, these fuels have dominated the transport sector during the last decades. The reason for their hegemony resides in the advantages that they provide in autonomy and at the purchase price compared to others alternative fuels, whose development still are premature. However, despite continuing to dominate the market, new technologies are beginning to develop, and with it questions about their benefits and whether or not there will be a time when they dominate the transport sector.

This chapter will carry out a detailed study on vehicles with conventional internal combustion engines (ICE), diesel and gasoline, and also on low polluting alternatives fuels, BEV (battery electric vehicle), NGV (natural gas vehicle), PHEV (plug-in hybrid electric vehicle) and LPG (liquefied petroleum gas). Despite the fact that there are a greater number of low polluting fuel alternatives, HEV (Hybrid Electric Vehicle), H2 (Hydrogen Vehicle) and LNG (Liquid Natural Gas Vehicle) among others, they will be left out of the study scenarios since they have decided to use the most implemented in Spain in the study and reduce their emissions to a greater extent.

In this chapter will have a special interest both knowing the emission levels of the different pollutants emitted by each fuel and knowing the cost associated with it, upfront purchasing price and cost per 100 km travelled among others. *Figure 18* illustrates the CO2 emissions of different types of fuels, taking into account not only the tank-to-wheel fuel cycle, but also the well-to-tank fuel cycle andthe vehicle's recyclability.

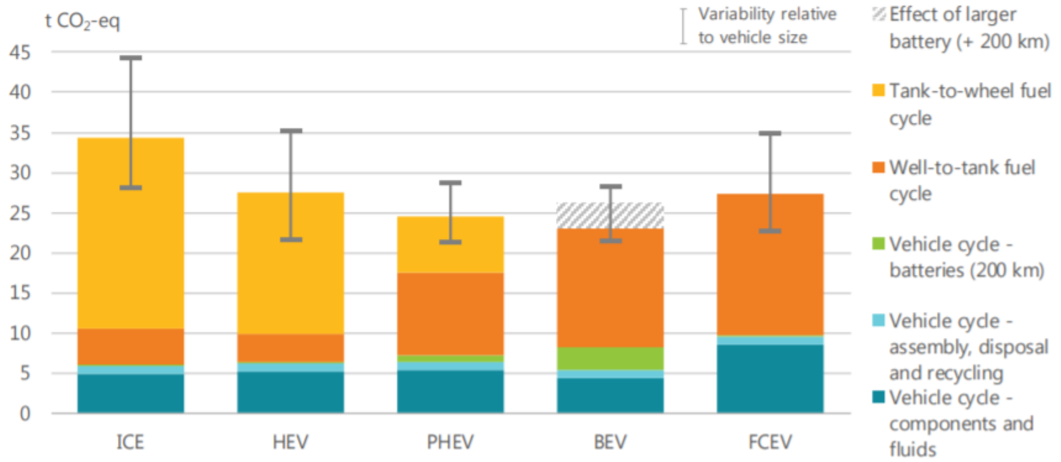

Figure 17:Comparative life-cycle GHG emissions of a mid-size global average car by powertrain, (Source: IEA Global Report [28])

3.1 CONVENTIONAL INTERNAL COMBUSTION ENGINES (ICE)

Combustion, also known as burning, is the basic chemical process of releasing energy from a fuel and air mixture. In an internal combustion engine (ICE), the ignition and combustion of the fuel occurs within the engine itself. It is the engine which partially converts the energy from the combustion to work (this conversion depends on the performance of the engine, in the ICE vehicles' performance cases are quite low compared to electric vehicles). The engine consists of a fixed cylinder and a moving piston. The expanding combustion gases push the piston, which in turn rotates the crankshaft. Ultimately, through a system of gears in the powertrain, this motion drives the vehicle's wheels.

Currently, there are being produced two main kinds of internal combustion: the spark ignition gasoline engine and the compression ignition diesel engine. Most of these are four-stroke cycle engines, meaning as their name suggest that for completing cycle it is required four piston strokes. The cycle includes four distinct processes: intake (or induction), compression, combustion (or ignition), and exhaust (or outlet). Spark ignition gasoline and compression ignition diesel engines differ in how they supply and ignite the fuel.

Most of the transportation sector emissions are caused by these types of fuels. In *figure 19* it is shown a comparative of the CO_2 emissions of both new gasoline and diesel passenger car, as it can be observed from the graphic, thanks to the European regulations that have been increasingly restrictive, manufacturers during the last decade have been working to reduce their vehicle's emissions while maintaining or even improving the performance of their vehicles. Thanks to it, will be possible to obtain a better understanding of the issue.

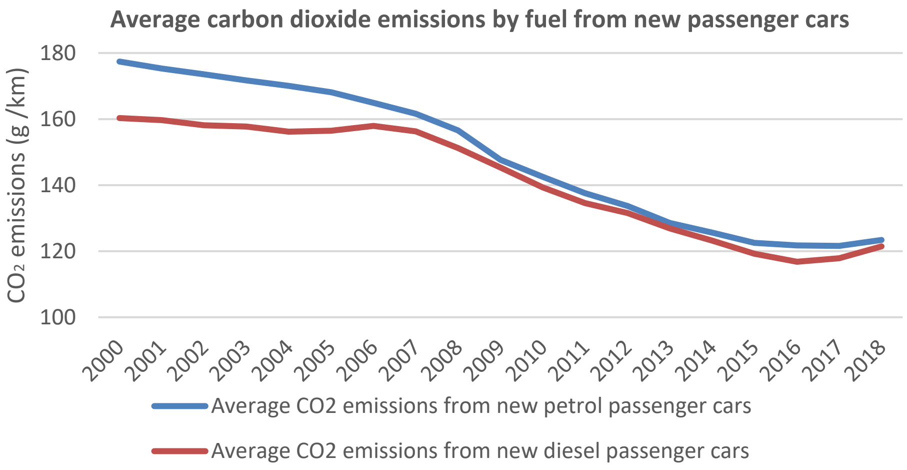

Figure 18: Average CO2 emissions by ICE fuel from new passenger cars (Source:European Environmental Agency [1])

Throughout this chapter the price per liter of each type of fuel will be studied, as shown in *Figure 20*, in the case of conventional fuels (gasoline and diesel), their values are very volatile and it is difficult to estimate a fixed price for the scenarios of this thesis. However, in order to carry out an analysis and draw conclusions it is required to set its value, 1.31 €

and 1.22 € per liter of gasoline and diesel respectively. This hypothesis is based on the average over the last years.

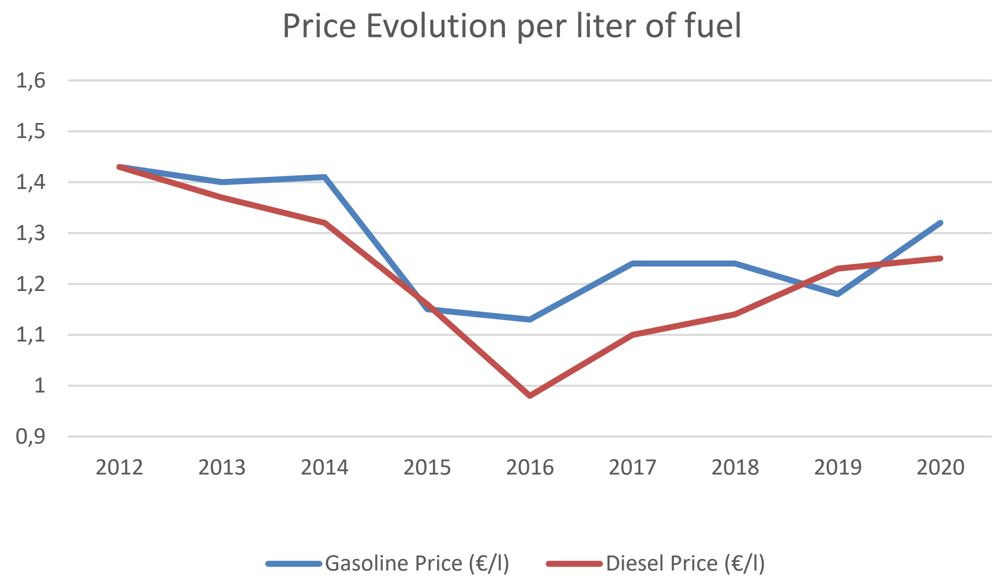

Figure 19: Price Evolution per liter of Petrol fuel (Source: Epdata [34])

3.1.1 GASOLINE COMBUSTION ENGINE VEHICLE:

Gasoline engine is an internal combustion engine with spark-ignition, designed to run on petrol (gasoline) and similar volatile fuels. In most petrol engines, the fuel and air are usually mixed after compression (although it is true that some modern petrol engines now use cylinder-direct petrol injection). The pre-mixing was formerly done in a carburetor, but now it is done by electronically controlled fuel injection, except in small engines where the cost and complication of electronics does not justify the added engine efficiency.

In addition, Gasoline powered automobiles take advantage of a modern infrastructure built for their presence. With gas stations and auto repair shops around every corner worldwide, these days owning a gas car is both convenient and easy. Gasoline cars are great for saving money on the upfront cost of purchasing a vehicle as it can be observed in *table 8* which represent the top 10 best-selling gasoline cars, resulting an average purchasing price of 17.383,20 €.

Table 12: Top 10 selling gasoline cars in Spain (Source: estadisticacoches.com [13])

Model	**Units sold**	**Purchase Price**
Dacia Sandero	25581	8.680,00 €
Seat Leon	23700	21.960,00 €
Seat Ibiza	21029	17.550,00 €
Volkswagen Polo	18392	17.662,00 €
Seat Arona	18316	19.180,00 €
Nissan Qashqai	17936	23.300,00 €
Citroen C3	17825	14.500,00 €
Opel Corsa	17351	16.300,00 €
Fiat 500	17160	17.300,00 €
Peugeot 208	16624	17.400,00 €
Average Purchase Price		**17.383,20 €**
Weighted Average Purchase Price		**17.188,10 €**

Moreover, apart from having a very competitive price, when it comes to autonomy range, gasoline cars have a clear advantage compared to technology recently arised, due to electric cars can’t travel more than 150 miles while with this type of fuel can have a range of 400 miles or more, and can be refueled in a shorter time. However, the total cost per 100 km travelled is a clear disadvantage of this fuel type due to is the most expensive of the studied fuel alternatives.

Table 13: Consumption and cost associated to Gasoline vehicle (Source: OVEMS [14])

Model	**T2W**	**Fuel price**	**Heating power**	**Energy consumed Price**	**Total cost**	**Average Consumption**
	kWh/100km	€/l	kWh/l	€/kWh	€/100km	l/100km
Gasoline	83,33	1,31	9,23	0,14	11,83	9,03

Gasoline fuel is also a toxic and highly flammable liquid. The vapors given off when gasoline evaporates and the substances produced when gasoline is burned such as nitrogen oxides, carbon dioxide and oxides or particulates, contribute to air pollution. *Figure 21* illustrate how much have changed emissions from gasoline vehicles in Spain, compared to 2015. It can be observed that gasoline manufacturers have achieved a considerable reduction of NO_x but still remaining a long way to reduce CO_2 emissions. Even though it has been decreased the average CO_2 emissions from new gasoline vehicles, due to the gasoline fleet increase, CO_2 emission also rose up during the last year. In addition, it has been also calculated in

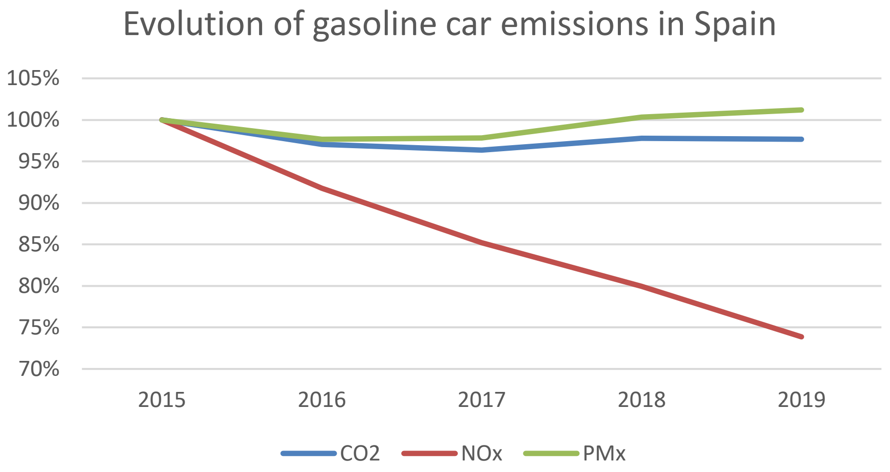

Figure 20: Evolution of gasoline car emissions in Spain compared to 2015 (Own source)

Table 14: Average emissions gasoline passenger cars (Source: OVEMS [14])

Model	**Average Emissions**					
	W2W (g CO2 /km)	W2T (g CO2 /km)	T2W (g CO2 /km)	NOx (mg/km)	PM2.5 (mg/km)	PM10 (mg/km)
Gasoline	246,04	54,04	192	126,00	2,54	0,05

3.1.2 DIESEL COMBUSTION ENGINE VEHICLE:

The diesel engine also known as a compression-ignition or CI engine, is an internal combustion engine in which ignition of the fuel is caused by the elevated temperature of the air in the cylinder due to the mechanical compression (adiabatic compression). This contrast to the gasoline engine, as it was commented previously it uses a spark plug to ignite an air-fuel mixture. Moreover, the diesel engine has the highest efficiency of any combustion engine due to its very high expansion ratio and inherent lean burn which enables heat dissipation by the excess air. A small efficiency loss is also avoided compared with non-direct-injection gasoline engines since unburned fuel is not present during valve overlap and therefore no fuel goes directly from the intake/injection to the exhaust.

Since the 1910s has been used diesel engines in many different industries and applications, in 1930s the first diesel vehicle was designed but it was in the 1980s when this type of fuel started to be popular within the transport sector. It was achieved because of its benefits associated. Regarding to the upfront purchasing price of this type of fuel is 26.316,70 €, more expensive than his combustion partner.

Table 15:Top 10 selling diesel cars in Spain (Source: estadisticacoches.com [11])

Model	**Units sold**	**Purchase Price**
Nissan QASHQAI	12214	24.200,00 €
Peugeot 3008	10867	26.750,00 €
Volkswagen Tiguan	9925	32.222,00 €
Seat Leon	8997	24.380,00 €
Mercedes Clase A	8900	31.600,00 €
BMW X1	8557	36.986,00 €
VOLKSWAGEN Golf	8538	26.639,00 €
Peugeot 308	8493	19.550,00 €
Renault Clio	7525	17.990,00 €
Peugeot 2008	7199	22.850,00 €
Average Purchase Price		**26.316,70 €**
Weighted Average Purchase Price		**26.492,40 €**

As previously was commented, one of the main benefits associated with the gasoline vehicles was its autonomy. In the case of Diesel engine this benefit is even greater, diesel engines are more fuel-efficient and have more low-end torque than similar-sized gasoline engines. Diesel fuel contains roughly 10% to 15% more energy than gasoline which enables to these types of vehicles to go about 20% or 35 % farther on a gallon of fuel than their gasoline counterparts. Moreover, if we take into account that diesel's fuel price is cheaper than gasoline, the total cost per 100 km travelled of it will be much lower, making diesel a good alternative for those who need a car for doing long distances.

Table 16:Consumption and cost associated to Diesel vehicle (Source: OVEMS [12])

Model	**T2W**	**Fuel price**	**Heating power**	**Energy consumed Price**	**Total cost**	**Average Consumption**
	kWh/100km	€/l	kWh/l	€/kWh	€/100km	l/100km
Diesel	71,4285714	1,22	10,26	0,119	8,4935	6,962

In addition to the increased efficiency and power, during the last decade has been also developed new engine designs, along with noise-damping and vibration-damping technologies have made them quieter and smoother.

Compliance with the standards of the EU regulations has made that today's diesels meet the same emissions standards as gasoline vehicles and as it is shown in *figure 22*, has also achieved to reduce their total emissions. It has been made possible thanks to the advances in engine technologies, ultra-low sulfur diesel fuel and an improved exhaust treatment. Despite all these advances, diesel vehicles still being one of the main causes of greenhouse gases emissions, which suggests finding low polluting alternatives. *Table 17* represent the average emissions of this type of fuel.

Table 17:Average emissions diesel passenger cars (Source: OVEMS [12])

Model	**Average Emissions**					
	W2W (g CO2 /km)	W2T (g CO2 /km)	T2W (g CO2 /km)	NOx (mg/km)	PM2.5 (mg/km)	PM10 (mg/km)
Diesel	212,96	42,96	170	170	1,5	0,15

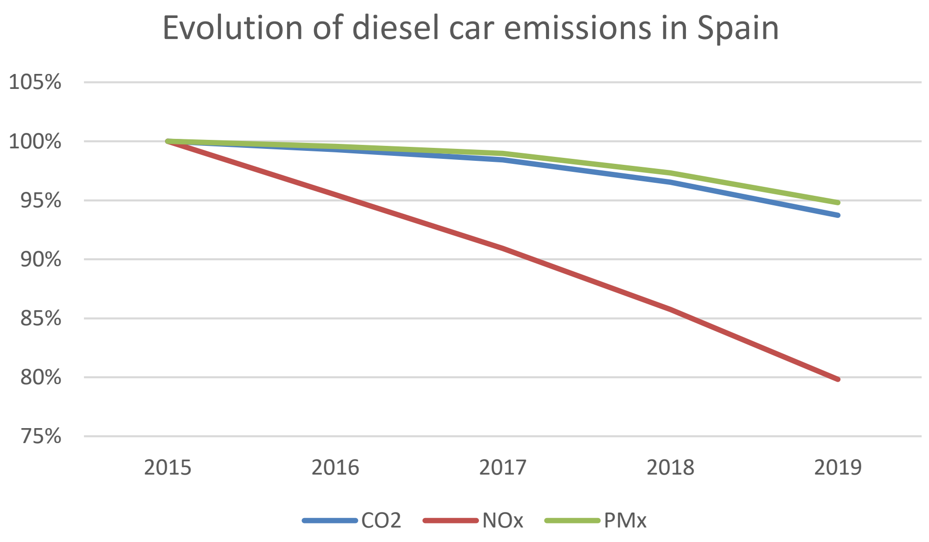

Figure 21:Evolution of diesel car emissions in Spain compared to 2015 (Own source)

3.2 LOW POLLUTING FUELS ALTERNATIVES

Despite the effort made by ICE manufacturers for reducing their vehicle's emissions and the improves achieved, as it shows the *figure 23*, road transport keeps being one of the most polluting sectors in terms of NO_x and CO_2 among others. Which suggest using other low polluting fuels as an alternative to diesel and gasoline vehicles. On this graph can also be observed how NO_x emissions have been drastically reduced since 2008 (it was when the European Union started to approve some regulations related to this issue). Since then, there have been made many researches about a lot of low polluting fuels. In this chapter, it will be covered just the most representative, which will be easier their implementation in the short-term. It will be divided in the electrification and gas path, in which as it happens to ICE vehicles, it will be studied the different pollutants emitted by each fuel and knowing the cost associated with it, upfront purchasing price and cost per 100 km travelled among others.

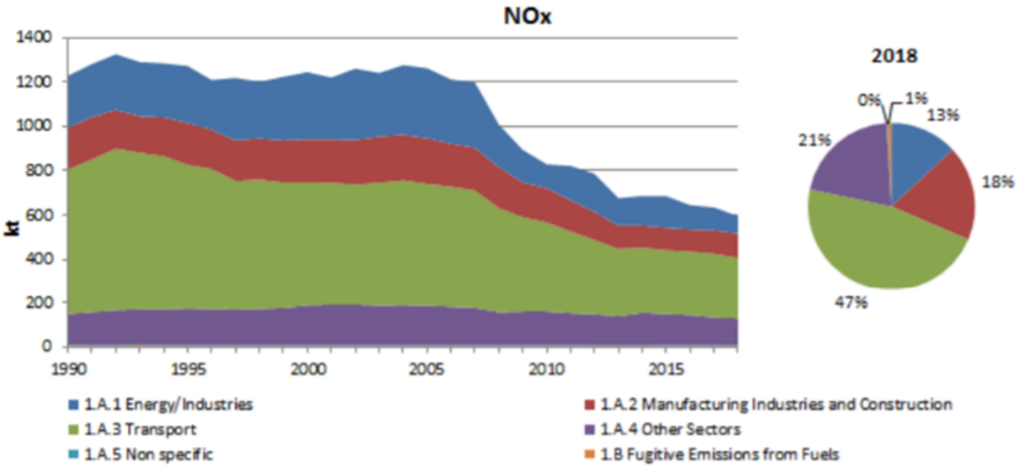

Figure 22: Evolution of NOX emissions by category and distribution in year 2018 (Source: Informative Inventory Report IIR)

3.2.1 ELECTRIC VEHICLE:

Among all the different alternatives of low polluting fuel, Electric Vehicles seems to be at this moment the most successful choice in which Governments and Companies are spending more amount of money developing it. This type of vehicle is receiving increasing attention due to their high fuel economy, low pollution emissions (CO_2, NO_x, PM_x) and reduction of the maintenance cost. These advantages versus the gasoline or diesel vehicles, combined with the increasing pollution problems are having most of the populated cities worldwide, suggest that EV can be an alternative to the conventional car and its progressive increase through next years. Currently there are two main different types of vehicles considered as electric, Battery Electric Vehicles and Plug-in Hybrid Vehicles. In *figure 24* is represented the new registration of both types, Battery and Plug-in Hybrid Vehicles in Spain. As it can be observed from the graph, there is an upward trend on both types of vehicles, being higher the number of Battery electric vehicles sold in Spain.

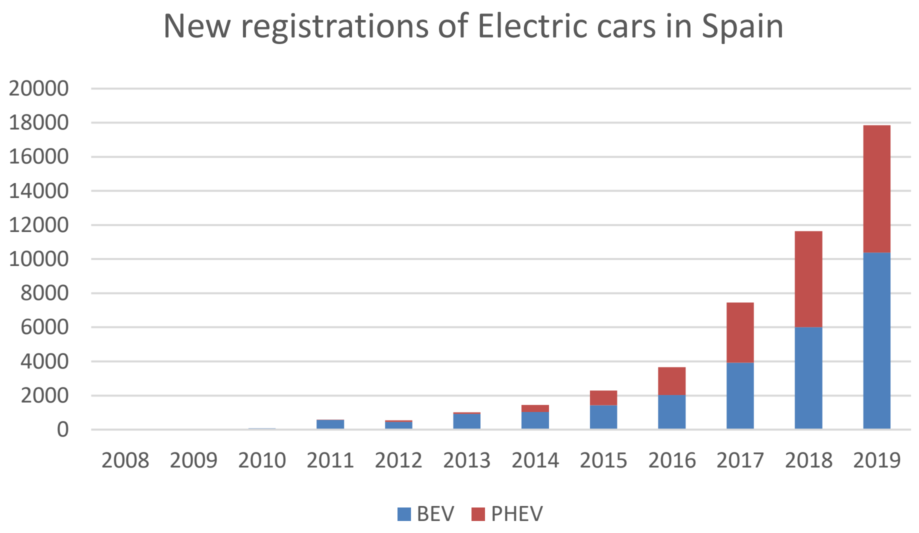

Figure 24:New registrations of Electric cars in Spain (Source: OVEMS [14])

Regarding to the price of the electricity in Spain, varies a lot over the time, and also among the different companies. Below, it is showed a graph where it can be observed the oscilation of the average price per MWh.

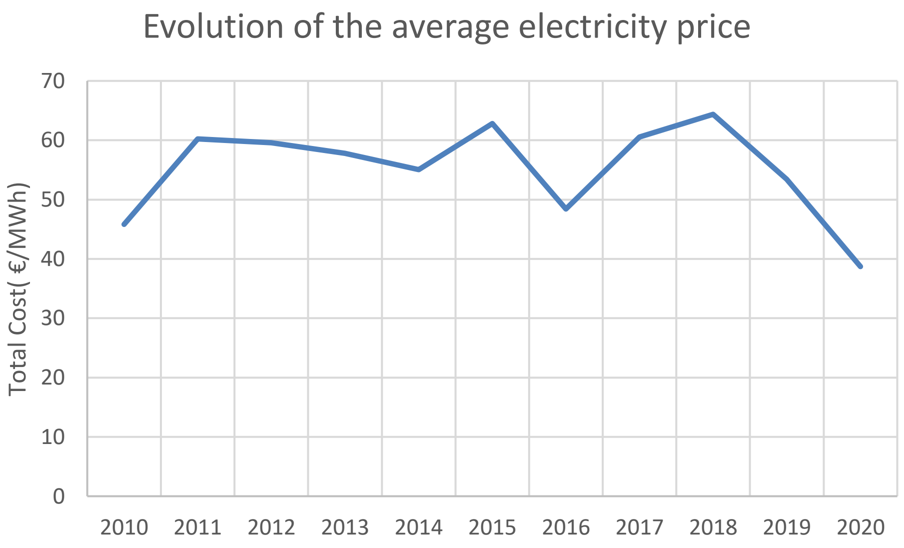

Figure 23:Evolution of the average electricity price (€/MWh) (Source: statista.com [36])

3.2.1.1 BATTERY ELECTRIC VEHICLE:

Battery Electric Vehicles (BEV) will be the first low polluting type of fuel studied. These vehicles are fully-electric vehicles equipped with rechargeable batteries and non-gasoline engines. In this type of vehicles, the electric motor and all onboard electronics are run by their battery power, instead of by combustion as it happens in diesel and gasoline vehicles. Because no combustion occurs during the process in the electric motor, electric cars do not emit any harmful emissions and the hazards caused by traditional gasoline-powered vehicles.

One of the downsides to BEVs is when it comes to charging the car's battery, BEVs are powered by electricity from an external source, and even though as it can be seen in *figure 25,* the infrastructures have greatly improved over the past decade, they are still hard to find. Electric vehicle (EV) chargers are classified according to the speed with which they recharge an EV battery. According to FAEN (Fundación Asturiana de la Energía) [15], it can be classified into 5 different types of recharging regarding how long it takes to recharge the batteries, which depends directly on the available power. As it is showed in aforementioned figure, they are usually summarized in two, slow recharge and fast recharge.

1. Super-slow recharging, when the current intensity is limited to 10 A or less due to not having a recharge base with protection and adequate electrical installation. Fully recharging the batteries of a average electric car, about 22 to 24 kWh capacity, can take ten to twelve hours.
2. Slow recharge, can also be called conventional or normal recharge. It is carried out at 16 A, demanding about 3.6 kW of power. Recharging those same batteries can take six to eight hours.
3. Semi-fast recharge, in English is often called quick-charge, less fast than fast-charge. It is done at a power of about 22 kW. Renault is quite committed to this type of recharging, for example with its Low-cost charger Chameleon, compatible with the Renault ZOE. Recharging can take an hour or hour and room.

4. Quick recharge, the power required is very high, between 44 and 50 kW. The recharge of those 22 to 24 kWh of batteries can take half an hour. The normal thing is that a recharge of 100% is not made but around 80% or 90%.
5. Ultra-fast recharge, hardly used, and should be considered as something still experimental, in electric vehicles tested with supercapacitor type accumulators (for example some electric buses). The recharging power is very high, and in about five or ten minutes the batteries can be recharged. The lithium ion batteries do not withstand the temperature so high that this type of recharge causes severely deteriorates its useful life.

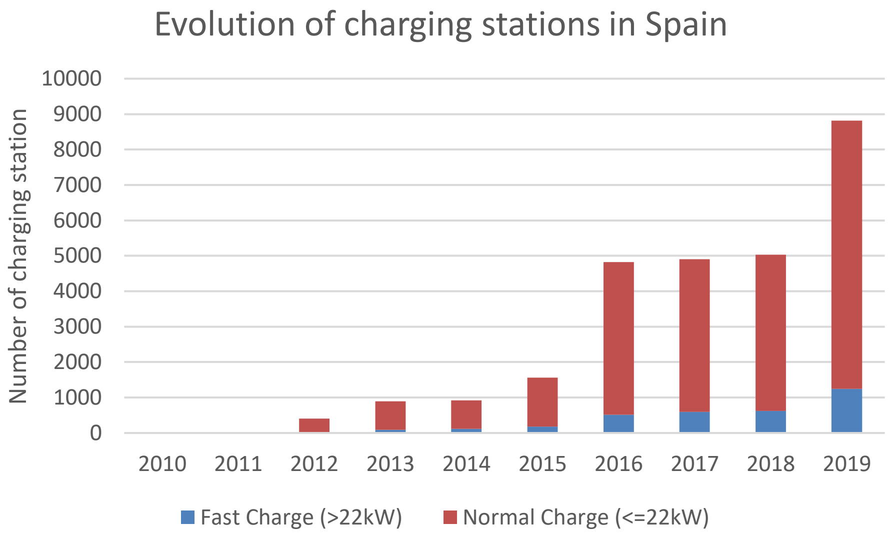

Figure 25:Evolution of charging stations in Spain (Source: OVEMS [14])

As Pedro González (Director of Regulation of AELEC) has stated in the second seminar #webinarsAELEC[3], there is a basic recharge of the electric car in Spain, which together with the increase in autonomy of EVs allows its users to make trips throughout the territory national. However, if we compare this network with that existing in countries

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[3] In this seminar, the exit plans of this crisis have been analyzed; they must be an engine to transform our economy and an opportunity to improve our quality of life through sustainable mobility.

such as France or the United Kingdom, it shows that Spain has a great margin for improvement in order to compete with them. Furthermore, if what is being looking for is to put an end to energy dependence (on oil), it is vitally important to be pioneers in the implementation of a recharge network throughout the entire national territory, using green electiricity.

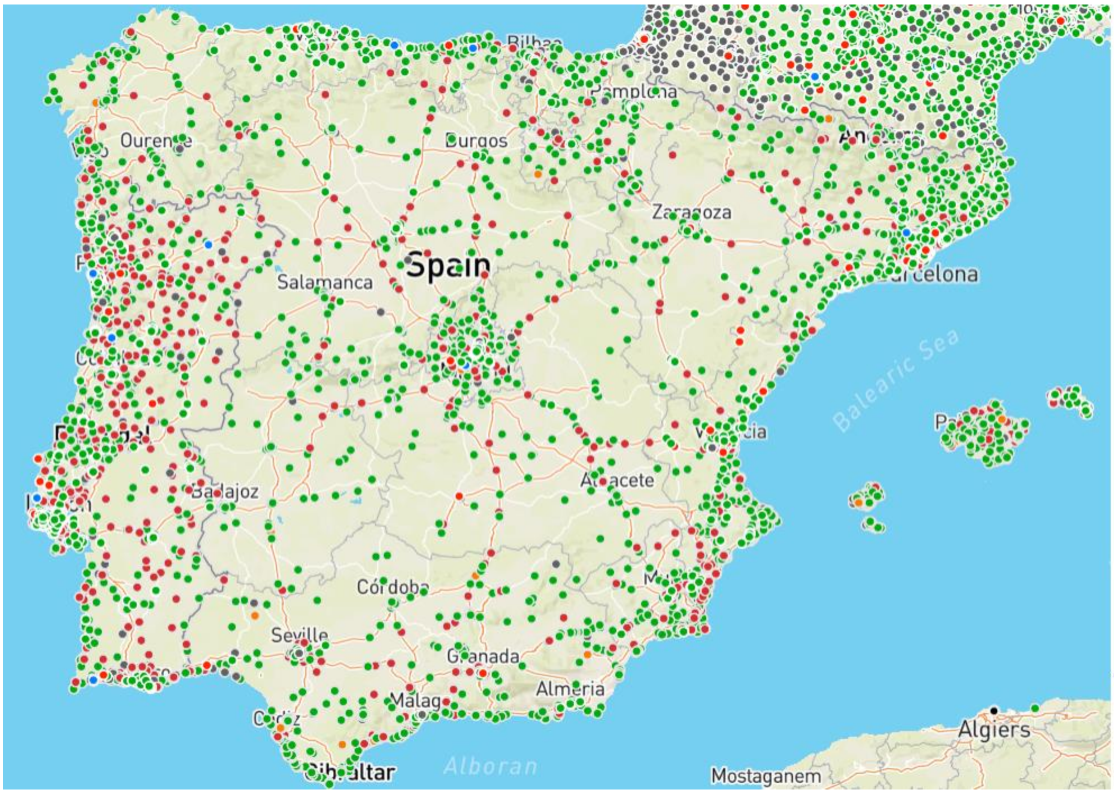


Figure 26: Map of Spain of electric vehicle charging infrastructures (Source: Electromaps [37])

To achieve the necessary level of penetration of electric mobility, it is essential to develop an infrastructure for charging both public and private access, adequate in terms of performance and availability. For this, it has been taken as a reference the study made by Monitor Deloitte [16] a few years ago, in which it was generated several scenarios about the evolution of electric recharging infrastructure. In the generation of this senior thesis' scenarios, the ratio of vehicles / charging posts will follow a distribution which can be compared to a Normal distribution or a Poisson distribution.

In Monitor Deloitte‘s report, not only is included the number of posts necessary for the penetration of the EV, but it also distinguishes between the existing ones, their benefits and associated costs, presented in *table 18*.

Table 18: Characteristics depending of the type of recharging used (Source: Monitor Deloitte [16])

Type	**Normal Recharge**	**Semi-fast Recharge**	**Fast Recharge**
Connection power (kW)	3,7 kW	7,3 kW	45 kW
Recharge time	6 – 10 h	3 – 4 h	30 min
Unit cost per charging pole (€)	500 – 1.500 €	2.500 – 15.000 €	40.000 – 80.000 €

Table 19 shows the number of each type of charging post assumed in the aforementioned report [16] and the cost associated with them, per 6000 electric vehicles. It is important to emphasize that this table presents the *number of recharging posts* (for example for every 6000 vehicles, there are not between 6 or 9 EV recharging stations, but there are between 6 and 9 recharging posts distributed in the recharging station). Monitor Deloitte defines a maximum and a minimum number of each of the electric infrastructures, in the generation of this thesis’ scenarios it will be taken the average.

In addition, it has been decided to limit the maximum number of posts. Having a limit does not mean that all the scenarios reach that number, but it is used to obtain a more accurate and feasible results. In case of Particular posts, the maximum number is 12 M, 40 k is the limit for Public posts, semi-fast charging station and fast-charging station posts and 16 k for Fleet posts.

The total cost in recharging posts per electric vehicle according to Monitor Deloitte’s Report [16] is 501.39 €.

Table 19: Number of infrastructures and associated costs for every 6,000 vehicles (Source: Monitor Deloitte [16])

	N. Min*	**N. Max***	**Type of Recharge**	**Unit cost**	**Total cost^**	**Cost per vehicle**
Particular	2430	3410	Normal	750 €	2.190.000 €	365,00 €
Public	65	95	Normal	750 €	60.000 €	10,00 €
Semi-fast EV charging station	30	40	Semi-fast	8750 €	306.250 €	51,04 €
Fast EV charging station	6	9	Fast	60.000 €	450.000 €	75,00 €
Fleet	0,8	4,8	Normal	750 €	2.100€	0,35 €

* Maximum and minimum number of charges posts for every 6000 vehicles
^ Total cost of implementing the recharging infrastructure for 6000 Electric vehicles

Regarding to the distribution (*figure 27*) used for defining the penetration of the charging post, is centered in 2030. It will be taken the same proportion than in Monitor Deloitte's report, but instead of a constant ratio of infrastructure per electric vehicle, the penetration will be faster during the first years, encouraging users to drive a low polluting vehicle and slower in the 2040s. Therefore, despite a non-constant rate of penetration, in 2050, the ratio vehicles per infrastructure will be the same than in Monitor Deloitte report [16].

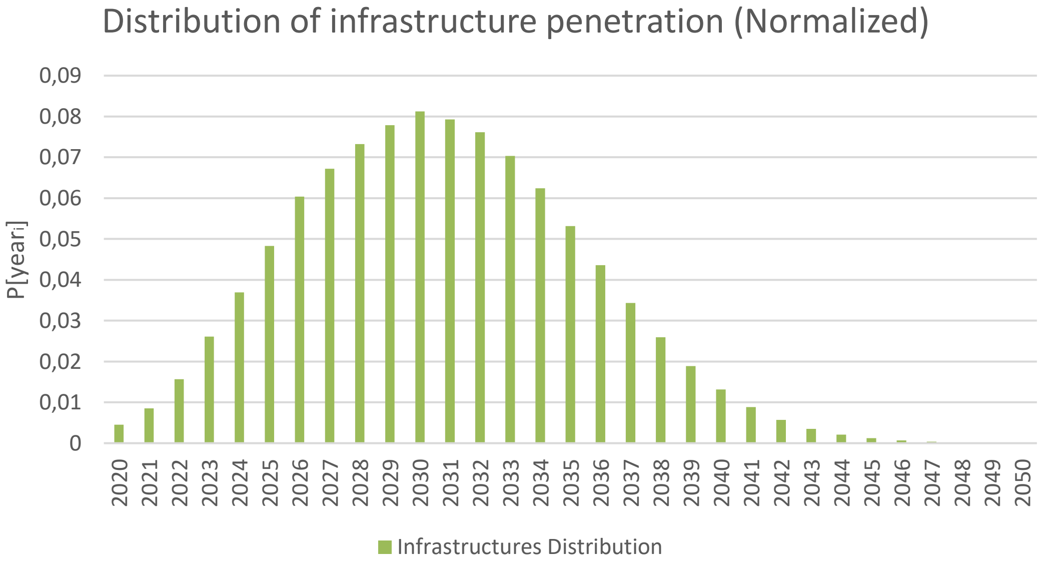


Figure 27:Distribution of infrastructure penetration (Own source)

In addition, if it is taken the accumulated distribution (*figure 28*), we observe that it is quite similar to the distribution of the park forecast (*equation 8*)

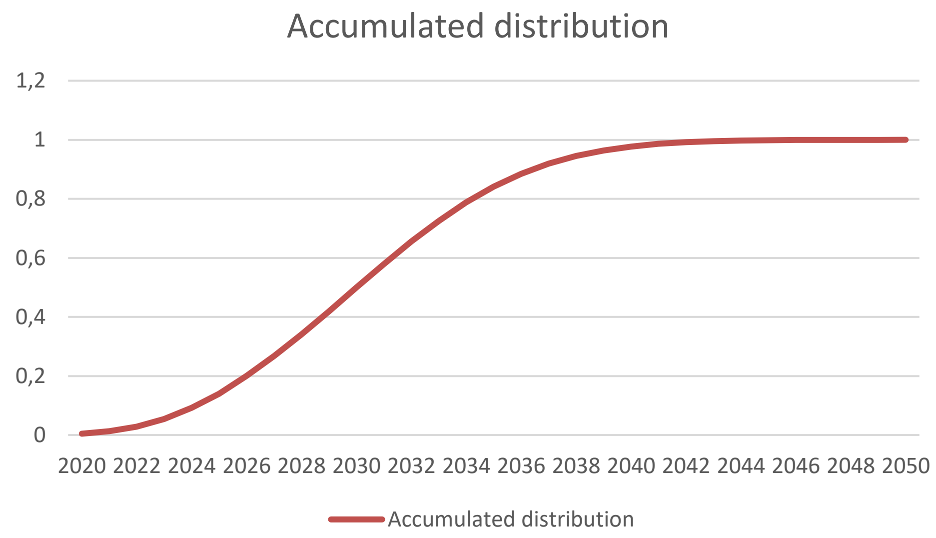


Figure 28: Accumulated distribution of post penetration (Own source)

To calculate the number of new posts required per year, it is used the following formula:

$$n^{\underline{o}} of\ accumulated\ posts_{year\ i,particular} = n^{\underline{o}} of\ accumulated\ posts_{year\ i-1,particular} + n^{\underline{o}}\ of\ posts_{year\ i,particular} \tag{7}$$

$$n^{\underline{o}}\ of\ posts_{year\ i,particular}\ (If\ n^{\underline{o}}posts < Limit) = \frac{n^{\underline{o}}\ of\ EVs_{2050}}{6000} * \frac{N.max_{particular} + N.min_{particular}}{2} * P[year_i] \tag{8}$$

$$n^{\underline{o}}\ of\ posts_{year\ i,particular}\ (If\ n^{\underline{o}}posts > Limit) = 0 \tag{9}$$

Equation 1,2 and 3 has been used not only for calculating the implementation of electric posts but also for LPG and CNG infrastructures. Furthermore, it has been used also the same distribution.

Another drawback of BEVs is their purchasing price, if the average price of the 10 most common BEV cars in Spain is calculated, we obtain € 43,929.21, much higher than the average price of gasoline car € 17,383.2 or diesel € 26,316.7. Table represent the top-10 selling BEV in Spain in 2019.

Table 20:Top 10 selling BEVs cars in Spain (Source: estadisticacoches.com [11])

Model	Units sold	Purchase Price
Tesla Model 3	1687	59.100,00 €
Nissan Leaf	1496	34.619,90 €
Renault Zoe	1050	18.847,23 €
Hyundai Kona BEV	1006	35.050,00 €
Volkswagen e-Golf	942	24.400,00 €
BMW i3	915	40.600,00 €
Smart Fortfour ED	766	27.465,00 €
Smart Fortwo ED	683	24.450,00 €
Tesla Model X	188	85.980,00 €
Tesla Model S	175	88.780,00 €
Average Purchase Price		**43.929,21 €**
Weighted Average Purchase Price		**37.731,82 €**

However, BEVs are a really good alternative if what is being looking for is a vehicle for travelling short distances (for example for using just in urban areas). As it was commented previously BEVs had a short autonomy, but its cost per 100km travelled is € 3.27 or € 1.72 depending on the speed in which it is charged.

Table 21:Consumption and cost associated to Diesel vehicle (Source: OVEMS [12])

Model	T2W	Fuel price	Heating power	Energy consumed Price	Total cost	Average Consumption
	kWh/100km	€/l	kWh/l	€/kWh	€/100km	l/100km
BEV Fast charge	19,50	-	-	0,17	3,27	-
BEV	19,50	-	-	0,09	1,72	-

There is no doubt that the main advantage of BEVs is when it comes to pollution terms, they do not have any competitors, as it was commented previously due to no combustion occurs during the process in the electric motor, electric cars do not emit any harmful emissions. Concerning climate change and environmental problems, BEVs is one of the best choices to combat this issue. This has led to an upward trend of BEVs. These types of vehicles have two objectives to beat, the first to reduce Well to tank emissions and the second to improve their economy. *Table 22* shows the average emissions of BEVs.

Table 22: Average emissions Battery electric passenger cars (Source: OVEMS [12])

Model	**Average Emissions**					
	W2W (g CO2 /km)	W2T (g CO2 /km)	T2W (g CO2 /km)	NOx (mg/km)	PM2.5 (mg/km)	PM10 (mg/km)
BEV	52,62	52,62	-	-	-	-

3.2.1.2 PLUG-IN HYBRID ELECTRIC VEHICLE:

Plug-in hybrid electric vehicle is a type of EV emerged recently, as a promising alternative that uses electricity to displace a significant amount of combustion fuel consumption. The plug-in electric vehicle is a mix between the battery electric vehicle and the hybrid vehicle, which differs from the latter in its ability to recharge its electromechanical electricity storage from an off-board source as it happens with the BEV.

This type of vehicle has two driving modes, charge-depleting mode and charge-sustaining mode. Sometimes it is also common to combine both modes, a car may begin a trip in low speed charge-depleting mode, then enter onto a freeway and operate in charge-sustaining mode, when it happens it is called blended mode or mixed-mode. Charge-depleting mode allows the PHEV to run exclusively on electric power until its battery is unloaded, until then, it is called the period vehicle's all-electric range, from then on, the operation automatically changes to internal combustion, although PHEVs can also use alternatives such as biofuels or hydrogen, typically is used petroleum (gasoline or diesel). PHEVs have many benefits compared to conventional or hybrid vehicles, since they save up to 60% or 40% respectively in energy cost, resulting as the total cost per 100 km travelled.

Table 23: Consumption and cost associated to PHEVs (Source: OVEMS [12])

Model	**T2W**	**Fuel price**	**Heating power**	**Energy consumed Price**	**Total cost**	**Average Consumption**
	kWh/100km	€/l	kWh/l	€/kWh	€/100km	l/100km
PHEV	34,09	1,31	9,23	0,14	4,84	-

In addition, due to their electric mode of operation, it enables to pollute less than these types of vehicles, making PHEVs an excellent choice for decarbonization path. *Table 24* shows their average emissions, as it happens to BEVs, there is still a long way for improving their well to tank emissions.

Table 24:Average emissions PHEV passenger cars (Source: OVEMS [12])

Model	**Average Emissions**					
	W2W (g CO2 /km)	W2T (g CO2 /km)	T2W (g CO2 /km)	NOx (mg/km)	PM2.5 (mg/km)	PM10 (mg/km)
PHEV	70,00	70,00	-	-	-	-

One of the greatest disadvantages of this car is its average purchasing price, which as it happens with Battery electric vehicle, are more expensive than ICE vehicles. In this case, the average purchasing price of the top 10 most common in Spain is 54,112 €, well above the average for other types of fuels.

Table 25:Top 10 selling PHEVs cars in Spain (Source: estadisticacoches.com [11])

Model	**Units sold**	**Purchase Price**
Mitsubishi Outlander PHEV	1255	36.300,00 €
Mini Countryman PHEV	1224	40.900,00 €
Mercedes Clase C	804	52.230,00 €
BMW 225 XE Active Tourer	710	44.000,00 €
Volvo XC60	444	63.750,00 €
Kia Niro PHEV	348	25.800,00 €
Hyundai Ioniq PHEV	176	35.525,00 €
Mini Countryman PHEV	235	40.900,00 €
Mercedes Clase CLS	183	67.400,00 €
Audi e-Tron	165	75.295,00 €
Average Purchase Price		**49.210,00 €**
Weighted Average Purchase Price		**46.772,40 €**

3.2.2 GAS VEHICLES:

Gas vehicles generate very few solid particles, make less noise than conventional vehicles, and generate about 30% less carbon dioxide than petroleum products. Within this category there are two different types of vehicles, natural gas and liquified petroleum (LPG). As it happens with the other fuel alternatives, the price per liter of fuel fluctuates a lot, and it is difficult to predict the value over the time. *Figure 29* represent the price evolution in the autonomous community of Madrid in the last years. The prices taken for CNG and LPG in this thesis will be 0.89 and 0.71 €/l respectively.

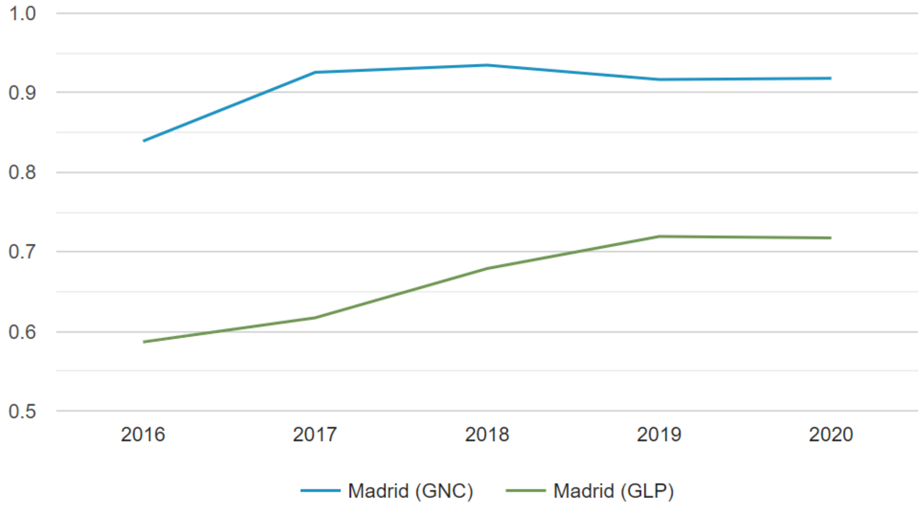
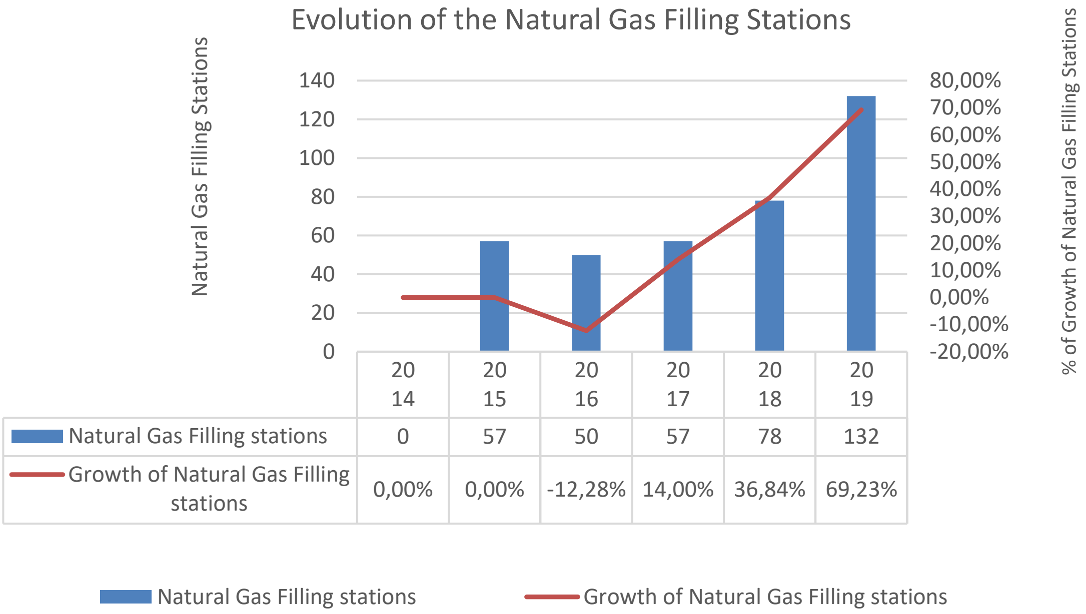


Figure 29:Price evolution per liter of fuel in Madrid (Source: geoportal [35])

3.2.2.1 COMPRESSED NATURAL GAS VEHICLE:

Natural Gas is a new emerging alternative fuel which uses compressed or liquid natural gas for running the vehicles. In a natural gas-powered vehicle, energy is obtained by the combustion of methane gas (CH_4) with oxygen (O_2) in an internal combustion. Methane is the cleanest burning hydrocarbon, and with it many contaminants are removed from. Natural Gas vehicles usually are bi-fuel, which means that the vehicle can be powered by natural gas or gasoline.

Compressed natural gas (CNG) is essentially natural gas stored at high pressures. Being mainly composed of methane, it produces less carbon dioxide than other hydrocarbons, such as gasoline or diesel. In addition to being cleaner, it is also cheaper, since it currently costs 0.89 euros / kg. These two factors have caused the demand for this type of vehicle to increase and, thanks to this, the infrastructure to refuel this fuel is also improving *(figure 30)*, since more and more service stations have a CNG pump.



	2014	2015	2016	2017	2018	2019
Natural Gas Filling stations	0	57	50	57	78	132
Growth of Natural Gas Filling stations	0,00%	0,00%	-12,28%	14,00%	36,84%	69,23%

Figure 30:Evolution of the Natural Gas Filling Stations (Source: EAFO [29])

Vehicles prepared to run on CNG can also run on gasoline. Therefore, they are bifuel models, but not hybrids, since they only have a combustion engine that works interchangeably with both types of fuel. This type of car, however, has at least two tanks, one for gasoline and one for CNG. By default, a CNG vehicle runs on gas until it runs out; the change to gasoline is carried out automatically and is imperceptible to the driver. And it is that, in progress, there are no differences between the gas and gasoline modes, so a CNG model drives exactly the same as a diesel or gasoline one. That is why despite not having a good refueling network through the national territory (*figure 31*), CNG vehicles are able to travel long distances all over the country, since in case of not having where to recharge the natural gas, the engine would run on gasoline. In addition, their upfront purchasing price is not as expensive as the other low polluting alternatives.

Figure 31: Map of Spain of Compressed Natural Gas filling stations (Source: Gasnam [38])

Table 26:Top 10 selling CNG cars in Spain (Source: estadisticacoches.com [11])

Model	**Units sold**	**Purchase Price**
Seat Leon	2943	27.550,00 €
Seat Ibiza	916	19.250,00 €
Seat Arona	870	20.870,00 €
Skoda Octavia	324	19.400,00 €
Seat Mii	186	14.800,00 €
Audi A3	141	30.916,00 €
Audi A4	37	47.994,00 €
Volkswagen Polo TGI	17	19.625,00 €
Audi A5	11	46.839,00 €
Fiat Panda	8	11.350,00 €
Average Purchase Price		**25.859,40 €**
Weighted Average Purchase Price		**24.387,04 €**

Regarding to their efficiency, this type of vehicle is a good choice, the total cost per 100 km travelled ran by Compressed Natural Gas is € 4.71 lower than usual ICE vehicles.

Table 27:Consumption and cost associated to CNG vehicles (Source: OVEMS [12])

Model	**T2W**	**Fuel price**	**Heating power**	**Energy consumed Price**	**Total cost**	**Average Consumption**
	kWh/100km	€/l	kWh/l	€/kWh	€/100km	l/100km
CNG	83,33	0,89	15,75	0,06	4,71	5,50

It should be noted that CNG cars have the DGT's ECO environmental mark. As we have indicated, they are not hybrids, but benefit from the same label as models equipped with a dual-drive system. As a result, they are less affected by traffic restrictions in episodes of high pollution, so their use in large cities is spreading. In the same way, this type of vehicle can access discounts in regulated parking areas, in some tolls and when paying municipal traffic tax. In short, CNG models are ecological, cheaper and just as safe as a diesel or gasoline car. Table represents their average emissions.

Table 28: Average emissions CNG passenger cars (Source: OVEMS [12])

Model	**Average Emissions**					
	W2W (g CO2 /km)	W2T (g CO2 /km)	T2W (g CO2 /km)	NOx (mg/km)	PM2.5 (mg/km)	PM10 (mg/km)
CNG	187,82	25,82	162	56,00	1,1	-

Finally, the cost of implementing the recharging stations necessary for the penetration of CNG vehicles in Spain has been studied. For this, the infrastructure per vehicle ratio established in the Directive 2014/94/UE has been taken as base but as happen with electric charging infrastructure, it has been used a distribution (*figure 27*). Actually, the aforementioned Directive sets the number of infrastructures for 2025, not the number of vehicles there will be for that year. But for the generation of this work, the hypothesis that there will be 55,000 vehicles will be taken. *Table 29* shows the number of infrastructures stablished by the Directive in urban cities in 2020, while *Table 30* shows the number of infrastructures in 2025 in roads.

Table 29: Number of new CNG infrastructures per city in 2020 stablished in the Directive 2014/94/UE
(Source: Estrategia VEA [17])

Number of cities	**Number of population**	**Infrastructure**	**Total**
2	> 1 M	10	20
4	> 0.5 M	5	20
23	> 0.2 M	2	46
33	> 0.1 M	1	33
		TOTAL	119

Table 30:Number of new CNG infrastructures in road in 2025 stablished in the Directive 2014/94/UE
(Source: Estrategia VEA [17])

	Total length (Km)	**CNG Infrastructure (1/150 km)**
Basic Network TEN-T	5.569 Km	37
Global Network TEN-T	6.518 Km	43
Rest of the State Highway Network	13.986 Km	93
CCAA High capacity roads	3.915 Km	26
TOTAL		199

Therefore, taking into account that in 2015 there were 37 infrastructures, and expecting in 2025 a fleet of 55,000 CNG vehicles, the Directive 2014/94/UE recommend to have at least 355 infrastructures (199 + 119 +37) is expected to be a total of 355 CNG infrastructure in both urban places and roads and a total fleet of 55,000 vehicles ran by Compressed natural gas, which makes a ratio of 154 vehicles per infrastructure and a cost of 3,200 € per vehicle. Finally, it will be considered that there will be a maximum of 12,000 charge stations, the same amount than the number of gas stations in Spain right now.

3.2.2.2 LIQUEFIED PETROLEUM GAS:

LPG or liquefied petroleum gas is a fuel that is manufactured with butane and propane under pressure, going from a gaseous to a liquid state, occupying less volume and thus facilitating its transport and distribution. LPG proceeds in 30% of the refining process of oil and 70%

of natural gas or oil fields. It is used in industry and transport for its economic and ecological advantages over gasoline and diesel. LPG vehicles, as was the case with those of natural gas, are not hybrids, but bicarburation vehicles that have two separate fuel tanks (LPG and gasoline) and can circulate interchangeably with both. The LPG tank is usually installed in the hole of the spare wheel and maintains the volume of the boot. The total cost per 100 km travelled is € 8.78, the most expensive within the low polluting alternatives.

Table 31:Consumption and cost associated to LPG vehicles (Source: OVEMS [12])

Model	**T2W**	**Fuel price**	**Heating power**	**Energy consumed Price**	**Total cost**	**Average Consumption**
	kWh/100km	€/l	kWh/l	€/kWh	€/100km	l/100km
LPG	100,00	0,7136	7,73	0,09	8,78	12,30

However, LPG vehicles are a fantastic alternatives in terms of its low purchasing price, if it is calculated the average purchasing price of the top 10 selling LPG vehicles, it is obtained € 13,771.10, being the cheapest alternative regarding to the purchase price. It has been achieved because most of the vehicles within this fuel type belongs to hatchback category, which historically has been cheaper than vehicle with a different shape.

Table 32:Top 10 selling LPG cars in Spain (Source: estadisticacoches.com [11])

Model	**Units sold**	**Purchase Price**
Opel Corsa	4840	9.900,00 €
Dacia Sandero	3780	9.980,00 €
Opel Clio	2441	17.180,00 €
Dacia Duster	1779	13.700,00 €
Dacia Lodgy	1675	13.225,00 €
Opel Mokka	1663	21.526,00 €
Fiat 500	1430	15.650,00 €
Fiat Tipo	1044	15.800,00 €
Fiat Panda	349	11.050,00 €
Dacia Logan	333	9.700,00 €
Average Purchase Price		**13.771,10 €**
Weighted Average Purchase Price		**13.233,68 €**

Regarding to the environment, its emissions are more innocuous in almost all respects to gasoline or diesel vehicles, without resorting to expensive hybrid or electric solutions. Besides, it is very easy to obtain since the oil refining process generates LPG and it is also possible to obtain it from natural gas fields. It considerably reduces NO_x emissions (nitrogen oxides) compared to a diesel, and CO_2 (carbon dioxide) emissions compared to gasoline. Only carbon monoxide (CO) and ammonia (NH_3) increase compared to their rivals.

Table 33:Average emissions LPG passenger cars (Source: OVEMS [12])

Model	**Average Emissions**					
	W2W (g CO2 /km)	W2T (g CO2 /km)	T2W (g CO2 /km)	NOx (mg/km)	PM2.5 (mg/km)	PM10 (mg/km)
LPG	228,43	47,77	180,66	88,00	1,3	-

Finally, the cost of implementing the recharging stations necessary for the penetration of LPG vehicles in Spain has been studied. In this case Directive 2014/94/UE does not stablish the number of infrastructures needed. These happen because of two main reason, the first one LPG infrastructures are cheaper than other alternatives infrastructures, and LPG's suppliers are the same as diesel and gasoline, making the transition much cheaper. Currently, the cost of implementing a new LPG infrastructure is around 100,000 euros, and that station could supply up to 300 vehicles according to the Ministry of Energy and Consumption [17]. The implementation of the infrastructure will follow the distribution of *figure 27*, and the limit will be 12,000 charging stations, which is the current number of petrol stations.

3.2.3 OTHERS:

In this section it will be discussed others low polluting alternatives which are less implemented in Spain or pollutes more than the previous one. Even though these types of vehicles will not be considered on the scenarios of the thesis, it is important to be explained for obtaining a better understanding of the current situation.

3.2.3.1 HYDROGEN VEHICLE:

Hydrogen is the most abundant chemical element, taking up three quarters of the mass of the Universe. The discovery of this element dates from 16th century when the Swiss Paracelsus realized as the result of mixing metals with acids. Although it was not until a century later when Cavendish, Lavoisier and Laplace discovered that the bubbles produced by this reaction were made up of a unknown element that reacted with oxygen in the air to give water, which was called as hydrogen : water producer.

Today, hydrogen represents one of the most used fuel in the industry. Every year, around 70 million tons of high-quality hydrogen are synthesized around the world, being China the country where hydrogen synthesize is the most implanted. It is true that hydrogen can be used in many different applications, but petrochemical cracking processes is where it is used the most. On these processes lighter hydrocarbons are obtained from other heavy ones by splitting the molecular chains with hydrogen.

Even though the first combustion engine in history was powered by hydrogen and space rockets have managed to leave the Earth's atmosphere, and even reach the Moon, burning hydrogen. However, hydrogen engine vehicle has not been able to catch on yet. The use of hydrogen in the automotive industry is linked to the discovery in 1848 of the fuel cell, a device capable of reacting hydrogen and oxygen to generate electricity and water. But it was not until Hyundai Tucson came up in 2013, hydrogen vehicles were not seen as an alternative to ICE vehicles.

This system uses the aforementioned gas to generate the electricity that drives the vehicle in the car itself, by combining it with the oxygen in the air. Therefore, it is like an electric vehicle, but with the difference that this energy is generated on board the car rather than in a power plan.

One of the key things, about hydrogen is that it keeps both the advantages of the combustion car and the electric battery, but without most of their disadvantages. As it can be observed in the last model of Hyundai (Nexo), hydrogen vehicles have a competitive autonomy, this model allows you to cover 666 km with the new homologation cycle, hammering EV's autonomy, and obtaining a similar result than ICE vehicles. Moreover, its recharge is quite fast, it only takes between six and eight minutes, far from what it takes to the electric vehicles which in case of loading it with less than 22 kWh, it can take around 10 hours. In addition, the recharge is provided without emissions.

However, for hydrogen to revolutionize transportation, it takes much more than building vehicles capable of movement. The hydrogen vehicle hardly can do a journey in Spain. This is mainly because of the lack of 'hydrogenerators'. Currently, the owners are not able to recharge their tanks in nearly any part of the country. Despite all the benefits of H2 vehicles, today the number of their filling stations (*figure 32*) are the main drawback for the popularization of these vehicles compared to those with electric batteries. It seems that it will take a long time to reach the necessary conditions for this technology to settle definitively. Therefore, it has been decided not to include this technology in any of the scenarios.

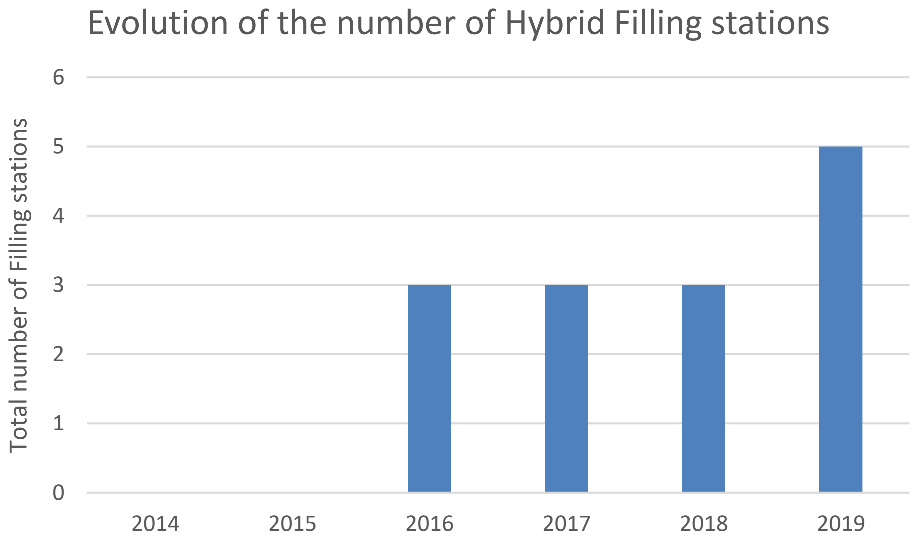


Figure 32:Evolution of the Hybrid Filling stations (Source: EAFO [29])

3.2.3.2 LIQUID NATURAL GAS VEHICLE:

Liquefied natural gas (LNG) is a natural gas that has been processed to be transported and stored in a liquid state at low temperatures, that goes 160 degrees below zero and the advantage is its autonomy which is much better. It is important not to confuse it with compressed natural gas (CNG), which is the same element but in a different phase (stored at high pressures, between 200 and 250 bars).

Regarding environmental performance, the benefits are significant with fossil natural gas, with a drastic reduction of 99% of suspended particles and 60% of NOx compared to the limits of the Euro VI standard. Furthermore, by running on biomethane, its CO_2 emissions are reduced by 95%. It also reduces noise pollution, with extremely quiet operation at less than 71 dB. This revolutionary truck gives transport operators the competitive advantage of offering truly sustainable logistics.

Liquefied natural gas is currently of the few real alternatives to using ICE vehicles for long-distance transportation. The existence of reserves that will guarantee the supply of LNG for the next decades, as well as the development of other technologies (electricity, biogas, hydrogen ...); which are still in the initial phase to be used on long routes, make liquefied natural gas a reality.

3.2.3.3 HYBRID VEHICLE:

A hybrid is a car powered by two engines of different natures: on the one hand, an efficient combustion engine and on the other, a powerful electric motor. In this way, the car uses or alternates both sources of energy to move in a more economical and sustainable way without losing the benefits of a traditional vehicle. Sometimes it circulates only in electrical and others with an electrical and combustion combination.

The good thing about hybrid vehicle is that they have a smart way of managing power and selecting what type of propulsion they use. Depending on the road and the needs of the driver, the car will distribute the work between the two engines in one way or another. It is not considered as a pure electric vehicle because of the way it works and obtain the energy. Instead of charging the vehicle battery off-board, the hybrid vehicles consist of their own battery recharging system, it is known as regeneration from braking. The drivetrain can be used to convert kinetic energy (from the moving car) into stored electrical energy (batteries). The same electric motor that powers the drivetrain is used to resist the motion of the drivetrain. This applied resistance from the electric motor causes the wheel to slow down and simultaneously recharge the batteries.

In addition, according to their principle of operation, Hybrid vehicles can be classified into three types:

1. Parallel Hybrid: Both the conventional and electric motors work at the same time to transmit power to the wheels. It is a relatively simple solution, but it is not the most efficient. They are also known as semi-hybrids.

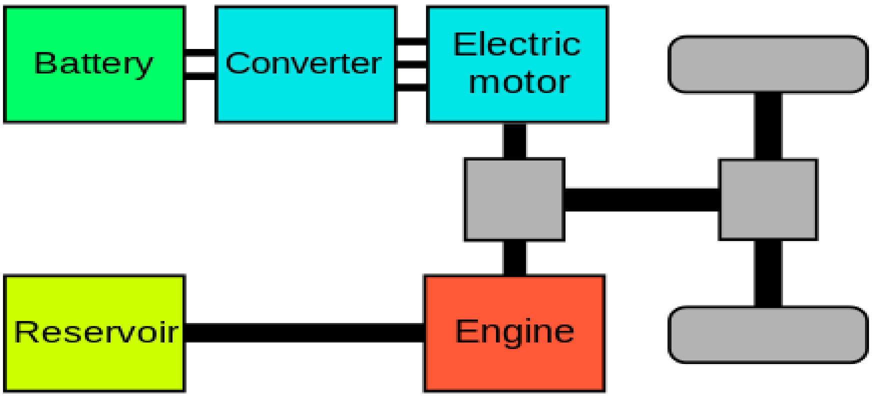


Figure 33: Structure of a parallel hybrid electric vehicle (Source: wikiwand [39])

2. Serial Hybrid: The conventional combustion engine has no mechanical connection to the wheels, it is only used to generate electricity. That is, its mission is to generate electricity so that the electric motor moves the vehicle. When the battery is full, the conventional motor is temporarily disconnected.

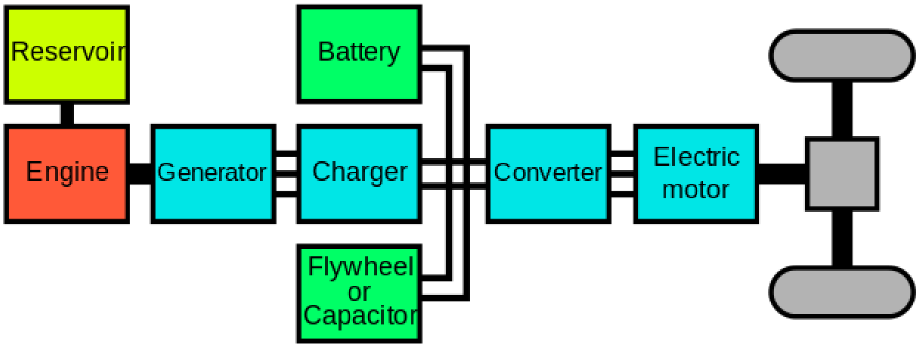


Figure 34:Structure of a series-hybrid vehicle (Source: wikiwand [39])

3. Combined hybrid: The car can be moved with the impulse of any of its motors (conventional and electric), since both have a mechanical connection with the wheels, which allows it to circulate in electric mode. It is the most efficient solution. They are also known as full-hybrid.

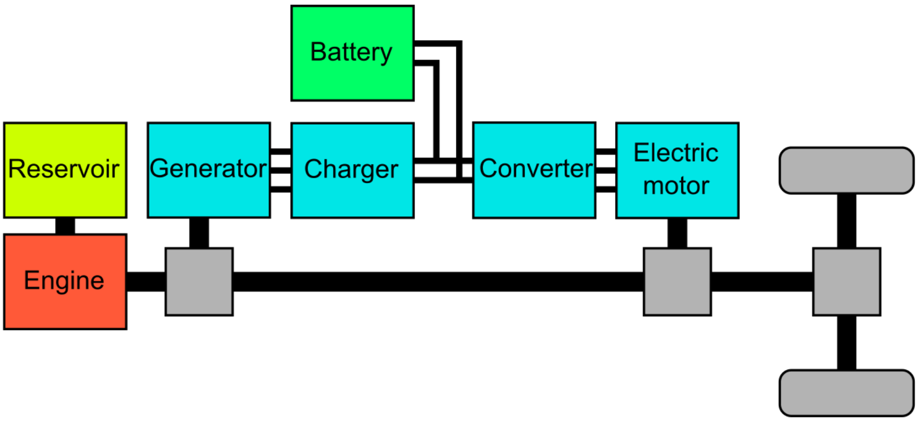


Figure 35:Structure of a combined hybrid electric vehicle (Source: wikiwand [39])

Regarding to the environmental impact of this type of vehicle, it can be considered as a low polluting fuel, their vehicle emissions are getting lower than the level recommended by the EPA (United States Environmental Protection Agency) which is set to 5.5 metric tons of carbon dioxide. If the metric tons of carbon dioxide of three most popular hybrid vehicles, Honda Civic, Honda Insight, and Toyota Prius, it is obtained 4.1, 3.5, and 3.5 tonnes of CO2 showing a significant improvement in carbon dioxide emissions. Hybrid vehicles can cut smog-forming pollutants into the air by up to 90% and cut carbon dioxide emissions in half. Despite the good results obtained during the car's operation, there is still a problem regarding the environmental damage of the hybrid car battery. Today most batteries in hybrid vehicles are nickel metal hydride or lithium ion battery, being the last one the less polluting choice.

3.3 FUEL COMPARISON:

After having analyzed each of the vehicles fuel types on the market separately, tables and graphs will be shown which will compare the efficiency, emissions, average purchasing price, consumption and its associated cost, of all fuels. This will provide an idea of both its strengths and its shortcomings per each fuel type. Moreover, it will also point out where they have to improve in order to be competitive and end up taking control of the market.

Regarding to the average purchasing price of the top 10 most sold models per type of fuel, it is observed that electric vehicles are the most expensive, existing a gap compared to their competitors. This table suggests gas fuels as good alternative to conventional combustion vehicles, due to its competitive prices.

Table 34: Comparison of the Average and Weighted Average Purchase Price of all the alternatives technology (Own source)

Fuel type	**Average Purchase Price**	**Weighted Average Purchase Price**
Gasoline	17.383,20 €	17.188,10 €
Diesel	26.316,70 €	26.492,40 €
Battery Electric Vehicle	43.929,21 €	37.731,82 €
Plug-in Electric Vehicle	48.210,00 €	44.508,69 €
Compressed Natural Gas	25.859,40 €	24.387,04 €
Liquid petrolum Gas	13.771,10 €	13.233,68 €

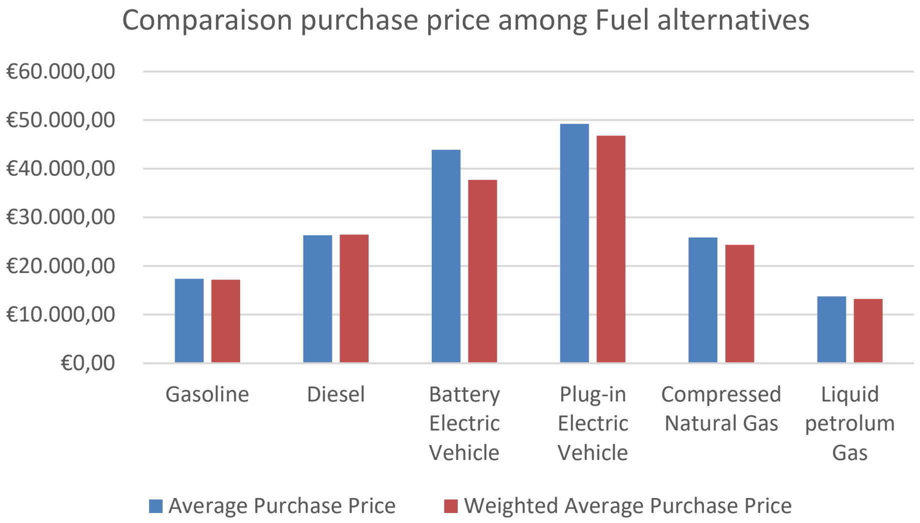


Figure 36:Average purchasing price (Source: estadisticacoches.com [11])

However, comparing the 10 best-selling cars of each type of fuel is not very accurate since it does not take into account the range of the vehicle or the type of vehicle (SUV, coupe, etc.) Moreover, in case of not checking the range and brand, the study could be biased, since it would not take into account the purchasing power of the average buyer of low polluting fuel vehicles. Because of that it will be compared vehicles that can be similar in terms of power, range and performance, and it will allow to draw conclusion about the up-front purchase price. It will be taken 5 of the most sold vehicles per fuel type which share similar characteristics. All the data presented in *table 35* has been obtained from their respective catalog, which can be found on its corporate website.

Table 35: Comparison characteristics of 5 of the most sold vehicles per fuel type (Source: Own source)

Model	Fuel	Price	Type	Average Consumption	CO_2	Autonomy
Dacia Sandero	Gasoline	8.680,00 €	Hatchback	5,845	131,5	-
Seat Leon	Gasoline	21.960,00 €	Hatchback	4,8	110	-
Seat Ibiza	Gasoline	17.550,00 €	Hatchback	6,5	154	-
Volkswagen Polo	Gasoline	17.662,00 €	Hatchback	5,5	125	-
Seat Arona	Gasoline	19.180,00 €	Hatchback	4,9	111	-

Nissan QASHQAI	Diesel	24.200,00 €	SUV	5,45	144	-
Peugeot 308	Diesel	26.750,00 €	Hatchback	4,5	119	-
Mercedes Clase A	Diesel	31.600,00 €	Hatchback	4,6	120	-
Seat Leon	Diesel	24.380,00 €	Hatchback	4,2	111	-
VOLKSWAGEN Golf	Diesel	26.639,00 €	Hatchback	5	131	-
Nissan Leaf	BEV	34.619,90 €	Hatchback	13,6kWh/100km	0	270
Renault Zoe Z.E. 50	BEV	18.847,23 €	Hatchback	17,7 kWh/100km	0	386
Hyundai Kona BEV	BEV	35.050,00 €	Hatchback	14,25 kWh/100km	0	449
Volkswagen e-Golf	BEV	24.400,00 €	Hatchback	15,4 kWh/100km	0	275
BMW i3	BEV	40.600,00 €	Hatchback	14,3 kWh/100km	0	337,5
Mitsubishi Outlander PHEV	PHEV	46.300,00 €	SUV	16,9 kWh/100km + 2 l/100km	46	45
Mini Countryman PHEV	PHEV	40.900,00 €	Hatchback	13,6 kWh/100km + 2 l/100Km	44	56
BMW 225 XE Active Tourer	PHEV	44.000,00 €	SUV	17,25 kWh/100 km + 2,6 l/100km	123	51,5
Kia Niro PHEV	PHEV	25.800,00 €	Hatchback	12,2 kWh/100km + 1,4 l/100km	31	49
Hyundai Ioniq PHEV	PHEV	35.525,00 €	Hatchback	15,1 kWh/100km + 1,1 l/100km	26	59
Seat Leon	CNG	27.550,00 €	Hatchback	4,25 Kg/100 Km	143,5	-
Seat Ibiza	CNG	19.250,00 €	Hatchback	3,85 Kg/100 Km	126,5	-
Seat Arona	CNG	20.870,00 €	SUV	3,95 Kg/100 Km	126	-
Skoda Octavia	CNG	19.400,00 €	Sedan	2,9 Kg/100 km	115	-
Volkswagen Polo TGI	CNG	19.625,00 €	Hatchback	3,3 Kg/100 Km	90	-
Opel Corsa	LPG	9.900,00 €	Hatchback	6,9 l/100km	113	-
Dacia Sandero	LPG	9.980,00 €	Hatchback	6,085	136,5	-
Opel Clio	LPG	17.180,00 €	Hatchback	5,5	123	-
Dacia Duster	LPG	13.700,00 €	SUV	6,45	138,5	-
Opel Mokka	LPG	21.526,00 €	SUV	7,7	124	-

In terms of consumption and cost per 100 km travelled, there is a clear winner, electric vehicles. This type of vehicles has achieved a price much lower than its competitors, reaching a price of up to 8 times lower as is the case with gasoline vehicles. As has happened throughout this chapter, a comparative table (*table 36*) obtained from OVEMS ("Observatory of electric vehicles and sustainable mobility") [14] shows the average consumption, heating price, and fuel cost per 100 km travelled among others, of each fuel type. Although the fuel price (per kilogram, liter or kWh) fluctuates over the time, for the analysis of this project it will be used the fix prices obtained from the OVEMS, which data from 2019. It is believed that it would be more accurate using the data from the past year rather than the current ones due to the fact that the current pandemic we are getting through could distortion the results.

Table 36:Consumption and cost associated to fuel type vehicles (Source: OVEMS [14])

Model	**T2W**	**Fuel price**	**Heating power**	**Energy consumed Price**	**Total cost**	**Average Consumption**
	kWh/100km	€/l	kWh/l	€/kWh	€/100km	l/100km
Gasoline	83,33	1,31	9,23	0,14	11,83	9,03
Diesel	71,43	1,22	10,26	0,119	8,49	6,96
BEV Fast charge	19,50	-	-	0,17	3,27	-
BEV	19,50	-	-	0,09	1,72	-
PHEV	34,09	1,31	9,23	0,14	4,84	-
CNG	83,33	0,89	15,75	0,06	4,71	5,50
LPG	100,00	0,7136	7,73	0,09	8,78	12,30

As it was commented previously, it is believed that for doing an accurate comparison among the fuel alternatives, it is required to compare vehicles with similar vehicles regarding their shape, range, brand etc. For this reason, it has been calculated the average of *table 37* where it can be observed that the cost obtained are not far from the one obtained from the OVEMS.

Table 37: Comparison characteristics per fuel type (Source: Own source)

Fuel	**Price (€)**	**Average Consumption**	**Total cost (€/100km)**	**TTW CO2 (g/100km)**
Gasoline	17.006,40 €	5,509 l/100km	7,217	126,3
Diesel	26.838,20 €	4,75 l/100km	5,795	125
BEV*	30.703,43 €	15,25 kWh/100km	2,593	0
PHEV*	38.505,00 €	15,01 kWh/100km + 1,82 l/100km	4,936	54
GNC	21.339,00 €	3,648 kg/100km	3,247	120,2
GLP	14.457,20 €	6,527 l/100km	4,658	127

**It has been used the fast charge*

Although it will be discussed in the next chapter, it is interesting to do a primitive analysis of the cost of the vehicle including the fixed cost and the variable costs. *Figure 37 and 38* shows this analysis, by means of a comparative graph where all the low polluting options are represented. It is presented twice because each one has used different data, the first one *(figure 37)* has used the data obtained from the OVEMS, using the weighted average purchase price as the fixed cost, while the second one will be drawn according to the data obtained from the catalog of 5 of the most sold car per fuel type.

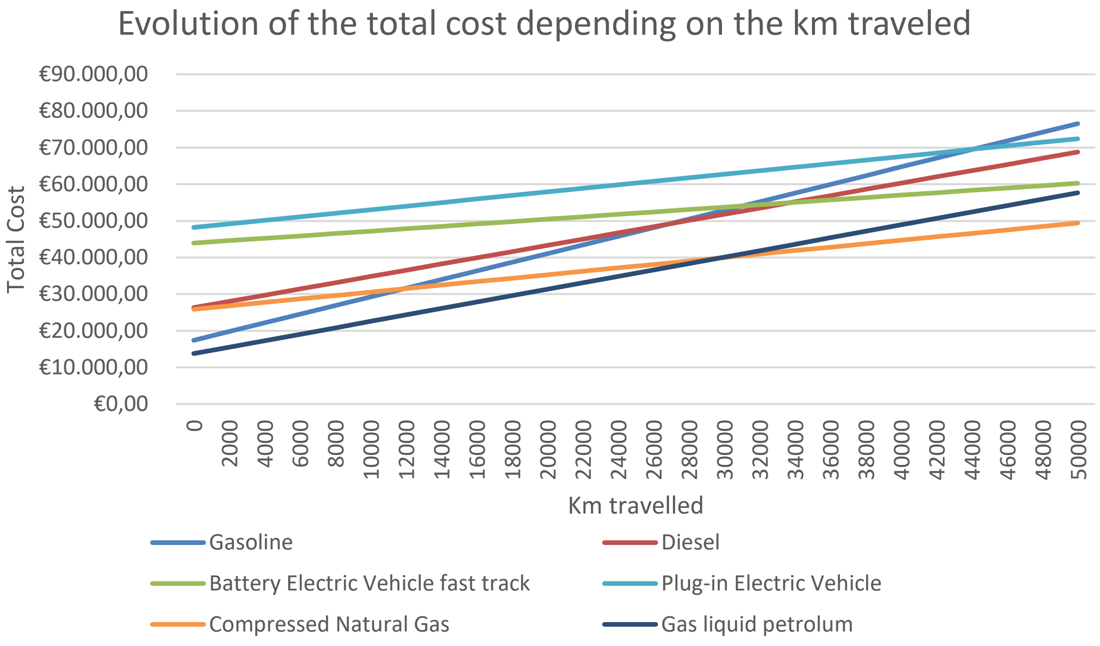


Figure 37: Evolution of the total cost depending on the km traveled (Source: OVEMS [14])

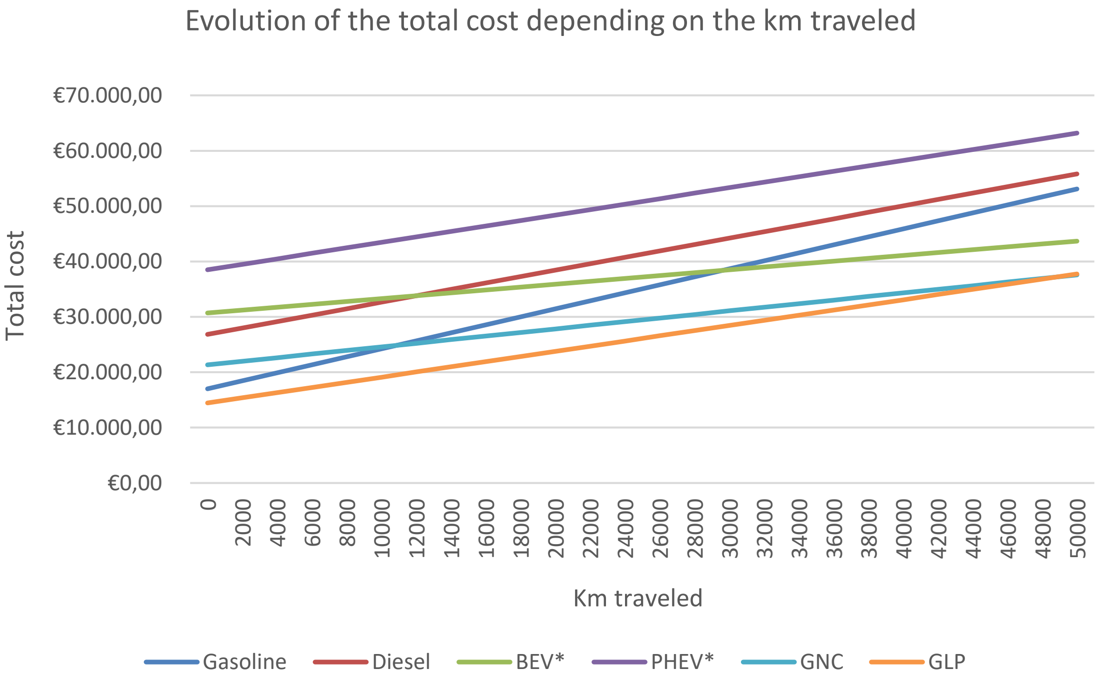


Figure 38:Evolution of the total cost depending on the km traveled (Own source)

In addition to all the variables studied, it will be important to also analyze other fixed and variable costs associated with the vehicle, such as the cost of insurance, vehicle registration, and maintenance costs. It seems necessary to include all of these expenses because it will provide a more accurate analysis of the total cost associated with each type of vehicle.

Therefore, in line with what has just been commented, the price of the Volkswagen Golf has been calculated with each of the fuels in one of the most important insurers in the country (Mapfre)[4]. Unfortunately, Mapfre has not yet included the version of the Golf LPG, which is why it has been decided to include the Opel Corsa LPG in the comparison, it will be considered that because it is a car with similar benefits, it will not have any negative impact on the analysis of this project.

Table 38: Insurance cost per vehicle type (Source: Mapfre [18])

	Cover	**Volkswagen E-Golf (BEV)**	**Volkswagen E-Golf (PHEV)**	**Volkswagen Golf (Diesel)**	**Volkswagen Golf (Gasolina)**	**Volkswagen Golf (CNG)**	**Opel Corsa (LPG)**
Third party	Basic Policy	247,74 €	278,40 €	268,19 €	250,56 €	246,46 €	309,18 €
	Theft + Fire	297,84 €	343,60 €	297,82 €	279,43 €	275,63 €	343,41 €
	Moons + Theft + Fire	334,57 €	381,28 €	327,41 €	305,11 €	303,93 €	369,38 €
Fully comprehensive	Franchise 600	585,27 €	577,70 €	480,20 €	430,89 €	450,65 €	444,38 €
	Franchise 150	792,61 €	733,34 €	581,48 €	509,96 €	550,16 €	528,01 €
	Without franchise	1.665,91 €	1.376,17 €	993,60 €	828,42 €	955,85 €	871,19 €

The different insurance costs shown in *Table 39* have been obtained on the website of Mapfre [18] for the same person insured, which has the following characteristics:

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[4] Mapfre is a Spanish multinational company dedicated to the insurance and reinsurance sector, with a presence in 49 countries.

Table 39: Characteristics of the driver insured (Source: Own source)

Gender	**Male**
Driver's birthdate	07/02/1963
Date of obtaining the driving license	11/01/1984
Vehicle purchase date	01/04/2020
Parking	Private unattended
Zip Code	45003 (Toledo)

As it can seen, there are a wide variety of types of insurance depending on the coverage selected. It is not the objective of this study to know the influence or impact of insurance on the total cost of the vehicle. Therefore, despite the fact that scenarios could be generated with different insurances, it is considered that it will not add value to the thesis. Hence, to compare the technologies, it will be assumed that the insurance taken is from third parties with basic coverage. In this way, the study will not be biased by the purchasing power of the vehicle buyer.

Next, the total maintenance cost of each type of vehicle will be shown based on the years of the car. The data has been taken from different sources, but mainly in the analysis that Xataca [19] makes comparing the maintenance costs of the Volkswagen Golf gasoline, diesel and BEV. The prices were obtained through a Volkswagen web application, which allowed calculating the maintenance price of your car over the years. Unfortunately, this website has stopped working, which is why this study has taken the data from the analysis made by Xataca [19] as a reference instead of having performed a new one.

Table 40: Maintenance cost over the years of the Gasoline Vehicle (Own source)

Gasoline	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Oil filter replacement	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €
Timing Belt Replacement	-	-	-	-	400 €	-	-	-	-	400 €	-	-	-	-	400 €	-	-	-	-	400 €
Wiper blade replacement and washer fluid	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €
Multipoint inspection	-	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €
New tires	-	-	-	450 €	-	-	450 €	-	-	450 €	-	-	450 €	-	-	450 €	-	-	450 €	-
Engine air filter replacement	-	-	-	45 €	-	-	-	45 €	-	-	-	45 €	-	-	-	45 €	-	-	-	45 €
Fuel filter replacement	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spark plug replacement	-	-	-	120 €	-	-	-	120 €	-	-	-	120 €	-	-	-	120 €	-	-	-	120 €
Brake pad replacement	-	-	35 €	-	-	35 €	-	-	35 €	-	-	35 €	-	-	35 €	-	-	35 €	-	-
ITV					35 €		35 €		35 €		35 €	35 €	35 €	35 €	35 €	35 €	35 €	35 €	35 €	35 €
Insurance Vehicle	251 €	251 €	251 €	251 €	251 €	251 €	251 €	251 €	251 €	251 €	251 €	251 €	251 €	251 €	251 €	251 €	251 €	251 €	251 €	251 €
Total	251 €	531 €	366 €	1.146 €	766 €	566 €	816 €	696 €	401 €	1.381 €	366 €	766 €	816 €	566 €	801 €	1.181 €	366 €	601 €	816 €	1.131 €
Average cost per year if the life is 10 years					692 €															
Average cost per year if the life is 15 years					682 €															
Average cost per year if the life is 20 years					716 €															

Table 41:Maintenance cost over the years of the Diesel Vehicle (Own source)

Diesel	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Oil filter replacement	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €
Timing Belt Replacement	-	-	-	-	400 €	-	-	-	-	400 €	-	-	-	-	400 €	-	-	-	-	400 €
Wiper blade replacement and washer fluid	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €
Multipoint inspection	-	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €
New tires	-	-	-	450 €	-	-	450 €	-	-	450 €	-	-	450 €	-	-	450 €	-	-	450 €	-
Engine air filter replacement	-	-	-	45 €	-	-	-	45 €	-	-	-	45 €	-	-	-	45 €	-	-	-	45 €
Fuel filter replacement	-	-	-	-	-	75 €	-	-	-	-	-	75 €	-	-	-	-	-	75 €	-	-
Spark plug replacement	-	-	-	0 €	-	-	-	0 €	-	-	-	0 €	-	-	-	0 €	-	-	-	0 €
Brake pad replacement	-	-	35 €	-	-	35 €	-	-	35 €	-	-	35 €	-	-	35 €	-	-	35 €	-	-
ITV	-	-	-	-	42 €	-	42 €	-	42 €	-	42 €	42 €	42 €	42 €	42 €	42 €	42 €	42 €	42 €	42 €
Insurance Vehicle	268 €	268 €	268 €	268 €	268 €	268 €	268 €	268 €	268 €	268 €	268 €	268 €	268 €	268 €	268 €	268 €	268 €	268 €	268 €	268 €
Total	268 €	548 €	383 €	1.043 €	790 €	658 €	840 €	593 €	425 €	1.398 €	390 €	745 €	840 €	590 €	825 €	1.085 €	390 €	700 €	840 €	1.035 €

Average cost per year if the life is 10 years	695 €
Average cost per year if the life is 15 years	689 €
Average cost per year if the life is 20 years	719 €

Table 42:Maintenance cost over the years of the Battery Electric Vehicle (Own source)

BEV	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Oil filter replacement	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Timing Belt Replacement	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wiper blade replacement and washer fluid	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €
Multipoint inspection	-	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €
New tires	-	-	-	450 €	-	-	450 €	-	-	450 €	-	-	450 €	-	-	450 €	-	-	450 €	-
Engine air filter replacement	-	-	-	0 €	-	-	-	0 €	-	-	-	0 €	-	-	-	0 €	-	-	-	45 €
Fuel filter replacement	-	-	-	-	-	0 €	-	-	-	-	-	0 €	-	-	-	-	-	0 €	-	-
Spark plug replacement	-	-	-	0 €	-	-	-	0 €	-	-	-	0 €	-	-	-	0 €	-	-	-	0 €
Brake pad replacement	-	-	-	35 €	-	-	-	35 €	-	-	-	35 €	-	-	-	35 €	-	-	-	35 €
ITV	-	-	-	-	33 €	-	33 €	-	33 €	-	33 €	33 €	33 €	33 €	33 €	33 €	33 €	33 €	33 €	33 €
Insurance Vehicle	248 €	248 €	248 €	248 €	248 €	248 €	248 €	248 €	248 €	248 €	248 €	248 €	248 €	248 €	248 €	248 €	248 €	248 €	248 €	248 €
Total	248 €	368 €	328 €	853 €	361 €	368 €	811 €	403 €	361 €	818 €	361 €	436 €	811 €	401 €	361 €	886 €	361 €	401 €	811 €	481 €
Average cost per year if the life is 10 years					492 €															
Average cost per year if the life is 15 years					486 €															
Average cost per year if the life is 20 years					511 €															

Table 43:Maintenance cost over the years of the Plug-in Electric Vehicle (Own source)

PHEV	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Oil filter replacement	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €
Timing Belt Replacement	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wiper blade replacement and washer fluid	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €
Multipoint inspection	-	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €
New tires	-	-	-	450 €	-	-	450 €	-	-	450 €	-	-	450 €	-	-	450 €	-	-	450 €	-
Engine air filter replacement	-	-	-	45 €	-	-	-	45 €	-	-	-	45 €	-	-	-	45 €	-	-	-	45 €
Fuel filter replacement	-	-	-	-	-	75 €	-	-	-	-	-	75 €	-	-	-	-	-	75 €	-	-
Spark plug replacement	-	-	-	0 €	-	-	-	0 €	-	-	-	0 €	-	-	-	0 €	-	-	-	0 €
Brake pad replacement	-	-	-	35 €	-	-	-	35 €	-	-	-	35 €	-	-	-	35 €	-	-	-	35 €
ITV	-	-	-	-	42 €	-	42 €	-	42 €	-	42 €	42 €	42 €	42 €	42 €	42 €	42 €	42 €	42 €	42 €
Insurance Vehicle	278 €	278 €	278 €	278 €	278 €	278 €	278 €	278 €	278 €	278 €	278 €	278 €	278 €	278 €	278 €	278 €	278 €	278 €	278 €	278 €
Total	278 €	558 €	358 €	1.088 €	400 €	633 €	850 €	638 €	400 €	1.008 €	400 €	755 €	850 €	600 €	400 €	1.130 €	400 €	675 €	850 €	680 €

Average cost per year if the life is 10 years	622 €
Average cost per year if the life is 15 years	615 €
Average cost per year if the life is 20 years	648 €

Table 44:Maintenance cost over the years of the Compressed Natural Gas Vehicle (Own source)

CNG	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Oil filter replacement	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €
Timing Belt Replacement	-	-	-	-	400 €	-	-	-	-	400 €	-	-	-	-	400 €	-	-	-	-	400 €
Wiper blade replacement and washer fluid	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €
Multipoint inspection	-	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €
New tires	-	-	-	450 €	-	-	450 €	-	-	450 €	-	-	450 €	-	-	450 €	-	-	450 €	-
Engine air filter replacement	-	-	-	45 €	-	-	-	45 €	-	-	-	45 €	-	-	-	45 €	-	-	-	45 €
Fuel filter replacement	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spark plug replacement	-	-	-	120 €	-	-	-	120 €	-	-	-	120 €	-	-	-	120 €	-	-	-	120 €
Brake pad replacement	-	-	35 €	-	-	35 €	-	-	35 €	-	-	35 €	-	-	35 €	-	-	35 €	-	-
ITV	-	-	-	-	120 €	-	120 €	-	120 €	-	120 €	120 €	120 €	120 €	120 €	120 €	120 €	120 €	120 €	120 €
Insurance Vehicle	246 €	246 €	246 €	246 €	246 €	246 €	246 €	246 €	246 €	246 €	246 €	246 €	246 €	246 €	246 €	246 €	246 €	246 €	246 €	246 €
Total	246 €	526 €	361 €	1.141 €	846 €	561 €	896 €	691 €	481 €	1.376 €	446 €	846 €	896 €	646 €	881 €	1.261 €	446 €	681 €	896 €	1.211 €
Average cost per year if the life is 10 years					776 €															
Average cost per year if the life is 15 years					786 €															
Average cost per year if the life is 20 years					830 €															

Table 45:Maintenance cost over the years of the Liquid Petroleum Gas Vehicle (Own source)

LPG	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Oil filter replacement	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €	-	160 €
Timing Belt Replacement	-	-	-	-	400 €	-	-	-	-	400 €	-	-	-	-	400 €	-	-	-	-	400 €
Wiper blade replacement and washer fluid	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €	-	40 €
Multipoint inspection	-	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €	80 €
New tires	-	-	-	450 €	-	-	450 €	-	-	450 €	-	-	450 €	-	-	450 €	-	-	450 €	-
Engine air filter replacement	-	-	-	45 €	-	-	-	45 €	-	-	-	45 €	-	-	-	45 €	-	-	-	45 €
Fuel filter replacement	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spark plug replacement	-	-	-	120 €	-	-	-	120 €	-	-	-	120 €	-	-	-	120 €	-	-	-	120 €
Brake pad replacement	-	-	35 €	-	-	35 €	-	-	35 €	-	-	35 €	-	-	35 €	-	-	35 €	-	-
ITV	-	-	-	-	120 €	-	120 €	-	120 €	-	120 €	120 €	120 €	120 €	120 €	120 €	120 €	120 €	120 €	120 €
Insurance Vehicle	309 €	309 €	309 €	309 €	309 €	309 €	309 €	309 €	309 €	309 €	309 €	309 €	309 €	309 €	309 €	309 €	309 €	309 €	309 €	309 €
Total	309 €	589 €	424 €	1.204 €	909 €	624 €	959 €	754 €	544 €	1.439 €	509 €	909 €	959 €	709 €	944 €	1.324 €	509 €	744 €	959 €	1.274 €

Average cost per year if the life is 10 years	713 €
Average cost per year if the life is 15 years	723 €
Average cost per year if the life is 20 years	767 €

To conclude the cost analysis section of each of the fuel alternatives, a table will be shown summarizing the cost per average year of maintenance of each of the fuels for a life of the car of 10, 15 and 20 years. Despite the fact that currently there are ICE vehicles older than 20 years, in the scenarios of this thesis, this possibility will not be analyzed or even compared because CNG and LPG vehicles according to the regulation EC 110/2010, their tanks have a maximum useful life of 20 years.

Table 46: Comparison per fuel type of the average maintenance cost (Own source)

	Gasoline	**Diesel**	**BEV**	**PHEV**	**CNG**	**LPG**
Average cost per year if the life is 10 years	691,6 €	694,8 €	491,6 €	621,5 €	713,0 €	775,7 €
Average cost per year if the life is 15 years	681,9 €	689,3 €	485,7 €	614,8 €	723,1 €	785,8 €
Average cost per year if the life is 20 years	716,1 €	719,5 €	511,2 €	648,0 €	767,2 €	829,9 €

Lastly, the costs associated with vehicle charging infrastructure will be taken into account in the macro analysis. To this end, it will be assumed that the proportion of recharging point vehicles remains constant throughout the years.

Table 47: Comparison between the cost of infrastructure per vehicle (Own Source)

	Vehicles per infrastructure	**Cost per vehicle**
Electric Vehicles	1,97	501,39 €
CNG	154,93	3.227,27 €
LPG	600,00	300,00 €

Not only it is important economic factors for this project, emissions are also of great interest. *Table 48* compares the average emissions per vehicle fuel. In this case, once again Electric vehicles obtain the best values in this category. But still have a long way for improving their Well to tank CO_2 emissions.

Table 48:Average emissions per passenger cars fuel type (Source: OVEMS [14])

Model	**Average Emissions**					
	W2W	**W2T**	**T2W**	**NOx**	**PM$_{2.5}$**	**PM$_{10}$**
	(g CO2 /km)	(g CO2 /km)	(g CO2 /km)	(mg/km)	(mg/km)	(mg/km)
Gasoline	246,04	54,04	192	126,00	2,54	0,05
Diesel	212,96	42,96	170	170	1,5	0,15
BEV	52,62	52,62	-	-	-	-
PHEV	70,00	70,00	-	-	-	-
CNG	187,82	25,82	162	56,00	1,1	-
GLP	228,43	47,77	180,66	88,00	1,3	-

CHAPTER 4: SPANISH CAR FLEET

4.1 CURRENT COMPOSITION OF CAR FLEET

Knowing the car fleet in Spain is very important for this study. In 2018, according to the last inventory from the General Directorate of Traffic (DGT) [21], the total number of vehicles registered in Spain amounted to 37.729 million vehicles. Of these, 24,074,151 were passenger cars, representing 71.37% of the total. This supposes a motorization rate[5] of 516 vehicles per thousand of habitants, and if it is calculated taking into account just the adult population (over 18 years old)[6], it is resulted a motorization rate of 628 vehicles per thousand of adult habitants, which is even more shocking.

Within the group of passenger cars, 43.65% use gasoline while a 56.08% of passenger's car use diesel as fuel. The percentage of passenger cars using alternative fuels keeps being low, standing at 0.26%, despite having increased by 117.5 % in just the last year.

The evolution of the total number of passenger cars and number of vehicles sold per year follows an upward trend during the last years, although as it happens between 2008 and 2014[7], it is expected that due to the appearance of the covid-19, it is expected a deep recession of this sector. The financial crisis of 2008 had a huge impact on this sector, during those years car sales fell by an average of 11.57%. In 2012, the number of cars sold was 710,738, whereas just 5 years earlier, in 2007 it had been 1,633,806, which represents a decrease of more than 50%, specifically a reduction of 56.5%.

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[5] Rate of motorization= number of vehicles/ 1000 habitants

[6] From the age of 18 years old, it is allowed to drive a passenger car in Spain

[7] 2008 The financial crisis of 2007–08, also known as the global financial crisis (GFC), was a severe worldwide economic crisis. It is considered by many economists to have been the most serious financial crisis since the Great Depression of the 1930s.

This drop in the number of registrations, resulted in an aging of the park, which has gone from an average age of 8 years in 2007 to 11.28 years in 2014. Despite the fact that the sector has recovered in recent years, the average age of the Spanish vehicle fleet has continued to grow up to 12.42 years.

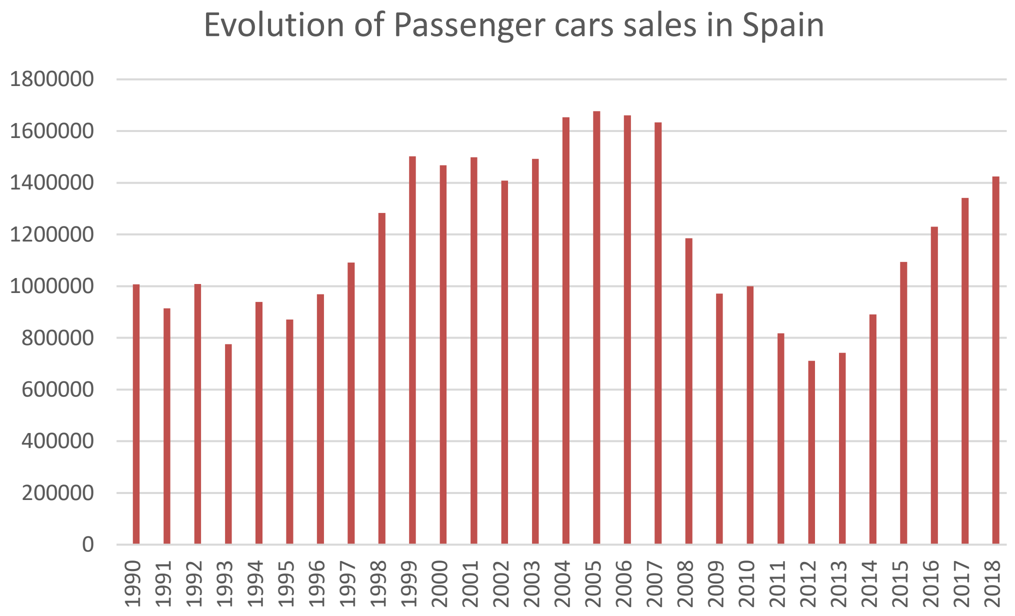

Figure 39:Evolution of Passenger cars sales in Spain (Source:ANFAC [33])

As it can be observed in *Figure 39*, there seems to be an average number of passenger sales of around 1,100,000 annual enrollments, which fluctuate depending on the economic situation. For instance, in the period between 1990 and 1995, a minimum number of registrations is observed. This was due to the fact that developed countries were affected by an economic and financial crisis caused by Japanese asset price bubble[8] in 1990 and aggravated by the tensions caused by the Gulf War[9]. There is also a peak in registrations

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[8] Japanese asset price bubble, The Japanese asset price bubble was an economic bubble in Japan from 1986 to 1991 in which real estate and stock market prices were greatly inflated.

[9] Gulf war was a war waged by coalition forces from 35 nations led by the United States against Iraq in response to Iraq's invasion and annexation of Kuwait arising from oil pricing and production disputes.

from 2004 to 2008, at the height of the Spanish economy, with the arrival of the crisis, as already mentioned, there was a drastic drop in the number of sales.

Figure 40 and 41 represent the evolution of passenger cars sales per fuel type during the last 5 years. As it can be observed on the graphic, despite the fact that diesel has been the leading fuel in Spain during the last decade, there has been an upward trend of gasoline and other low polluting fuels, making gasoline vehicles the most sold. The reason for this change, according to a report made by "Standard & Poor's" (S&P) [22], are found in the air quality policies developed at an European and a local level, like it has happened in Madrid. As it has been shown in the section dedicated to the comparison between ICE and electric vehicles, diesel vehicles emit a greater quantity of nitrogen oxides (NO_x) than vehicles that use gasoline as fuel, this pollutant is very harmful to our health. This has led city councils in large cities, where pollution levels reach very high values, to take special measures against this type of vehicle. The aforementioned report points out that, in the year 2030, only 30% of registrations in the EU will be for diesel vehicles, being the countries where Germany and Spain will fall the most.

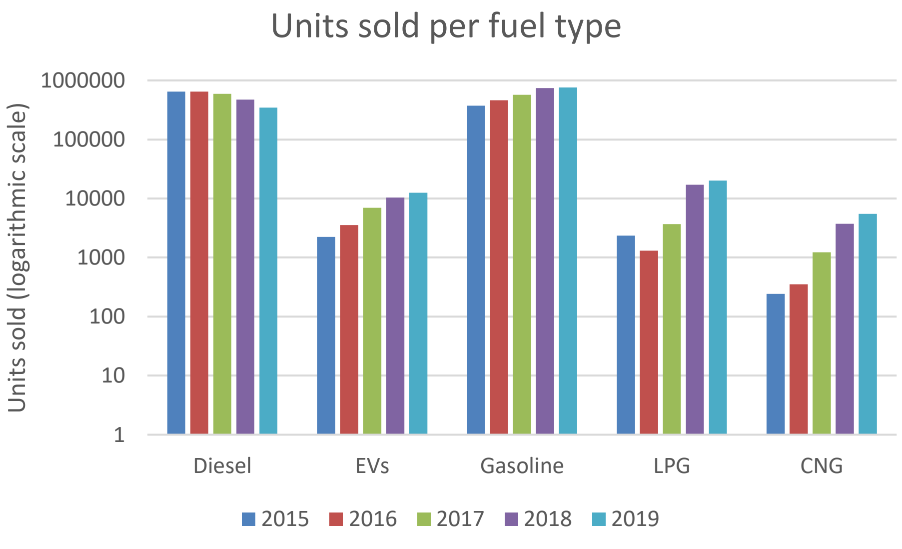

Figure 40: Units sold per fuel type (Source: estadisticacoches.com [13])

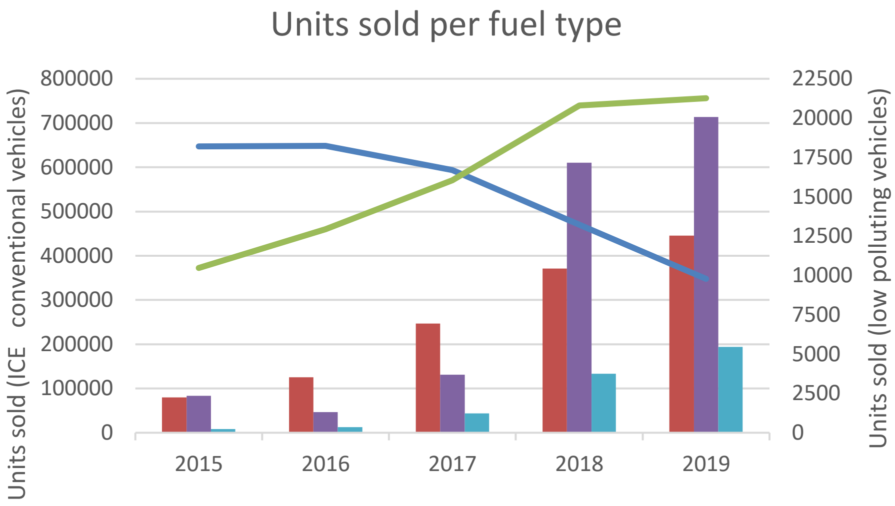

Figure 41:Units sold per fuel type (Source: estadisticacoches.com [11])

Gasoline passenger cars have regained popularity in recent years, in part thanks to the decline of diesel passenger cars, surpassing the diesel car as the best-selling fuel type in the last few years. Passenger cars that use alternative fuels are also experimenting large increases in the number of registrations, and infrastructures, but still represent a very small percentage of the park.

Spanish Government classifies his fleet according to their polluting potential, the criteria established by the EU and the information technique available in the National Vehicle Registry. The criteria for cataloging the units have their origin in the National Plan of Air Quality 2013-2016, which indicates that road traffic is an important source of emissions in large cities, so that proposes the cataloging of vehicles to positively discriminate the most environmentally friendly units.

- Zero emissions: Mopeds, tricycles, quadricycles and motorcycles; passenger cars; light vans, vehicles with more than 8 seats and goods transport vehicles classified in the DGT Vehicle Registry as battery electric vehicles (BEV), extended range electric vehicle (REEV), plug-in hybrid electric vehicle (PHEV) with a minimum range of 40 kilometers or fuel cell vehicles.

- Echo emissions: Cars, light vans, vehicles with more than 8 seats and goods transport vehicles classified in the Registry of Vehicles such as plug-in hybrid vehicles with autonomy <40km, non-pluggable hybrid vehicles (HEV), vehicles powered by natural gas, vehicles powered by natural gas (CNG and LNG) or liquefied petroleum gas (LPG). In any case, they must meet the criteria of label C.
- C: Passenger cars and light gasoline vans registered from January 2006 and diesel from 2014. Vehicles of more than 8 seats and freight transport, both gasoline and diesel, registered from 2014. Therefore, gasoline engines must comply with the Euro 4,5 and 6 standards and with Diesel the Euro 6
- B: Passenger cars and light gasoline vans registered from January 2000 and diesel from January 2006. Vehicles with more than 8 seats and transportation of goods, both gasoline and diesel, registered from 2005. Therefore, gasoline engines must comply with the Euro 3 standard and in Diesel the Euro 4 and 5.

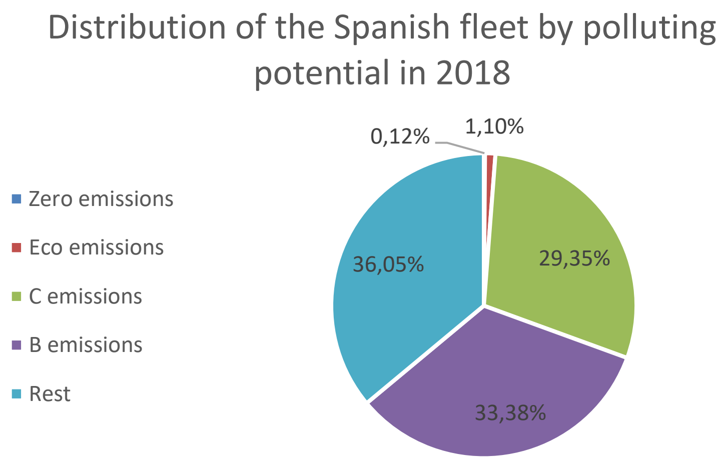

Figure 42:Distribution of the Spanish fleet by polluting potential in 2018 (Source:Arval Observatory [32])

4.2 PARK EVOLUTION FORECAST

Given the current situation and recent evolution of the Spanish fleet, in this section it will be estimated the composition of the park in the medium and long run, until 2050. To achieve it, it will be used an Excel tool developed by the OVEMS [14], which will allow obtaining the distribution of passenger cars both by age and by type of fuel used over the years depending on the different scenarios carried out, modeled from a sigmoid function.

This function has been chosen as the most representative for the introduction of the low polluting fuel alternatives. This sigmoid function will have 2 variables with which it can be modified. The year in which it is centered and its slope, depending of those values, it is possible to control whether the strategy followed is more or less aggressive. The sigmoid function allows calculating the percentage of additions of each type of fuel in each year.

$$f(year_i) = (\%_{2050} - \%_{2019}) * \frac{1}{1 + e^{-\frac{year_i - c1}{c2}}} \tag{10}$$

$\%_{2050} = Target\ level\ of\ implementation\ in\ 2050$
$\%_{2019} = Level\ of\ implementation\ in\ 2019$
$c1 = centered\ year\ of\ the\ sigmoid$
$c2 = slope\ of\ the\ sigmoid$

The constant C1 allows to set the centered year of the implementation, which allows us to model the moment in which the hypothesis penetration of the scenario begins to take place, while the constant C2 allows the slope of the function to be varied, used to model the rate of variation of each type of fuel once it has started.

To carry out the scenarios, the following hypotheses have been used:

1. The total number of Km traveled in Spain will remain constant. Although there may be a slightly increasing tendency of them, thanks to new business models such as carpooling by Blablacar, or carsharing implemented by Car to go and Emov among

others, combined with the increase in urban population versus rural and the increase of the use of Public transport, suggest it is an accurate hypothesis.

2. All enrollments that will occur in Spain will be of aforementioned alternatives fuel: Diesel, Gasoline, CNG, LPG and Electric (BEV and PHEV). The level of implementation of each fuel will depend on each scenario.
3. Effect of antiquity in the deregistration's of the park, the excel tool is programmed to automatically deregister vehicles as they get older, it is measured in pu. It is assumed that all the vehicle types are affected by the antiquity effect in the same effect

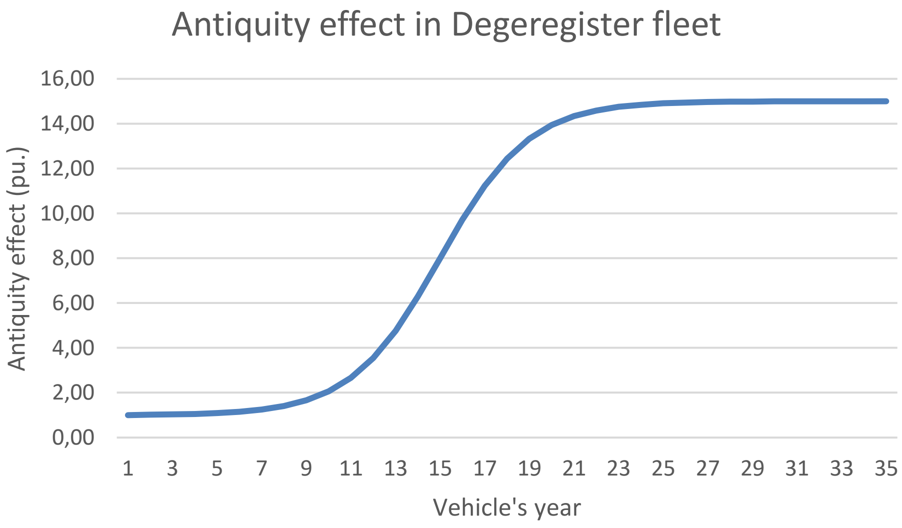

Figure 43: Effect of antiquity in the number of degestration vehicles (Own source)

4. Effect of antiquity in the number of km covered per year, this effect has been assumed that it decreases lineally until the vehicle is 20 years which the effect is followed by the following formula:

$$Antiquity\ effect_{year_i} = \frac{Antiquity\ effect^2_{(year_i-1)}}{Antiquity\ effect_{year_i-2}} \tag{11}$$

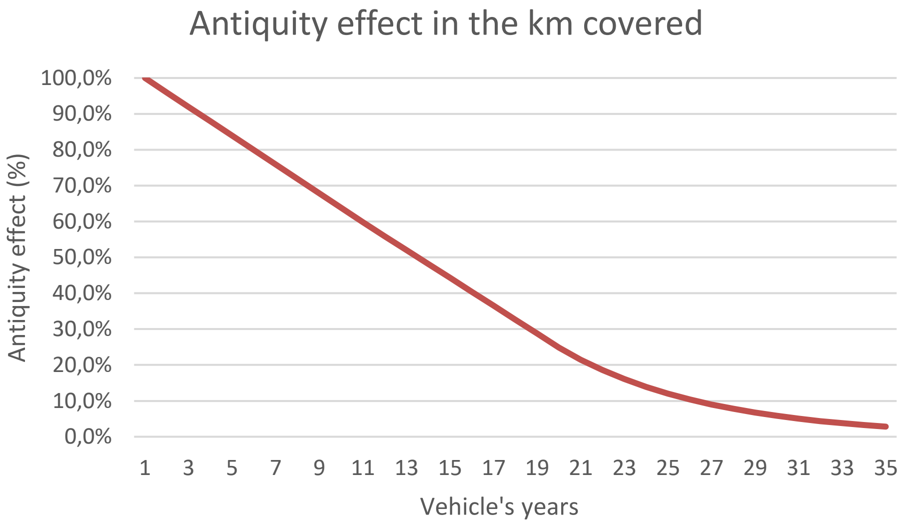

Figure 44: Effect of antiquity in the number of degestration vehicles (Own

5. In addition, the developed tool has the ability to differentiate between kilometers traveled by road or in urban areas. This allows the generated scenarios to adjust better to reality, regarding the current limitations of some of the low-pollution technologies, such as the BEVs.

The idea is to compare 3 different strategies (Electrification of the fleet, Gasification of the fleet and a slight introduction of low polluting technologies) the transportation sector could take with the ICE scenario (the fleet is taken up just by Gasoline and Diesel vehicles), and observe the advantages or disadvantages each of the forecasts would bring to the Spanish economy and the Environmental impact.

It will help to decide the Government or large institutions of the automotive Industries to take the future strategies and positioned themselves on the markets.

4.2.1 BASE SCENARIO 0

This scenario tries to simulate what would happen if current trends were followed (business as usual), that is, neither incentivize nor cut current aid. This scenario simulates a progressive penetration of electric cars, in which there are 2 million EVs in the Spanish fleet. It is true that it is more conservative than PNIEC[10] forecasts presented to the European Union, but it is also more realistic since PNIEC intends to have 5 million electric cars by 2030. Reaching that figure was a rather complicated challenge, but after the corona virus crisis irruption, it seems impossible that this objective could be reached due to the fact transport sector is expected to experience a decline of around 40% this year. Moreover, the Spanish citizen's economy will suffer considerably, causing an imminent decrease in the number of vehicle sales. This will not only affect electric vehicles, but any type of vehicle.

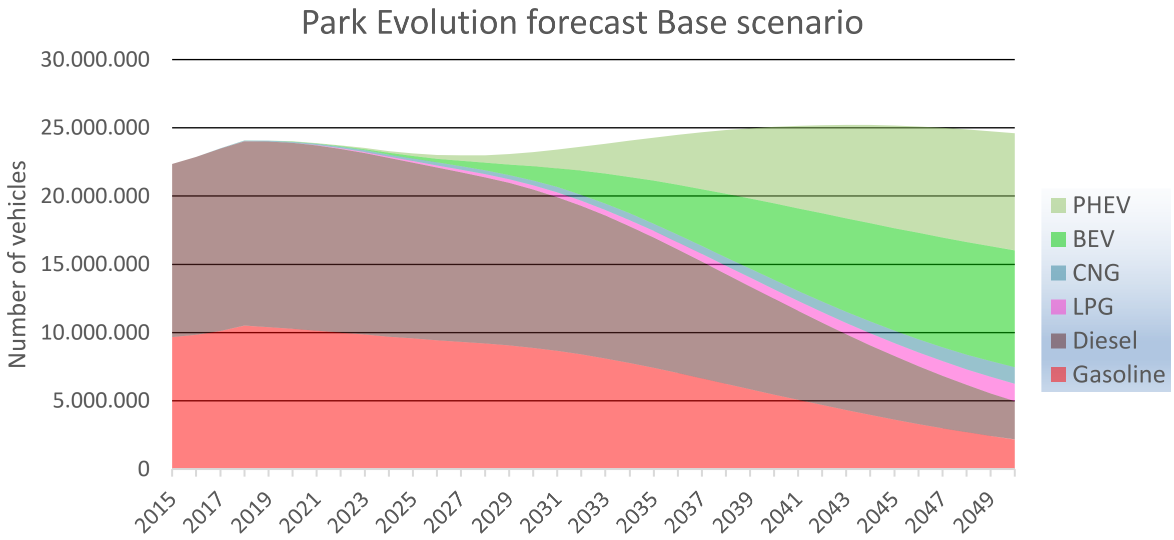

Figure 45: Park Evolution forecast Base scenario (Own source)

As it can be observed in *Figure 45*, new technologies, especially electric ones, are being introduced little by little, achieving in 2050 that more than half of the total vehicle fleet is taken up by electric cars, there will be around 17 million of EVs which is also a quite optimist scenario since it would mean almost the total electrification of the automobile fleet.

In addition, in the following figure (*Figure 46*), the efficiency in the consumption of each technology can be perfectly observed, being the Battery Electric vehicles the ones that win

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[10] National Integrated Energy and Climate Plan (PNIEC) 2021-2030: defines the objectives of reducing greenhouse gas emissions, penetration of renewable energy and energy efficiency.

in that matter. This scenario distinguishes between kilometers covered in urban roads and in highways.

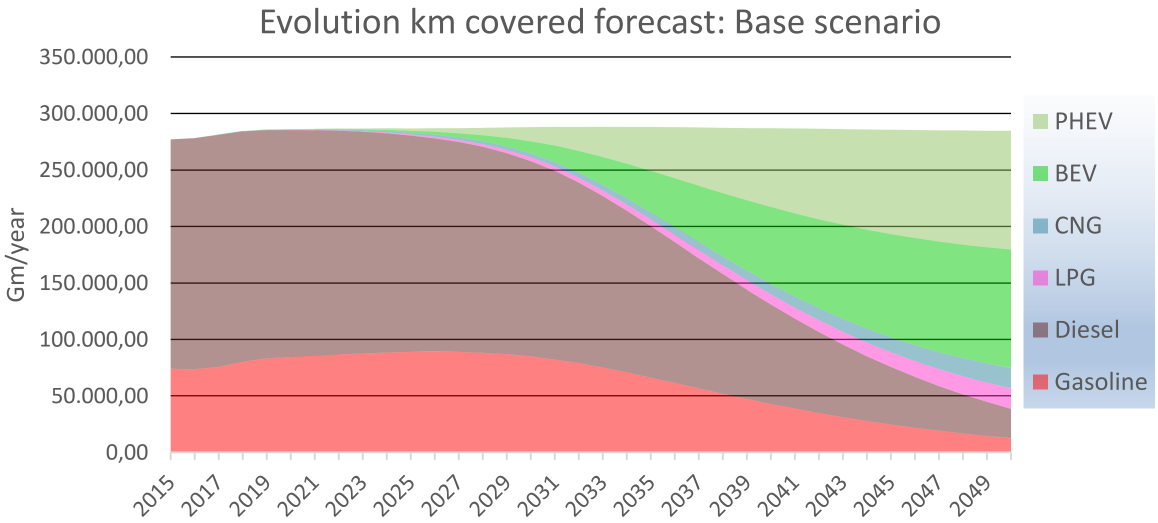

Figure 46:Evolution Kilometers covered forecast, Base scenario (Own source)

Regarding GHG emissions, such as CO_2, NO_X or PM_x, they are drastically reduced in this scenario. Reaching to reduce CO_2 emissions by 69.82% in 2050 compared to 2015, NOx emissions by 92.17% and PM emissions by 85.72%. This result is much more optimistic

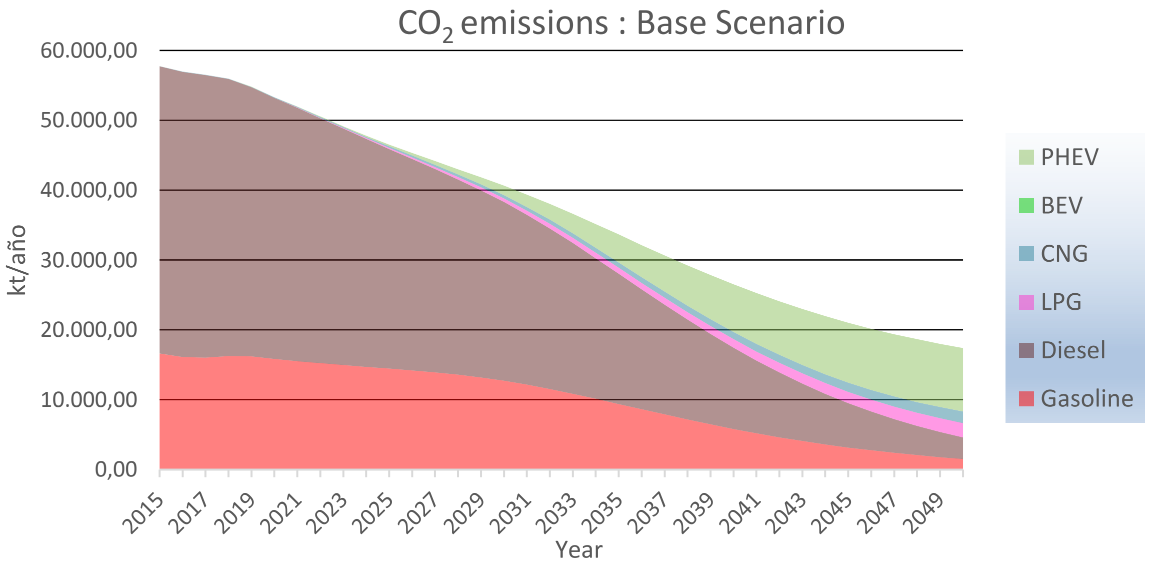

Figure 47: CO_2 emissions evolution over the years (Own source)

than a priori is expected to reduce in 2050. *Figure 47 and Figure 48* will present the evolution of CO_2 and NO_x emissions respectively over the years per vehicle type.

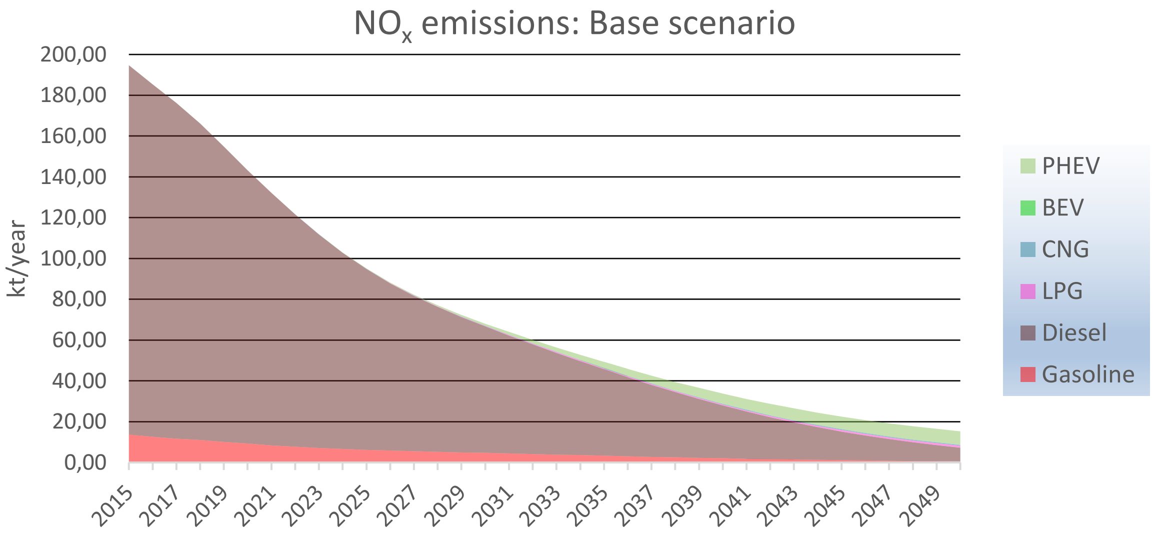

Figure 48: NOx emissions evolution over the years (Own source)

4.2.2 ELECTRIFICATION SCENARIO (BEV & PHEV)

In this scenario, a radical penetration of the electric car is considered, in which 100% of sales in the year 2037 will be electric vehicles (BEV and PHEV).

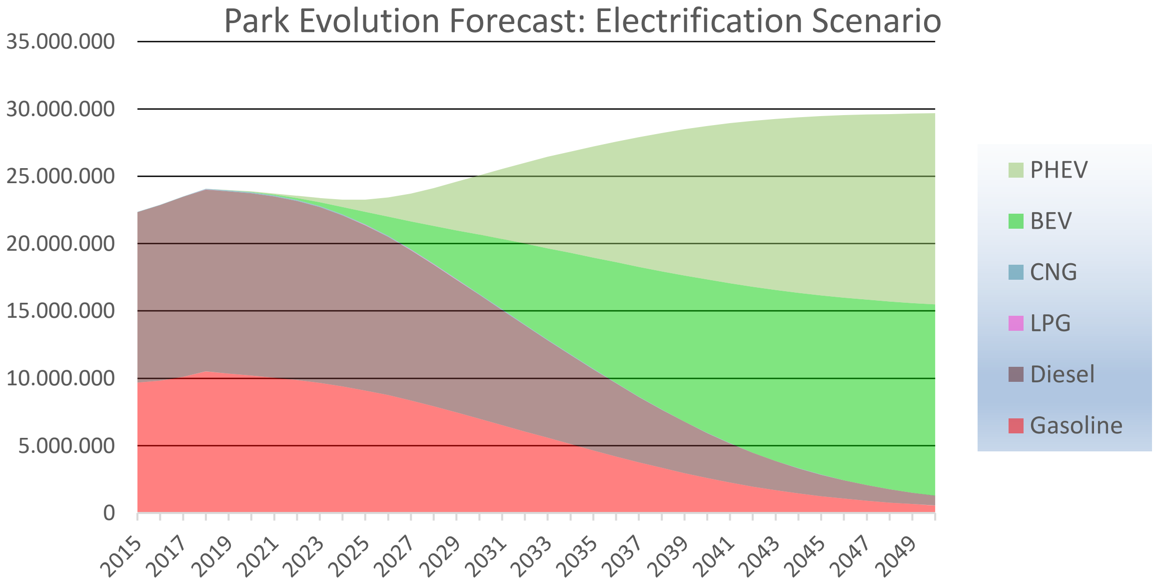

Figure 49: Park Evolution forecast Electrification scenario (Own source)

In addition, this scenario has taken into account the current limitations of the Battery Electric vehicles when it comes to cover kilometers in highways, as it can be observed in *Figure 50*. Because of that reason despite the total kilometers covered remain constant, there is an increase in the number of registrations of the Spanish fleet.

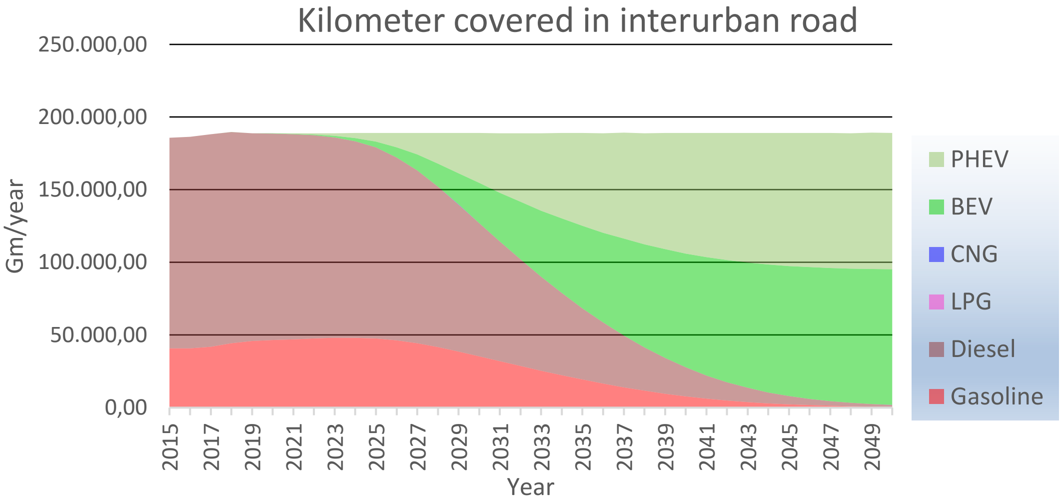

Figure 50:Kilometers covered in interurban roads (Own source)

In this scenario, the total electrification of the Spanish car park occurs. As it was explained in the section comparison of vehicle types, electric vehicles are the ones which pollutes the least Green-House Gases. For this reason, it has been obtained the best environmental results. In this scenario, CO_2 emissions have been reduced by 77.55 % in 2050 compared to 2015, NOx emissions by 94.94% and PM emissions by 99.14%.

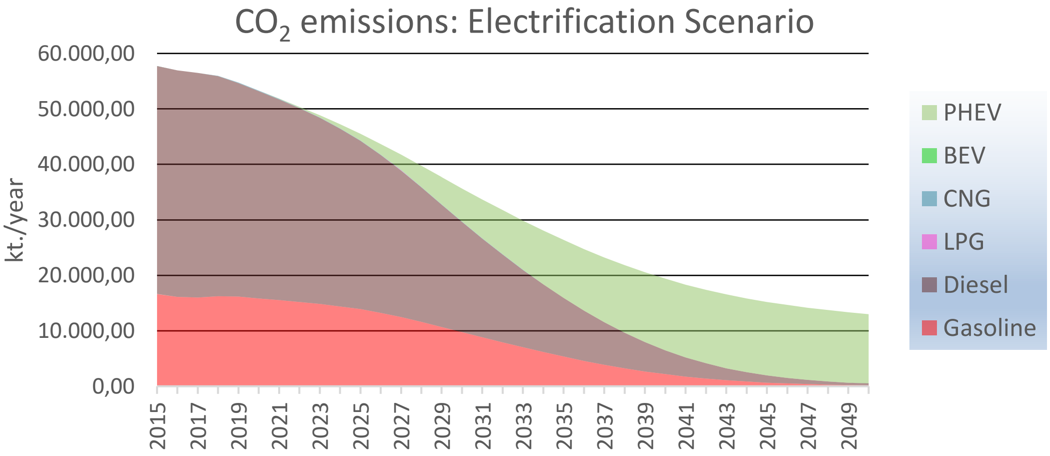

Figure 51: CO_2 emissions evolution over the years, Electrification scenario (Own source)

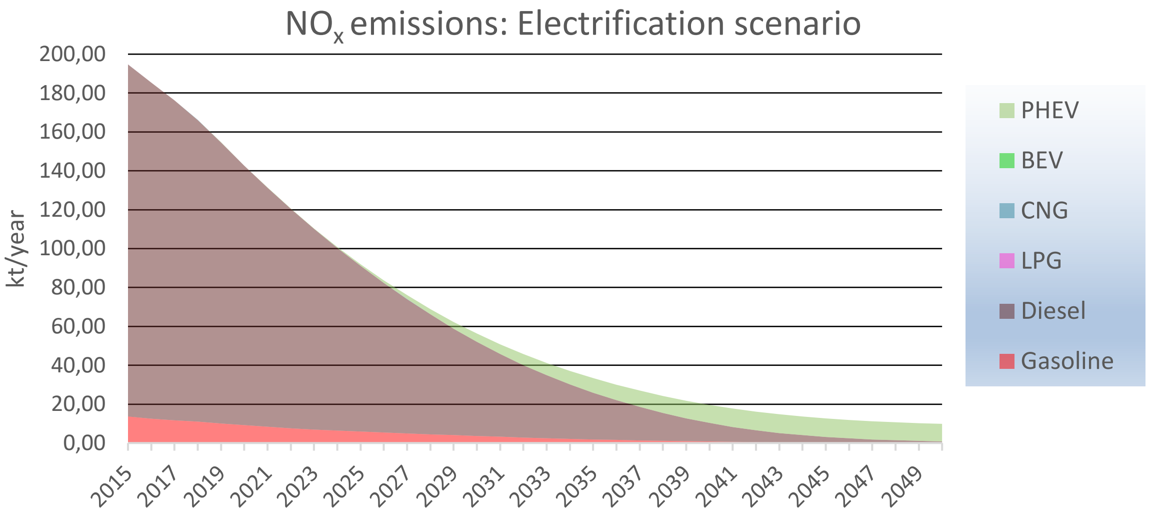

Figure 52: CO_2 emissions evolution over the years, Electrification scenario (Own source)

4.2.3 GAS SCENARIO (CNG & LPG)

This scenario is very similar to the previous one, but in this case, instead of being electrified, the vehicle fleet is gasified. All the sales occurred in 2050 are formed by CNG or LPG vehicles. Reaching 7.5 million vehicles of each type of these vehicle gas, in that year. As it can be seen in *figure 53*, because the autonomy of these vehicles is quite competitive, an increase in the Spanish fleet is not needed, remaining nearly constant throughout the years. Moreover, in this scenario, there is a less pronounced penetration of gas vehicle than in the

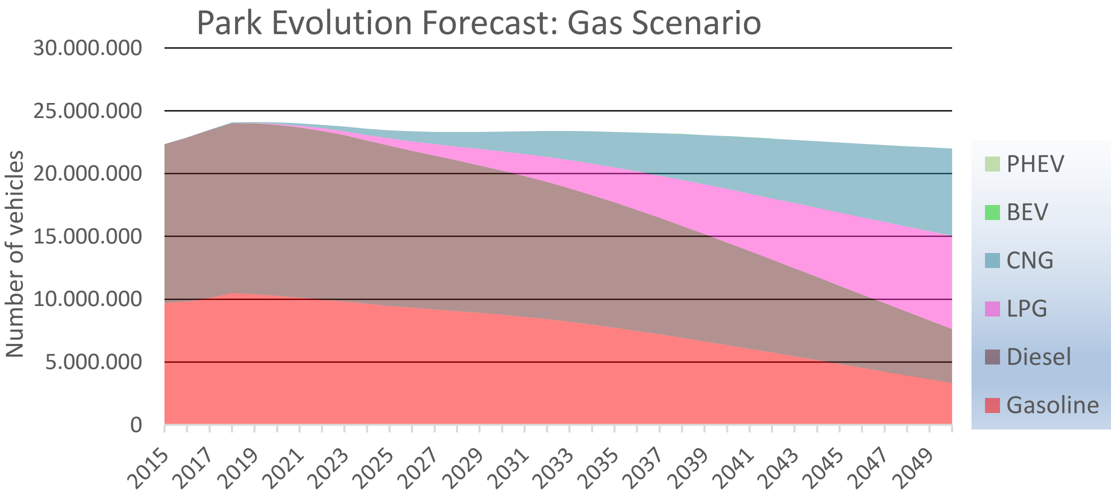

Figure 53:Park Evolution forecast Gas scenario (Own source)

electrification scenario. As can be seen, in this scenario, there is still an important representation of ICE vehicles (around a third of the total fleet). *Figure 55* represent the kilometers covered by the Spanish fleet over the year. As it can be observed, the initial hypothesis of constant kilometers is fulfilled.

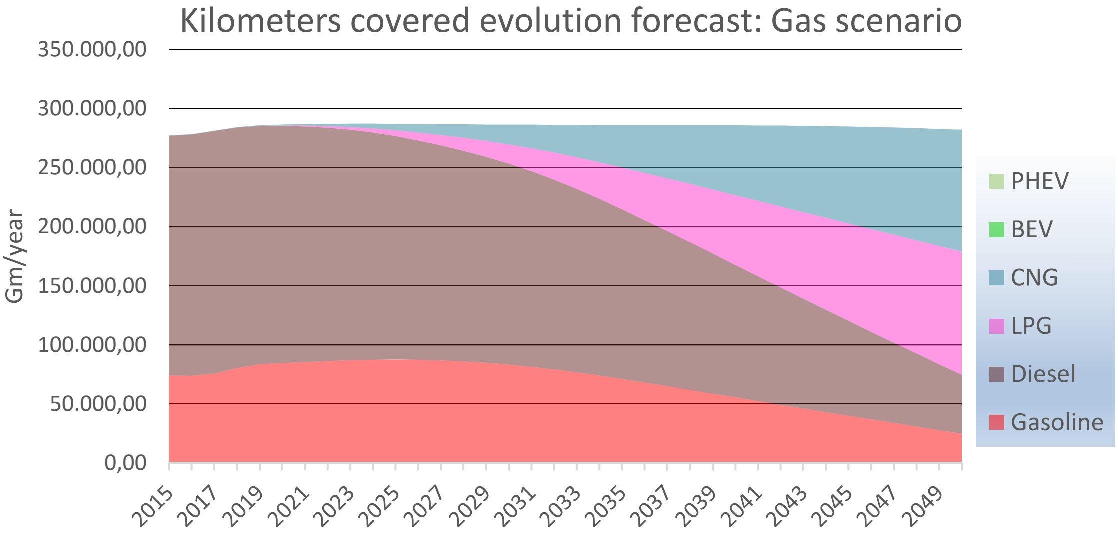

Figure 54:Kilometers covered evolution forecast, Gas scenario (Own source)

Regarding the emissions, because gas vehicles are more polluting than electric vehicles, and there is still a considerable presence of ICE vehicles, in this case, the reduction of GHG emissions is not as abrupt than the previous scenario. it has been obtained the best

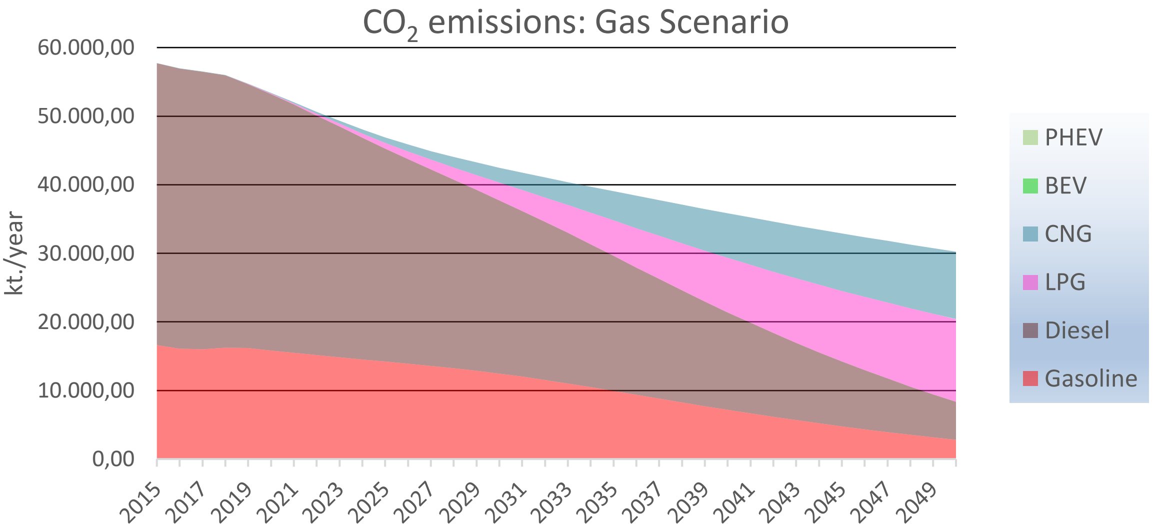

Figure 55: CO2 emissions evolution over the years, Gas scenario (Own source)

environmental results. In this scenario, CO_2 emissions have been reduced by 47.64 % in 2050 compared to 2015, NOx emissions by 88.97% and PM emissions by 52.64%.

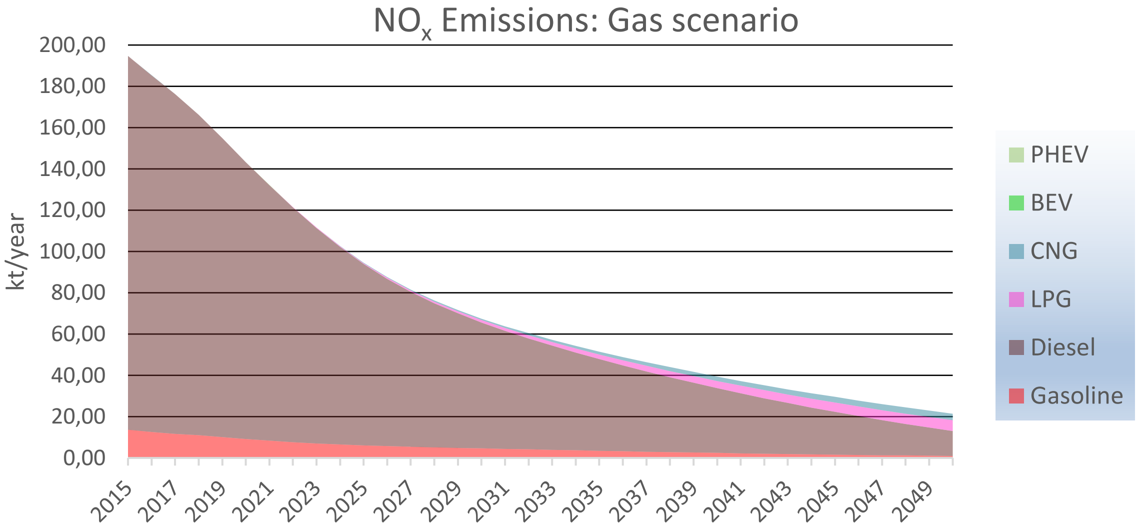

Figure 56:CO2 emissions evolution over the years, Gas scenario (Own source)

4.2.4 ICE SCENARIO (GASOLINE & DIESEL)

This scenario is perhaps the least plausible, as everything points to the new less polluting technologies settling in Spain. But despite the fact that low-pollution technologies are likely to increase in popularity in the coming years, it is interesting to compare the previous scenarios with this scenario, where the automobile fleet will only consist of gasoline and diesel vehicles as it has happened over the last decades. This scenario is hypothesized that the proportion of gasoline and diesel vehicles are equalizing over time.

In addition, all the previous scenarios (Gas, Electric and Base scenarios) will be compared to this one. It will help to discover the advantages and disadvantages of each of the technologies, and it will help Government to take the optimum strategies. The main advantage of this scenario is that it does not incur any extra cost to create recharging infrastructures, on the contrary, it is the scenario in which the greatest number of emissions occur, despite the improvement in the reduction of vehicle emissions new. *Figure 58* shows the park evolution over the year while *Figure 59* present the total consumption of the Spanish fleet, it can be observed that even though the total number of vehicles do not increase nor the kilometers covered, the consumption (measured in GWh) decrease. This happens because the scenarios take also into account the improvement of the vehicles performances.

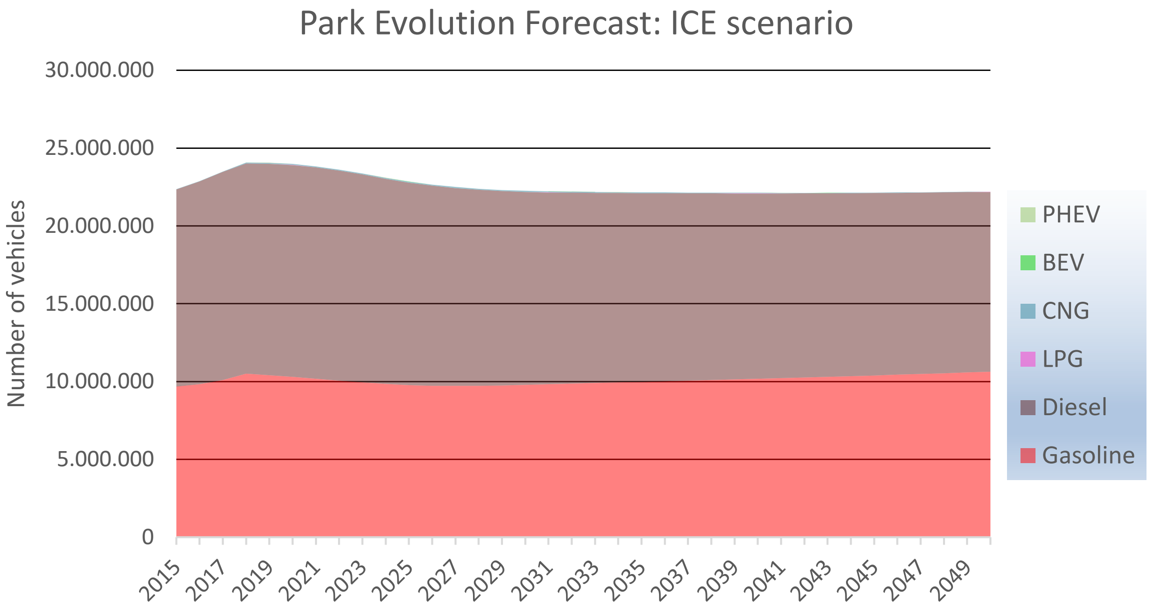

Figure 58: Park evolution forecast of the ICE scenario (Own source)

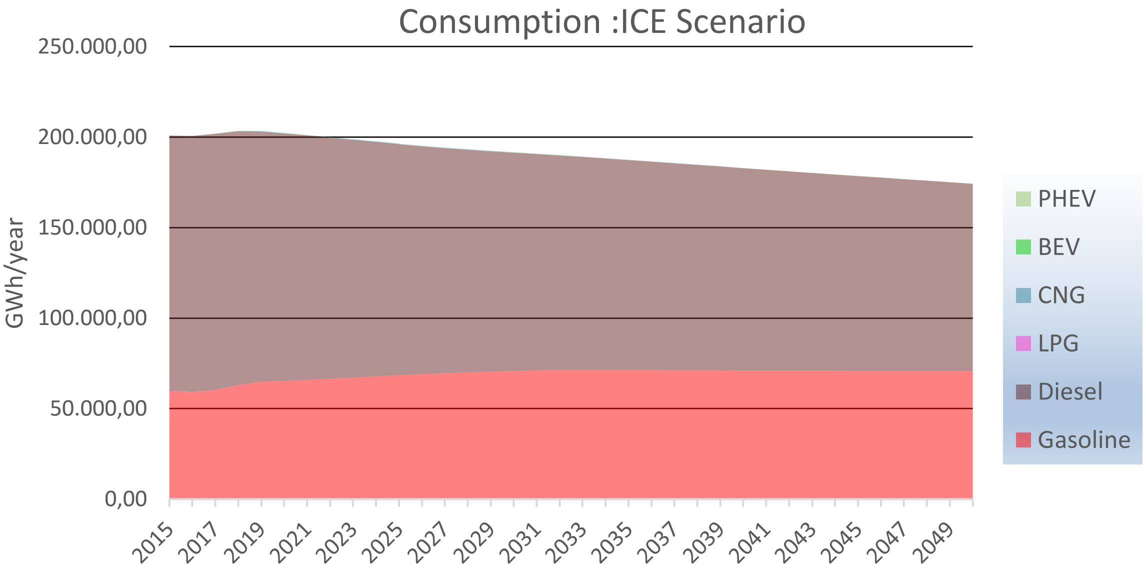

Figure 57: Consumption evolution forecast, ICE scenario (Own source)

Regarding the emissions of this scenario, as it was expected, they are much higher than in the previous scenarios. The reduction in emissions from these vehicles is due to the improvement in vehicles, probably driven by future regulations of the European Union. In this scenario, CO_2 emissions have been reduced by 51.24 % in 2050 compared to 2015, NO_x emissions by 78.72% and PM emissions by 41.20%.

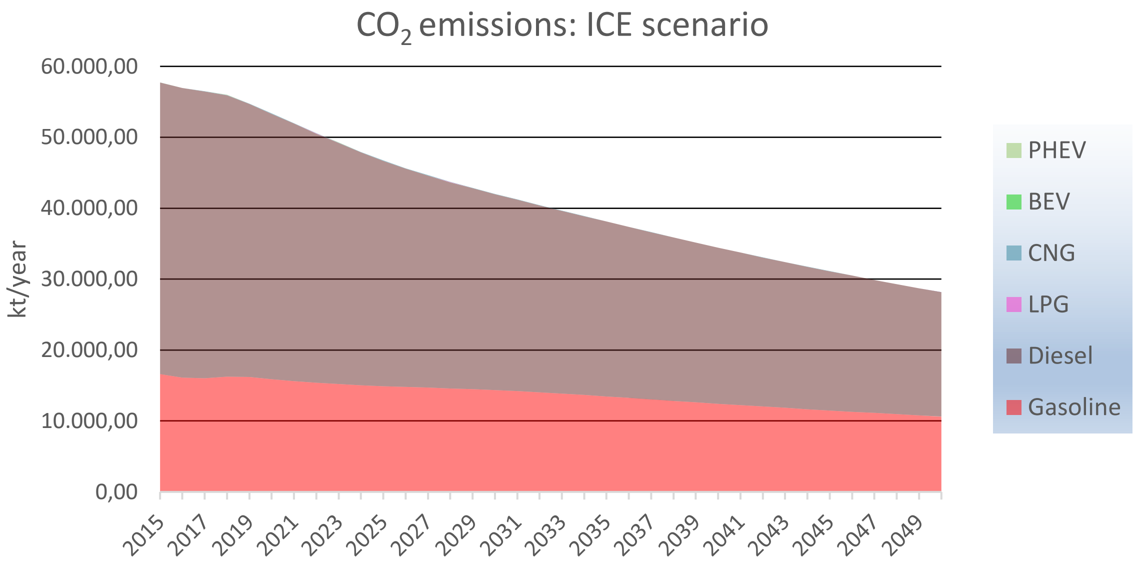

Figure 59: CO2 emissions evolution over the years, ICE scenario (Own source)

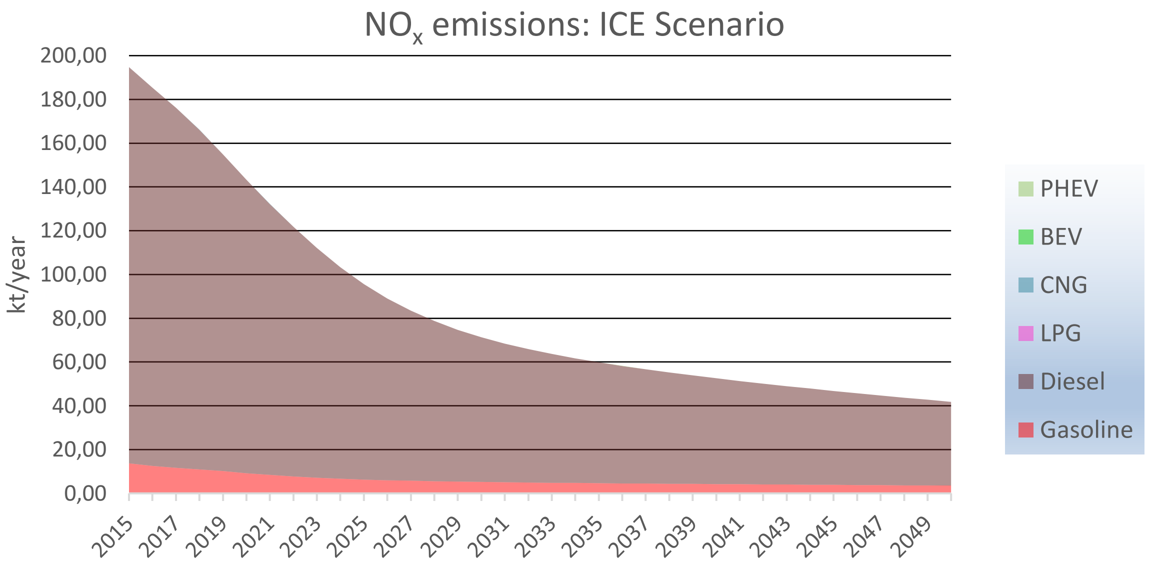

Figure 60: NOx emissions evolution over the years, ICE scenario (Own source)

CHAPTER 5: TRANSPORT SECTOR INFLUENCE IN THE ECONOMY

5.1 MICRO LEVEL

The main objective of this chapter is to carry out an economic analysis of the different technologies, and of the costs associated with the consumer, that is, what it will really cost a user to buy a car of each type of fuel through its useful life. Furthermore, this chapter wants to answer a question that probably many drivers have asked themselves before buying their vehicle, which is better, buy the car now or wait a few years to buy it? Therefore, a comparison of the total cost of the vehicle has been made based on the annual kilometers traveled for a car purchased in 2020, 2025 and 2030.

Instead of performing a static analysis, it is believed that it would be more accurate doing it dynamically, since new technologies evolve by leaps and bounds, it allows us to think that the scenario in 5, 10 or 15 years will differ considerably from the current one. If we add to this the firm commitment that the Government seems to show towards the decarbonization of the transport sector, with the presentation of the National Integrated Energy and Climate Plan (PNIEC)[11], to Brussels at the end of last March, in which maintains its firm commitment to this sustainable mobility and the scenario of 5 million electric vehicles in our country by 2030.

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[11] National Integrated Energy and Climate Plan (PNIEC) 2021-2030, this plan defines the objectives of reducing greenhouse gas emissions, penetration of renewable energy and energy efficiency. In addition, it determines the lines of action and the path that, according to the models used by the ecological transition ministry, is the most appropriate and efficient, maximizing opportunities and benefits for the economy, employment, health and the environment.

As Manuel García stated in the #webinarAELEC on May 13, 2020, current deputy director general of electrical energy, the Ministry for the ecological transition aims to end energy dependence. For this, a plan is being developed in which the Spanish economy is electrified, being the transport sector among its main objectives.

As happened a few years ago with the spending and the aid that was provided to promote renewable energy, also known as green energy, it meant, instead of public spending, a long-term investment, which we are now beginning to see results.

For Manuel García something similar should happen with the decarbonization of the transport sector, covering both passenger vehicles and rail and maritime transport. All this suggests that there will be both economic and fiscal aids to promote sustainable technologies.

For this reason, a new excel tool has been developed, in which different sub-scenarios have been generated, which represent possible future situations depending on how the economic situation evolves, the aid offered by the government and the improvement of vehicle efficiency.

All the sub-scenarios have been generated based on the data showed in *table 49*, generating all the hypotheses of evolution of the transport sector. For calculating the total cost per vehicle it has been included both fixed and variables cost, like the upfront purchasing price, the maintenance cost including the insurance (showed in the *tables 40, 41, 42, 43, 44 and 45*) and the cost per kilometers traveled.

Table 49: Data taken as the basis for the year 2020(Source: Own Source)

Fuel	Price (€)	Average Consumption	Fuel Price (€/l or €/kWh)
Gasoline	17.006,40 €	5,509 l/100km	1,31 €/l
Diesel	26.838,20 €	4,75 l/100km	1,22 €/l
BEV Fast Charge	30.703,43 €	15,25 kWh/100km	0,17 €/kWh
BEV	30.703,43 €	15,25 kWh/100km	0,09 €/kWh
PHEV	38.505,00 €	15,01 kWh/100km + 1,82 l/100km	1,31 €/l + 0,17 €/kWh
GNC	21.339,00 €	3,648 kg/100km	0,89 €
GLP	14.457,20 €	6,527 l/100km	0,71 €

5.1.1 SUB-SCENARIOS

5.1.1.1 PURCHASE PRICE VEHICLE SUB-SCENARIOS

It is intuitive to think that as time passes and cleaner technologies become more popular, economies of scale will appear in their production and distribution. This together with the possible aid offered by the government would produce a considerable decrease in the purchase price of the vehicle. Regarding to the evolution of the vehicle upfront cost, it has been generated three different sub-scenarios:

1. Sub-scenario 1: This sub-scenario generates a hypothesis in which new technologies become cheaper over time at a rate of constant 1% per year, while the purchase price of diesel and gasoline vehicles remains constant. It can be observed that despite the decrease in the PHEV upfront cost, still is the most expensive alternative.

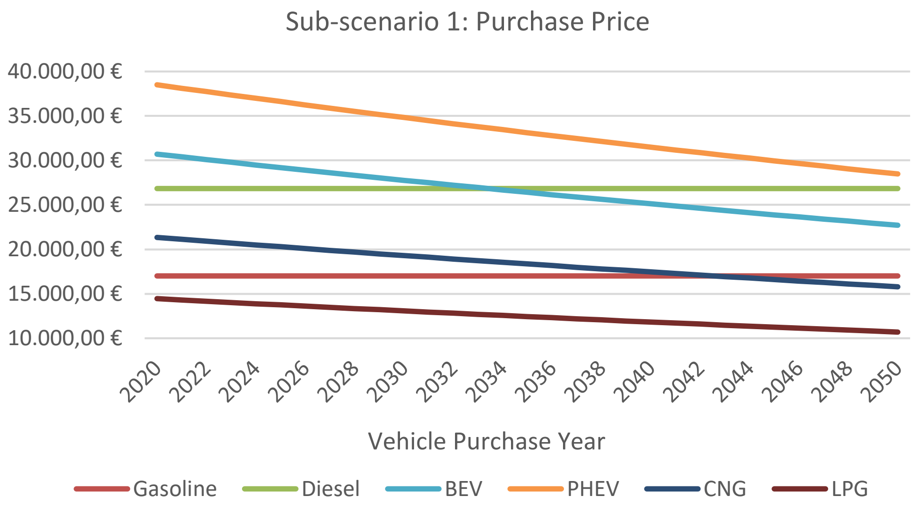

Figure 61:Sub-scenario 1, Evolution of the Purchasing price over the years (Source: Own Source)

2. Sub-scenario 2: This sub-scenario generates a hypothesis in which the government is betting more on electrification, the cost of electric cars decreases at a constant rate of 1%, while CNG and LPG technologies remain constant. In addition, in this

hypothesis it is considered that the Government take a similar measure to the one took in 2019 with the "dieselazo"[12], increasing the taxes on this fuel. Therefore, this hypothesis considers a 1% increase in the purchase price of conventional vehicles. Due to the increase in the diesel vehicle price, this type of vehicle will become the most expensive at the end of the next decade.

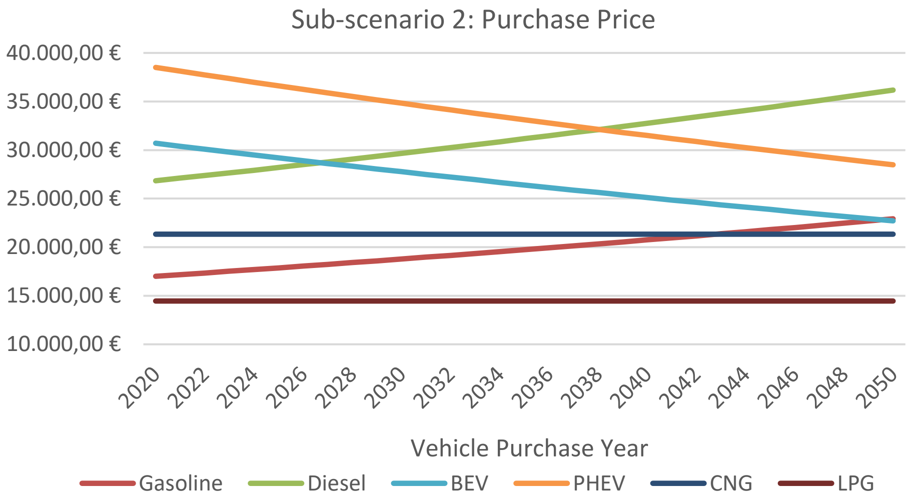

Figure 62:Sub-scenario 2, Evolution of the Purchasing price over the years (Source:Own Source)

3. Sub-scenario 3: This scenario is probably the one that most closely resembles reality, since the long-term changes (30 years until 2050) do not occur with constant increases, but the changes are more like a sigmoidal function like the one used in the evolution of the park. The time progression of the price change of the vehicles is initially low, until after a certain time it approaches a climax, where the changes increase abruptly until it arrives close to the final value, which changes become small again .

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[12] The dieselazo supposed an increase in the taxation of the fuel, the liter of fuel happened in Spain to be worth 3.8 more cents. The Government has affirmed on numerous occasions that they are studying to further increase the taxation of conventional fuels since they are below the average of other European countries.

$$f(year_i) = (\%_{2050} - \%_{2020}) * \frac{1}{1 + e^{-\frac{year_i - c1}{c2}}} \tag{12}$$

$\%_{2050} = Target\ level\ of\ implementation\ in\ 2050$
$\%_{2020} = Level\ of\ implementation\ in\ 2020 = 0$
$c1 = centered\ year\ of\ the\ sigmoid\ \ = 2027$
$c2 = slope\ of\ the\ sigmoid\ \ = 1{,}5$

In this sub-scenario, the hypothesis taken is that the price of conventional fuel vehicles remains constant, while there is a decrease in the price of new technologies.

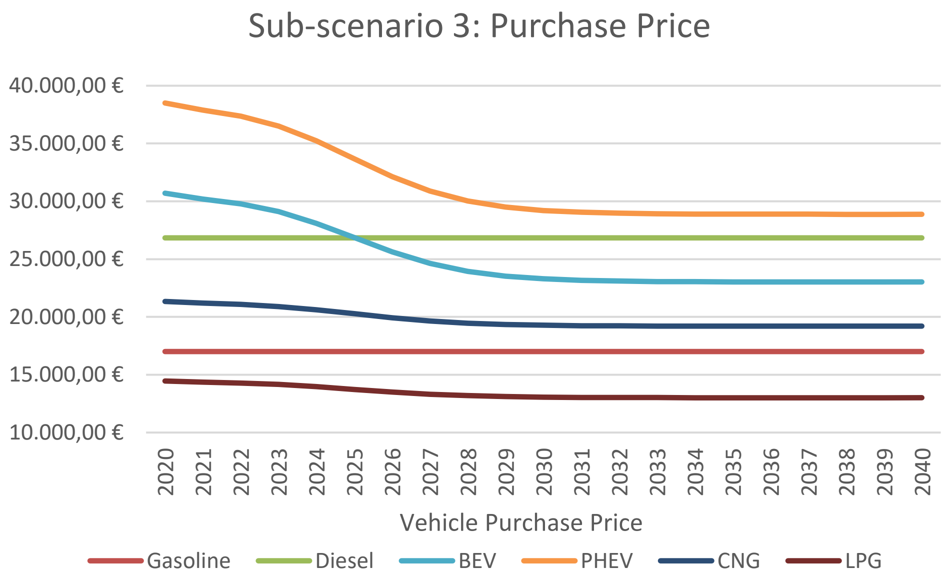

Figure 63:Sub-scenario 3, Evolution of the Purchasing price over the years (Source:Own Source)

In addition, the decrease in the electric vehicle is greater since it starts from a much higher cost (There is more room for improvement, especially when it comes to reduce the cost of its batteries).

5.1.1.2 AVERAGE CONSUMPTION SUB-SCENARIOS:

In these sub-scenarios has been generated different hypotheses about how will evolve the average consumption of the vehicles regarding the year are bought. Due to the novelty of new technologies (Electric and Gas vehicles), there is the possibility of a greater margin for improvement in their yields

1. Sub-scenario 1: This sub-scenario generates a hypothesis in which all the technologies improves their average consumption, reducing it at a constant rate of 1% per year. It is intuitive to think that mechanical engineers, after investing a large amount of money and effort, manage to reduce the consumption of their cars.
2. Sub-scenario 2: This sub-scenario generates a hypothesis in which all the technologies improves their average consumption, but in this case, not all technologies do it at the same rate, while electric vehicles reduce its average consumption at a rate of 1,5 % per year, the remaining technologies decrease just 1 % per year.
3. Sub-scenario 3: Even though this sub-scenario might seem inaccurate and unrealistic, it might be useful to perform an static analysis, meaning that if it is assumed that the prices will not change over the years, what would happen.

5.1.1.3 FUEL COST SUB-SCENARIOS:

As it can be observed in chapter 3 types of vehicles, it is very difficult trying to predict the cost of each type of fuel over the years due to its fluctuation and volatility. However, it is required to assume some hypothesis in order to perform numerical analysis. In addition, in this hypothesis it is considered that the Government take a similar measure to the one took in 2019 with the "dieselazo"[13], increasing the taxes on ICE conventional fuel. All the sub-scenarios studied has considered a gradual increase or decrease of fuel prices. The three sub-scenarios taken are:

1. Sub-scenario 1: This sub-scenario generates a hypothesis in which low polluting fuels decrease at a constant rate of 1 %. This is because of a reduction of the taxes

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[13] The dieselazo supposed an increase in the taxation of the fuel, the liter of fuel happened in Spain to be worth 3.8 more cents. The Government has affirmed on numerous occasions that they are studying to further increase the taxation of conventional fuels since they are below the average of other European countries.

associated with these technologies. On contrast, Gasoline and Diesel fuel remain constant over the years.

2. Sub-scenario 2: This sub-scenario generates a hypothesis in which all the fuels alternatives remain its costs constant. In this hypothetical scenario, the Government would play no role in the evolution of costs.
3. Sub-scenario 3: As previously was commented, last year the Government decided to increment the taxes associated with Diesel fuel. Following this line has been generated this scenario, the cost associated to conventional fuel increase at a rate of 1 % per year while the cost of each of the low polluting alternatives are reduced by 1 % due to some aids provided by the Government.

5.1.1.4 KM TRAVELED SUB-SCENARIOS:

In all the sub-scenarios analyzed, it has been assumed a decrease of 1.5 % per year, due to the fact that as the vehicle gets older, it will travel less and less kilometers, it will be called as the effect of vehicle age.

1. Sub-scenario 1: The vehicle travels 20,000 km in its first year, as it is getting older, it travels fewer kilometers.
2. Sub-scenario 2: The vehicle travels 15,000 km in its first year, as it is getting older, it travels fewer kilometers.
3. Sub-scenario 3: The vehicle travels 10,000 km in its first year, as it is getting older, it travels fewer kilometers.

5.1.2 COST ANALYSIS DEPENDING ON THE PURCHASE YEAR

In this section, it is intended to perform an analysis about the total cost associated with every type of vehicle, and understand that depending of the aids provided by the Government or any private entity, it is possible to decarbonize the transportation even before it was thought at first. The analysis made, will be very useful for those drivers who are thinking to buy a new car but they do not have a clue about when it will be the most beneficial depending of the fuel used.

Apart from all the sub-scenarios aforementioned, the developed excel tool allows you to carry out the analyzes based on the useful life of the car, it calculates all the associated costs, both variable and fixed throughout the life. Hence, the user can select the useful life of their vehicle, and the Excel automatically will generate the economical analysis. All the generation ran, has been analyzed for 12 and 15 as the life expectancy. As it was described in the previous chapter, the average age in Spain is 12.3 years, is increasing more and more. Since the financial crisis of 2008 was around, the average age of the Spanish fleet has not stopped growing. If we add to this, the impact that the corona virus is causing in the automobile sector, everything suggests that the average life of vehicles in our country will increase in the coming years. For this reason, a useful life of 15 years will also be analyzed.

The total cost in *year i* associated with a vehicle purchased in *year j* is calculated with the following formula:

$$\begin{aligned} Total\ Cost\ year_i = Purchase\ price_{(if\ i=j)} + Manteinance\ cost_{i-j} + km\ covered_i \\ * Consumption_j * fuel\ cost_i * antiquity\ effect_{i-j} \end{aligned} \tag{13}$$

Time value of money dictates that time affects the value of cash flows, for this reason the Excel tool has been designed keeping in mind that inflation and interest occur over time. Due to the costs managed do not occur in the same year (it is a time function), in order to perform a correct comparison along the years, it is required to consider inflation and currency interest. Because of this, the Excel tool also incorporates the real interest as an input variable, which allows to calculate the Net Present Value (NPV)[14] of each operation. Because analyzing how this value fluctuates over time would be a thesis in itself, and it is not the aim

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[14] Net present value: NPV accounts for the time value of money. It provides a method for evaluating and comparing capital projects or financial products with cash flows spread over time, as in loans, investments, payouts from insurance contracts plus many other applications.

of this project, for all the scenarios presented in this work, a constant value of 1.5 % will be assumed. It will simplify the calculation and the result analysis.

Therefore, to compare the total cost of the vehicle over different years, is required to calculate the net present value, that is, calculate the total cost associated with the operation of the vehicle per year projecting it on the base year (2020). Due to the characteristics of the associated vehicle costs, it can be associated these costs with a non-constant, prepayable, immediate and entire rent.

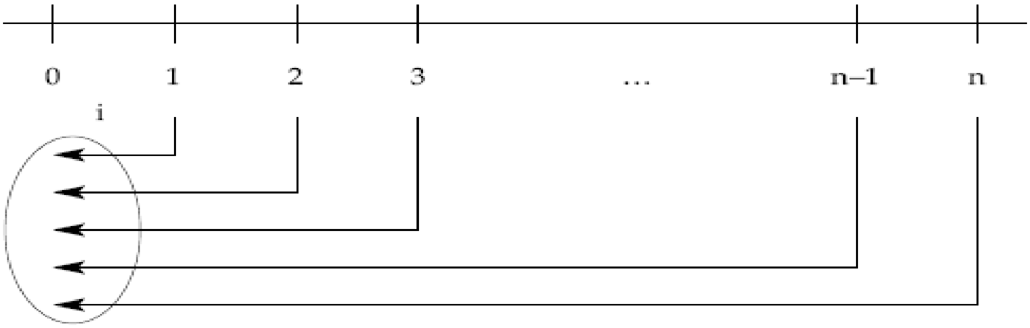

Figure 64: Graphical representation of a rent similar to the costs of a vehicle. (Source:Blog Udima [41])

As has just been commented, the Excel tool enables to calculate the net present value not only when the real interest is constant but also when fluctuates over the year. So, for calculating the total cost of a vehicle purchased in *year j* through its entire life expectancy *(n years)* and a constant interest *(i)* will be used the following formula:

$$\begin{aligned} &Net\ Present\ Value_{2020} \\ &= \frac{Total\ Cost\ year_j}{(1+i)^{j-2020}} + \frac{Total\ Cost\ year_{j+1}}{(1+i)^{j+1-2020}} + \cdots \\ &+ \frac{Total\ Cost\ year_n}{(1+i)^{j+n-2020}} \end{aligned} \quad (14)$$

In case the interest would not be constant, the Net Present value for a vehicle purchased in *year j* and a life expectancy of *n years* should be calculated by the following procedure:

$$Net\ Present\ Value_{2020} = \frac{Net\ Present\ Value_{2020+1}}{(1+i_{2020})^1} + Total\ Cost\ year_{2020} \tag{15}$$

$$Net\ Present\ Value_{2020+1} = \frac{Net\ Present\ Value_{2020+2}}{(1+i_{2020+1})^1} + Total\ Cost\ year_{2020+1} \tag{16}$$

$$\dots$$

$$Net\ Present\ Value_{j+n-1} = \frac{Net\ Present\ Value_{j+n}}{(1+i_{j+n-1})^1} + Total\ Cost\ year_{j+n-1} \tag{17}$$

$$Net\ Present\ Value_{j+n} = Total\ Cost\ year_{j+n} \tag{18}$$

After having explained how the total costs associated per vehicle type have been calculated, it will be explained how the analyzes will be carried out and their subsequent conclusions. For this, it will be used the data shown in *Table 50*. Previously was presented different sub-scenarios about the evolution of different variables (km covered, purchase price, fuel cost and average consumption). The aforementioned table contains the sub-scenarios in which the maximum and minimum cost of each type of vehicle is produced. Basically, this table represent two opposite scenarios, the first one, which will be called as “Decarbonization Path”, Government provide aids towards a low polluting mobility, promoting and encouraging user to purchase low polluting vehicles such as EVs or gas vehicles through a reduction in taxation, while the second one it is business as usual. This scenario will represent the evolution that would happen if nothing changes (There would be no increase in MOVES plan incentives as it has been requested by the electric lobby).

Table 50: Sub-scenarios in which the maximum and minimum cost of the vehicle is produced (Own Source)

	Min. (Decarbonization Path)			**Max. (Business as Usual)**		
	CONSUMPTION	FUEL COST	PURCHASE PRICE	CONSUMPTION	FUEL COST	PURCHASE PRICE
Gasoline	S-ESC1	S-ESC1	S-ESC1	S-ESC3	S-ESC3	S-ESC2
Diesel	S-ESC1	S-ESC1	S-ESC1	S-ESC3	S-ESC3	S-ESC2
BEV	S-ESC2	S-ESC1	S-ESC3	S-ESC3	S-ESC2	S-ESC1
PHEV*	S-ESC1	S-ESC1	S-ESC3	S-ESC3	S-ESC1	S-ESC1
CNG	S-ESC1	S-ESC1	S-ESC1	S-ESC3	S-ESC2	S-ESC2
LPG	S-ESC1	S-ESC1	S-ESC1	S-ESC3	S-ESC2	S-ESC2

* Due to PHEV can run using conventional carburant and electricity, in both scenarios the extreme values of both gasoline and electricity have been taken.

Although the following table *(Table 51)* presents the same data as *Table 50*, it has been included to facilitate the understanding of the two scenarios (business as usual and decarbonization path), since instead of showing the sub-scenario for which the Maximum or Minimum cost is produced, shows the hypothesis of each sub-scenario.

Table 51: Hypothesis in which the maximum and minimum cost of the vehicle is produced (Own Source)

	Min. (Decarbonization Path)			**Max. (Business as Usual)**		
	CONSUMPTION	FUEL COST	PURCHASE PRICE	CONSUMPTION	FUEL COST	PURCHASE PRICE
Gasoline	-1% per year	Const	Const	Const	+1% per year	+1% per year
Diesel	-1% per year	Const	Const	Const	+1% per year	+1% per year
BEV	-1.5% per year	-1% per year	-30% in 2050	Const	Const	-1 % per year
PHEV	-1.5 % per year (electricity) -1% per year (gasoline)	-1% per year (electricity) const (gasoline)	-30% in 2050	Const	Const (electricity) + 1 % per year (gasoline)	-1 % per year
CNG	-1% per year	-1% per year	-1% per year	Const	Const	Const
LPG	-1% per year	-1% per year	-1% per year	Const	Const	Const

Finally, the residual value of the vehicle has not been considered (once the life expectancy is reached to 12 years or 15 years depending, the value of the car is neglectable). This has been assumed because cars, once they are over 5 years old, are devalued exponentially, with very little difference between a 12 years old car and 15 years old one. Therefore, it is aware that this expense, even though it is small, could influence the comparison of scenarios, but the objective of this thesis is not to make a study of the second-hand cost of a car.

Following, it will be generated different scenarios which will provide an idea about how beneficial each type of vehicle is depending on the characteristics of the driver.

5.1.2.1 COST ANALYSIS TRAVELLING 20000 KM

This scenario is thought for those travelers who covers more kilometers per year than the average in Spain.

1. Cost Analysis Travelling 20,000 Km with an expected useful life of 12 years:
   This section will seek to answer the question which car should a person buys if he makes about 20,000 km per year and hopes that its useful life will be 12 years (the Spanish average). For this, the stressed scenarios (business as usual and decarbonization path) will be generated and it will be compared which technologies are better in each case depending on the purchasing year.
2. Cost Analysis Travelling 20,000 Km with an expected useful life of 15 years:
   As it happen with the previous section, it will seek to answer the question which car should a person buy if covers about 20,000 km per year and hopes that its useful life will be 15 years (predicting an increase of the life expectancy of the vehicles).

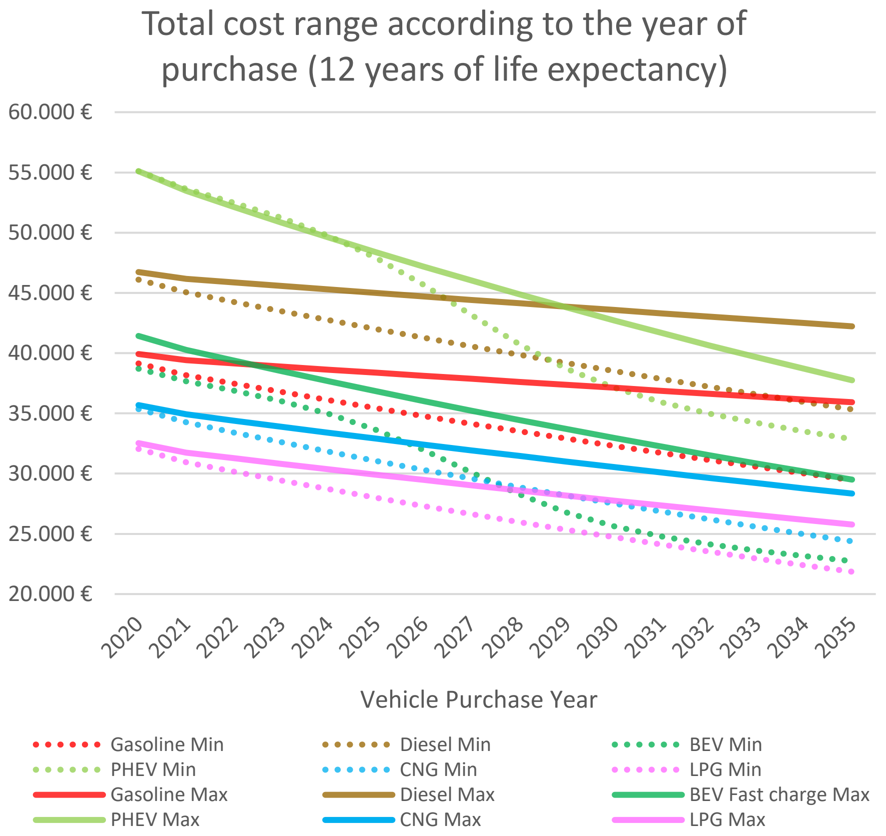

Figure 65: Total cost range per fuel type depending on the purchase year assuming an useful life of 12 years and 20,000 km (Own Source)

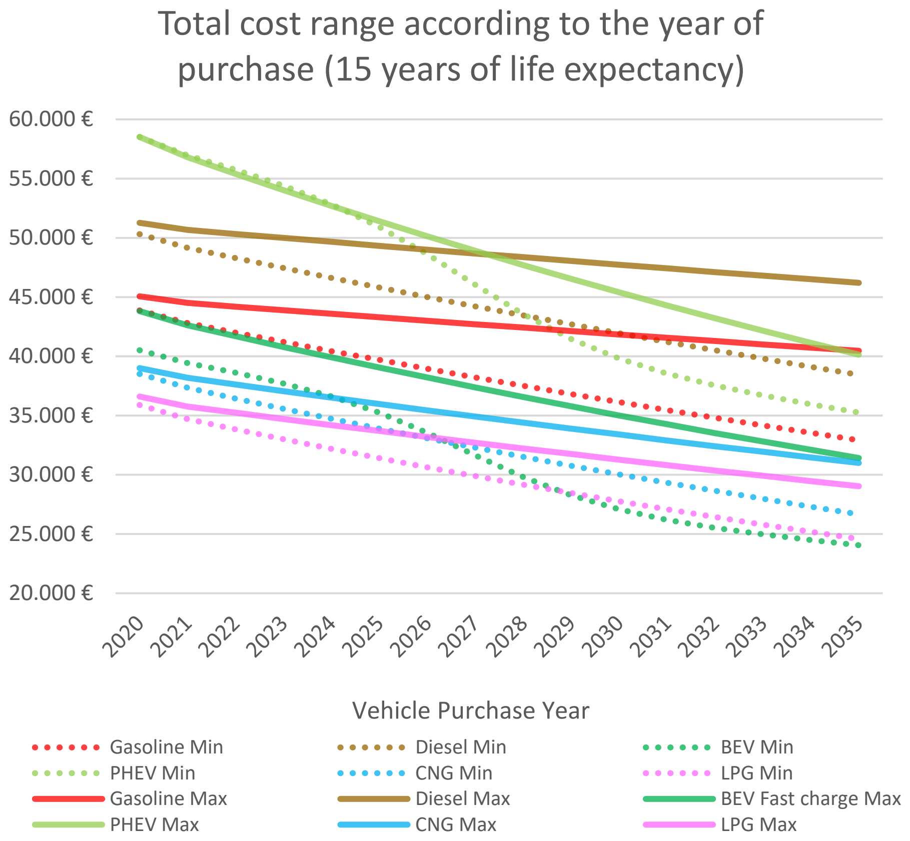

Figure 66:Total cost range per fuel type depending on the purchase year assuming an useful life of 15 years and 20,000 km (Own Source)

Table 52:Total cost interval depending on the year of purchase assuming a useful life of 12 years and 20,000 km (Own Source)

	Min. Total Cost 2020	**Max. Total Cost 2020**	**Min. Total Cost 2025**	**Max. Total Cost 2025**	**Min. Total Cost 2030**	**Max. Total Cost 2030**	**Min. Total Cost 2035**	**Max. Total Cost 2035**
Gasoline	39.141 €	39.926 €	35.429 €	38.370 €	32.294 €	37.122 €	29.454 €	35.926 €
Diesel	46.099 €	46.729 €	42.004 €	44.990 €	38.514 €	43.579 €	35.331 €	42.225 €
BEV	38.704 €	38.849 €	33.612 €	34.435 €	25.618 €	30.732 €	22.735 €	27.438 €
PHEV	55.102 €	55.102 €	47.888 €	48.373 €	37.120 €	42.715 €	32.862 €	37.748 €
CNG	35.354 €	35.685 €	31.058 €	32.896 €	27.503 €	30.536 €	24.378 €	28.346 €
LPG	32.048 €	32.530 €	27.988 €	29.909 €	24.715 €	27.764 €	21.854 €	25.772 €

Table 53: Total cost interval depending on the year of purchase assuming a useful life of 15 years and 20,000 km (Own Source)

	Min. Total Cost 2020	Max. Total Cost 2020	Min. Total Cost 2025	Max. Total Cost 2025	Min. Total Cost 2030	Max. Total Cost 2030	Min. Total Cost 2035	Max. Total Cost 2035
Gasoline	43.872 €	45.061 €	39.687 €	43.295 €	36.129 €	41.847 €	32.910 €	40.463 €
Diesel	50.313 €	51.268 €	45.808 €	49.330 €	41.951 €	47.731 €	38.438 €	46.200 €
BEV	40.511 €	40.726 €	35.233 €	36.178 €	27.078 €	32.349 €	24.053 €	28.940 €
PHEV	58.512 €	58.512 €	50.909 €	51.394 €	39.804 €	45.399 €	35.253 €	40.138 €
CNG	38.510 €	39.002 €	33.885 €	35.976 €	30.041 €	33.395 €	26.662 €	30.999 €
LPG	35.888 €	36.605 €	31.403 €	33.692 €	27.759 €	31.275 €	24.574	29.31

5.1.2.2 COST ANALYSIS TRAVELLING 15000 KM

The current average of kilometers covered by vehicle in Spain is close to 13000 km. This scenario aims to simulate the characteristics of the average Spanish driver, covering that amount of km per year. It may be a little shocking that it is being said that traveling 15,000 km can be simulated as 13,000 km. But it is important to remember that the Excel tool designed, takes into account the antiquity effect of the vehicle. Which mean that as the vehicle is getting older, it covers fewer kilometers per year (Only in the year of purchase will it travel 15,000 km). Therefore, it can be assumed that this simulation fits perfectly with the needs of the average Spanish driver.

1. Cost Analysis Travelling 15000 Km with an expected useful life of 12 years:
   This section will seek to answer the question which car should a person buys if he makes about 15,000 km per year and hopes that its useful life will be 12 years (the Spanish average). For this, the stressed scenarios (business as usual and decarbonization path) will be generated and it will be compared which technologies are better in each case depending on the purchasing year.
2. Cost Analysis Travelling 15,000 Km with an expected useful life of 15 years:
   As it happen with the previous section, it will seek to answer the question which car should a person buy if covers about 15,000 km per year and hopes that its useful life will be 15 years (predicting an increase of the life expectancy of the vehicles).

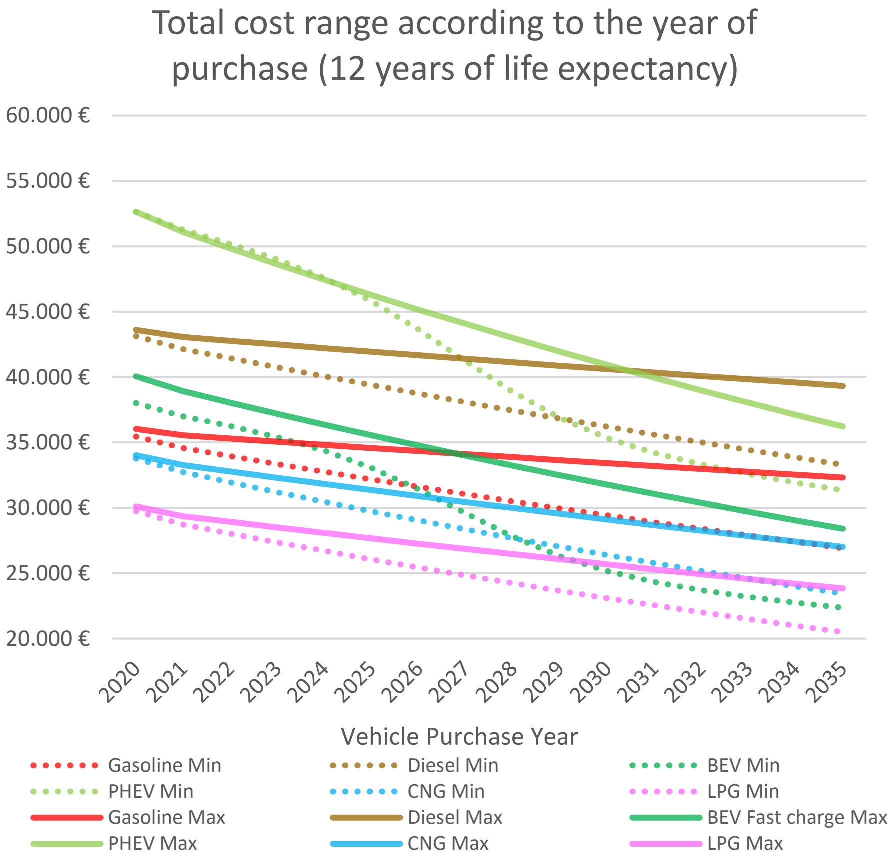

Figure 68: Total cost range per fuel type depending on the purchase year assuming an useful life of 12 years and 15,000 km (Own Source)

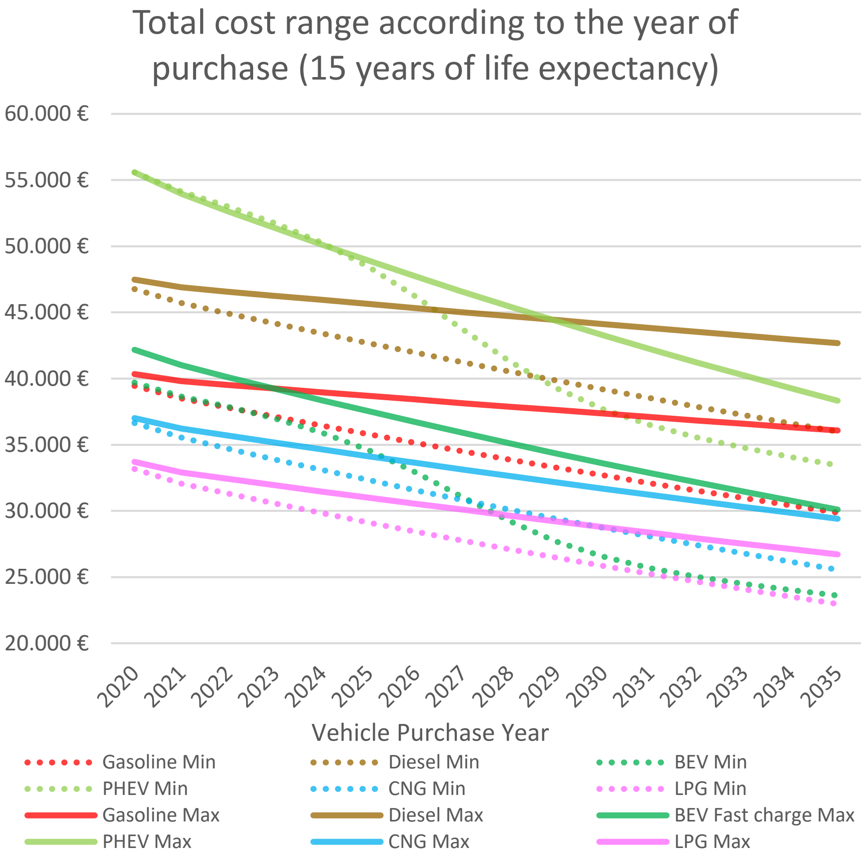

Figure 67:Total cost range per fuel type depending on the purchase year assuming a useful life of 15 years and 15,000 km (Own Source)

Table 54:Total cost interval depending on the year of purchase assuming a useful life of 12 years and 15,000 km (Own Source)

	Min. Total Cost 2020	**Max. Total Cost 2020**	**Min. Total Cost 2025**	**Max. Total Cost 2025**	**Min. Total Cost 2030**	**Max. Total Cost 2030**	**Min. Total Cost 2035**	**Max. Total Cost 2035**
Gasoline	35.450 €	36.038 €	32.171 €	34.578 €	29.418 €	33.422 €	26.915 €	32.316 €
Diesel	43.135 €	43.608 €	39.387 €	41.945 €	36.205 €	40.608 €	33.292 €	39.326 €
BEV	38.015 €	38.124 €	33.048 €	33.762 €	25.156 €	30.107 €	22.357 €	26.859 €
PHEV	52.643 €	52.643 €	45.796 €	46.281 €	35.339 €	40.934 €	31.344 €	36.229 €
CNG	33.776 €	34.024 €	29.733 €	31.355 €	26.391 €	29.105 €	23.445 €	27.017 €
LPG	29.750 €	30.111 €	26.059 €	27.664 €	23.095 €	25.680 €	20.495 €	23.837 €

Table 55:Total cost interval depending on the year of purchase assuming a useful life of 15 years and 15,000 km (Own Source)

	Min. Total Cost 2020	**Max. Total Cost 2020**	**Min. Total Cost 2025**	**Max. Total Cost 2025**	**Min. Total Cost 2030**	**Max. Total Cost 2030**	**Min. Total Cost 2035**	**Max. Total Cost 2035**
Gasoline	35.450 €	36.038 €	32.171 €	34.578 €	29.418 €	33.422 €	26.915 €	32.316 €
Diesel	43.135 €	43.608 €	39.387 €	41.945 €	36.205 €	40.608 €	33.292 €	39.326 €
BEV	38.015 €	38.124 €	33.048 €	33.762 €	25.156 €	30.107 €	22.357 €	26.859 €
PHEV	52.643 €	52.643 €	45.796 €	46.281 €	35.339 €	40.934 €	31.344 €	36.229 €
CNG	33.776 €	34.024 €	29.733 €	31.355 €	26.391 €	29.105 €	23.445 €	27.017 €
LPG	29.750 €	30.111 €	26.059 €	27.664 €	23.095 €	25.680 €	20.495 €	23.837

5.1.2.3 COST ANALYSIS TRAVELLING 10000 KM

It may seem wrong to carry out car scenarios that cover 10,000 km per year since it is below the Spanish average of around 13,000 km and passenger vehicles are becoming more efficient, allowing many more kilometers a year than they did years ago. However, this assumption is not misguided since many users (especially those who live in urban areas) will increasingly reduce the kilometers covered. This is because of the upward trend of using public transport and the emergence of new business models such as carpooling[15] by Blablacar, or carsharing[16] implemented by Car to go and Emov among others.

1. Cost Analysis Travelling 10,000 Km with an expected useful life of 12 years:
   This section will seek to answer the question which car should a person buys if he makes about 10,000 km per year and hopes that its useful life will be 12 years (the Spanish average). For this, the stressed scenarios (business as usual and decarbonization path) will be generated and it will be compared which technologies are better in each case depending on the purchasing year.
2. Cost Analysis Travelling 10,000 Km with an expected useful life of 15 years:
   As it happen with the previous section, it will seek to answer the question which car should a person buy if covers about 10,000 km per year and hopes that its useful life will be 15 years (predicting an increase of the life expectancy of the vehicles).

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[15] Carpooling is the sharing of car journeys so that more than one person travels in a car, and prevents the need for others to have to drive to a location themselves.

[16] Carsharing is a model of car rental where people rent cars for short periods of time, often by the hour. It differs from traditional car rental in that the owners of the cars are often private individuals themselves, and the carsharing facilitator is generally distinct from the car owner.

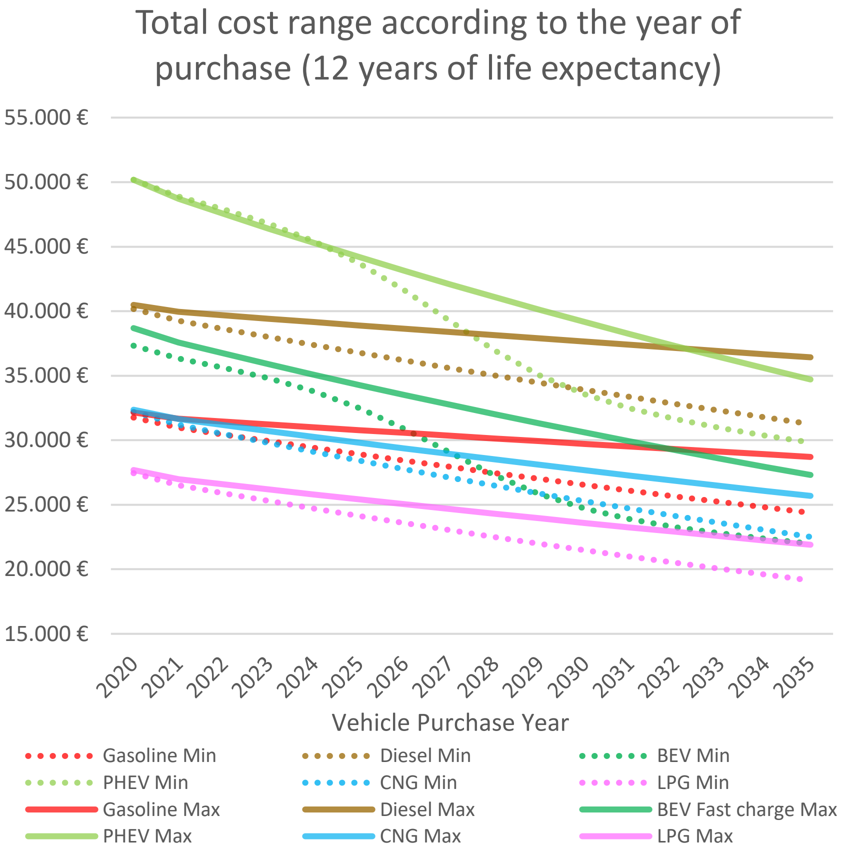

Figure 70:Total cost range per fuel type depending on the purchase year assuming a useful life of 12 years and 10,000 km (Own Source)

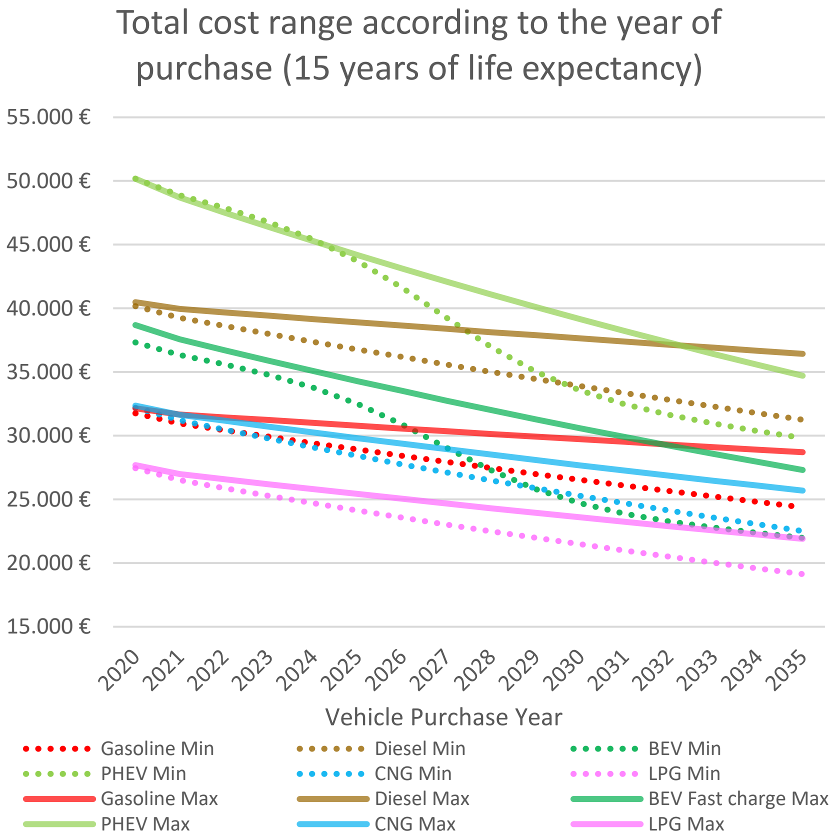

Figure 69:Total cost range per fuel type depending on the purchase year assuming a useful life of 12 years and 10,000 km (Own Source)

Table 56:Total cost interval depending on the year of purchase assuming a useful life of 12 years and 10,000 km (Own Source)

	Min. Total Cost 2020	**Max. Total Cost 2020**	**Min. Total Cost 2025**	**Max. Total Cost 2025**	**Min. Total Cost 2030**	**Max. Total Cost 2030**	**Min. Total Cost 2035**	**Max. Total Cost 2035**
Gasoline	31.759 €	32.151 €	28.912 €	30.786 €	26.542 €	29.722 €	24.376 €	28.706 €
Diesel	40.171 €	40.486 €	36.771 €	38.899 €	33.895 €	37.637 €	31.253 €	36.428 €
BEV	37.327 €	37.399 €	32.484 €	33.089 €	24.695 €	29.482 €	21.979 €	26.279 €
PHEV	50.183 €	50.183 €	43.705 €	44.190 €	33.558 €	39.152 €	29.825 €	34.710 €
CNG	32.198 €	32.364 €	28.409 €	29.813 €	25.279 €	27.675 €	22.511 €	25.689 €
LPG	27.452 €	27.693 €	24.130 €	25.419 €	21.476 €	23.595 €	19.135 €	21.903 €

Table 57:Total cost interval depending on the year of purchase assuming a useful life of 15 years and 10,000 km (Own Source)

	Min. Total Cost 2020	Max. Total Cost 2020	Min. Total Cost 2025	Max. Total Cost 2025	Min. Total Cost 2030	Max. Total Cost 2030	Min. Total Cost 2035	Max. Total Cost 2035
Gasoline	35.023 €	35.618 €	31.876 €	34.082 €	29.234 €	32.859 €	26.823 €	31.694 €
Diesel	43.208 €	43.685 €	39.536 €	41.932 €	36.414 €	40.514 €	33.550 €	39.159 €
BEV	38.881 €	38.988 €	33.899 €	34.564 €	25.985 €	30.852 €	23.158 €	27.550 €
PHEV	52.654 €	52.654 €	45.926 €	46.411 €	35.559 €	41.154 €	31.632 €	36.517 €
CNG	34.776 €	35.022 €	30.750 €	32.280 €	27.408 €	29.965 €	24.452 €	27.815 €
LPG	30.448 €	30.807 €	26.836 €	28.310 €	23.925 €	26.279 €	21.356 €	24.393

5.1.2.4 COMPARISON AND RESULTS

The main purpose of having carried out all these simulations is to observe how the vehicle total cost will evolve over the years. Thanks to these scenarios, it can be understood that changes made around the structure associated with each type of vehicle (purchase price, efficiency, fuel costs ...) take time to see the results. In other words, although the government suddenly gives aids to promote low-pollution mobility, it will take a few years for these aids to show up in the driver's pocket.

In all the simulations generated, purely economic factors, fixed and variable costs have been taken into account throughout the useful life of the vehicle. As it can be seen, there is a huge difference depending on the scenario analyzed, Business as usual and Decarbonization Path. In generating the "decarbonization path" scenarios, there is some aids/economies of scale/reductions of the costs which can come in the form of Government aids (reduction of fuel and registration taxes, VAT incentives…), economies of scale (OEMs manufacturing the vehicles), improved efficiency (decreasing their average consumption)…For example, there is currently a Plan for Incentives for Efficient and Sustainable Mobility (MOVES)[17], but instead of giving directly the money to the consumer, the aids come reducing the prices of the vehicles, which probably will end in a greater consumption (more vehicles sold).

After analyzing the scenarios generated based on the year of purchase, determining the useful life of the vehicle and the annual kilometers traveled, we can draw the following conclusions:

- In the next cost analysis (cost depending on the kilometers covered) will dive deeper in this issue, trying to focus at the very detail. However, thanks to this analysis can

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[17] The Efficient and Sustainable Mobility Incentives Program (MOVES), endowed with 45 million euros and aimed at encouraging the purchase of alternative vehicles, installing electric vehicle charging infrastructures, developing incentives for implement electric bicycle loan systems and the implementation of measures included in Transportation Plans to Work centers.

also be drawn preliminary conclusions regarding the kilometers covered by a vehicle. As more kilometers are traveled, electrical technologies become more relevant due to the low cost of fuel, this is because the price of electricity is lower compared to other fuels. This suggests that the transport sector is likely to end up transforming into electric mobility.

However, one must be aware of the current limitations of electric cars. An electric car (BEV) currently could not cover 25,000km a year, neither for autonomy nor for infrastructure. Today, this technology is limited to cover its kilometers mainly in urban spaces (traveling short distances). Therefore, in the following analysis (in the section "total cost depending on the km covered"), viable alternatives will be studied for those consumers who make more than 20,000 km per year.

- When comparing the total cost per vehicle over the year there are a clear winner, the emerging technologies. In both scenarios, business as usual and decarbonization path, these technologies, especially the EVs, benefit the most from the passage of time, meaning that as time passes, the total cost reduction of these vehicles is greater than that of conventional vehicles. To calculate the cost variation with respect to 2020, it has been used the following formula:

$$\%\ Growth\ of\ total\ cost_{sc,fuel,year} = \frac{Total\ cost_{sc,fuel,year} - Total\ cost_{sc,fuel,2020}}{Total\ cost_{sc,vehicle,2020}} * 100 \tag{19}$$

$sc: The\ business\ as\ usual\ or\ decarbonization\ path\ scenario\ is\ defined$
$Vehicle: The\ type\ of\ vehicle\ is\ calculed$
$Year: Comparison\ year$

Table 58 present the total cost growth of both scenarios (decarbonization path and business as usual) over the years. As it was commented previously, it can be seen that emerging technologies decrease more than conventional ones. It may be surprising that by 2035, ICE vehicles would decrease by around 10%, this is due to two factors, the first is the increase in the efficiency of the vehicles, a vehicle that is purchased within 15 years is expected to have greater efficiency, which would result in a decrease in fuel use. The second would be the effect of the real interest that has been assumed by generating the stages (1.5%).

Table 58:Total cost decline over the time (Own source)

	Business as usual 2025	**Decarbonization path 2025**	**Business as usual 2030**	**Decarbonization path 2030**	**Business as usual 2035**	**Decarbonization path 2035**
Gasoline	-9,25%	-4,09%	-17,04%	-7,35%	-24,13%	-10,47%
Diesel	-8,71%	-3,86%	-16,12%	-6,98%	-22,89%	-9,97%
BEV	-12,99%	-11,35%	-33,49%	-20,87%	-40,86%	-29,34%
PHEV	-12,95%	-12,05%	-32,55%	-22,18%	-40,15%	-31,10%
CNG	-11,88%	-7,82%	-21,73%	-14,43%	-30,40%	-20,57%
LPG	-12,29%	-8,08%	-22,20%	-14,67%	-30,89%	-20,80%

In addition, from this data another conclusion can be drawn that may perhaps be surprising, if it is calculated two new tables that show the same as before but in this case one table will present just the scenarios whose useful life is 15 years and another table which shows just the scenarios whose life expectancy useful is 12 years, it is observed that for ICE vehicles, if the useful life of the car is increased, there is a greater drop in the Present Value of any of any years compared to 2020, while in the case of low-pollution technologies As its useful life increases, the decrease in price compared to that of 2020 is less. Which means that in the future, an increase of the life expectancy will benefit ICE vehicles the most.

- As it was expected, *table 58* shows a further decrease in the price of new technologies compared to 2020 if the Decarbonization path scenario occurs, in which the government provides aid in the form of a lower tax burden of the costs associated with said vehicles.

Table 59 and 60 shows the top three vehicle alternatives of each of the simulations generated. It has been decided to include them because it enables with just a look to check which vehicle is the most beneficial and its evolution over the years.

In addition, these table shown are very useful for people who for a given life expectancy of the vehicle and kilometers covered by it, want to know what is the type of vehicle that best suits them. It can help to decide which and when it should be purchased the vehicle depending on the type.

Table 59:Top three options for the Business as usual scenario and its purchase year (Own source)

		Business as usual 2020	**Business as usual 2025**	**Business as usual 2030**	**Business as usual 2035**
15 Years & 20,000 km	Best choice	1.LPG	1.LPG	1.LPG	1.BEV
	Second Best choice	2.CNG	2.CNG	2.BEV	2.LPG
	Third Best choice	3.BEV	3.BEV	3.CNG	3.CNG
12 Years & 20,000 km	Best choice	1.LPG	1.LPG	1.LPG	1.LPG
	Second Best choice	2.CNG	2.CNG	2.CNG	2.BEV
	Third Best choice	3.BEV	3.BEV	3.BEV	3.CNG
15 Years & 15,000 km	Best choice	1.LPG	1.LPG	1.LPG	1.LPG
	Second Best choice	2.CNG	2.CNG	2.BEV	2.BEV
	Third Best choice	3.BEV	3.BEV	3.CNG	3.CNG
12 Years & 15,000 km	Best choice	1.LPG	1.LPG	1.LPG	1.LPG
	Second Best choice	2.CNG	2.CNG	2.CNG	2.BEV
	Third Best choice	3.Gasoline	3.BEV	3.BEV	3.CNG
15 Years & 10,000 km	Best choice	1.LPG	1.LPG	1.LPG	1.LPG
	Second Best choice	2.CNG	2.CNG	2.CNG	2.BEV
	Third Best choice	3.Gasoline	3.Gasoline	3.BEV	3.CNG
12 Years & 10,000 km	Best choice	1.LPG	1.LPG	1.LPG	1.LPG
	Second Best choice	2.Gasoline	2.CNG	2.CNG	2.CNG
	Third Best choice	3.CNG	3.Gasoline	3.BEV	3.BEV

Table 60:Top three options for the Decarbonization Path scenario and its purchase year (Own source)

		Decarbonization Path 2020	**Decarbonization Path 2025**	**Decarbonization Path 2030**	**Decarbonization Path 2035**
15 Years & 20,000 km	Best choice	1.LPG	1.LPG	1.LPG	1.BEV
	Second Best choice	2.CNG	2.CNG	2.CNG	2.LPG
	Third Best choice	3.BEV	3.BEV	3.BEV	3.CNG
12 Years & 20,000 km	Best choice	1.LPG	1.LPG	1.LPG	1.LPG
	Second Best choice	2.CNG	2.CNG	2.CNG	2.BEV
	Third Best choice	3.BEV	3.BEV	3.BEV	3.CNG
15 Years & 15,000 km	Best choice	1.LPG	1.LPG	1.LPG	1.LPG
	Second Best choice	2.CNG	2.CNG	2.CNG	2.BEV
	Third Best choice	3.Gasoline	3.BEV	3.BEV	3.CNG
12 Years & 15,000 km	Best choice	1.LPG	1.LPG	1.LPG	1.LPG
	Second Best choice	2.CNG	2.CNG	2.CNG	2.BEV
	Third Best choice	3.Gasoline	3.Gasoline	3.BEV	3.CNG
15 Years & 10,000 km	Best choice	1.LPG	1.LPG	1.LPG	1.LPG
	Second Best choice	2.CNG	2.CNG	2.CNG	2.BEV
	Third Best choice	3.Gasoline	3.Gasoline	3.Gasoline	3.CNG
12 Years & 10,000 km	Best choice	1.LPG	1.LPG	1.LPG	1.LPG
	Second Best choice	2.CNG	2.CNG	2.CNG	2.BEV
	Third Best choice	3.Gasoline	3.Gasoline	3.Gasoline	3.CNG

5.1.3 COST ANALYSIS DEPENDING ON THE KMS COVERED

As previously was anticipated, it is of great interest to carry out a study of all types of vehicles based also on the kilometers traveled per year. In addition, this section will include a subsection where the emissions emitted per vehicle type will be compared and it will be tried to obtain a "emissions cost", which would be the cost of reducing the GHG emissions.

To carry out this analysis, as in the previous study, the two scenarios already explained will be used, business as usual and decarbonization path. The net present value will be compared of each of the vehicle's types bought in 2020, 2025 and 2030 for a life expectancy of 15 years. In this case it will not be studied a life expectancy of 12 years old because it is believed that all conclusions around the vehicle's life expectancy have been obtained in the other analysis.

5.1.3.1 COST ANALYSIS FOR A VEHICLE PURCHASED IN 2020

It will be performed an analysis of the total cost associated with a vehicle purchased this year (2020) and with a life expectancy of 15 years.

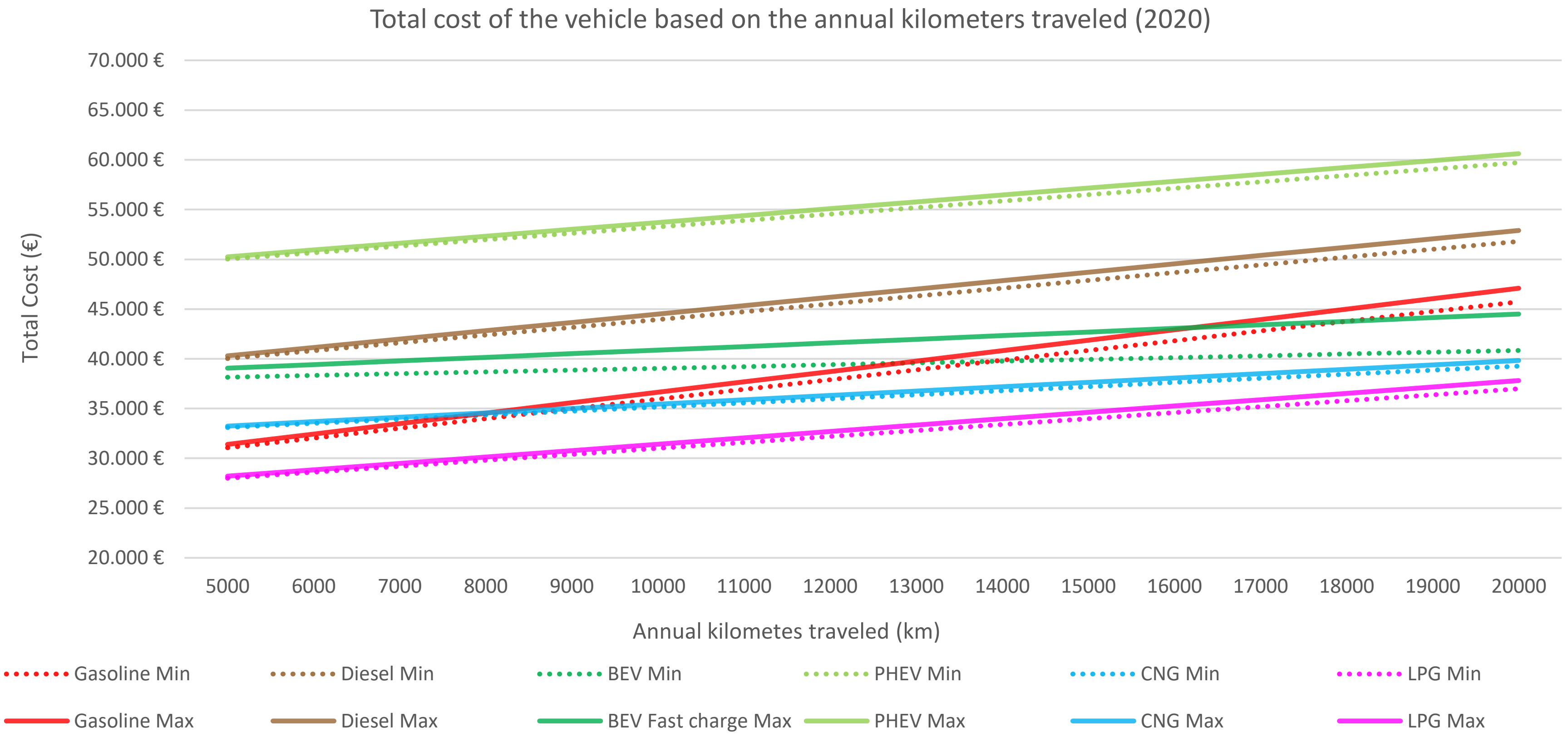

Figure 71:Total Cost per vehicle type purchased in 2020 based on the annual kilometers covered (Own Source)

Figure 71 represent the total cost per vehicle type bought in 2020 based on the kilometers covered. As it can be observed from it, new low polluting technologies have emerged to stay, their competitive prices together with the reduction of GHG gases (*figure 72, 73 and 74*) allow to think this. For example, gas fuels (LPG and CNG), due to its low purchase cost and a reasonable cost of fuel per km traveled, make them the most economical almost from the beginning.

Electric vehicle has already achieved a very competitive price, reaching a lower price than the ICE vehicles in both scenarios (business as usual and decarbonization path) if more than 16,000 km are traveled annually.

Plug-in Electric Vehicles are yet to be a competitive alternative. Actually, these types of vehicles are two vehicles in one. Therefore, the following graph (*figure 72, 73 and 74*) is very interesting, since we can compare the PHEV with the cost of buying a BEV and a gasoline one. It is good to remember that reducing NO_x and PM emissions are even more important than CO_2, because they harm directly to our health.

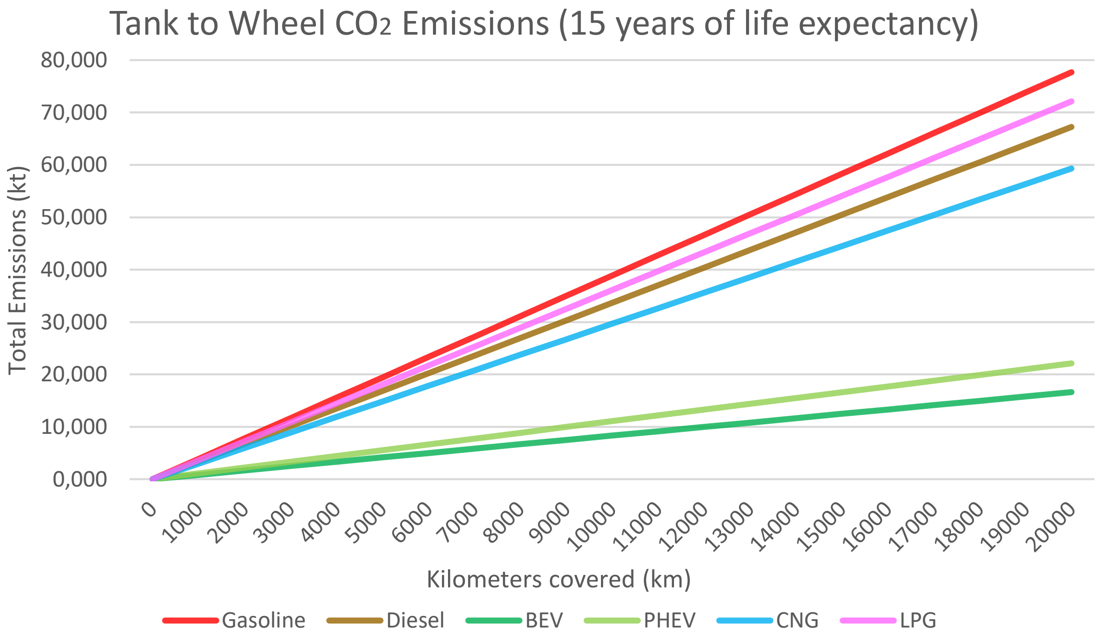

Figure 72: CO_2 emissions per vehicle type purchased in 2020 based on the kilometers covered (Own source)

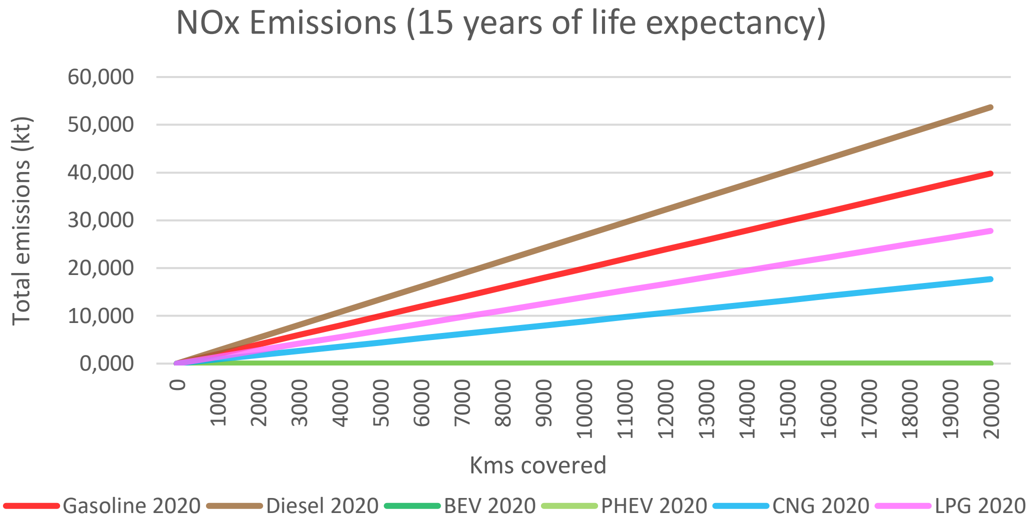

Figure 73: NOx emissions per vehicle type purchased in 2020 based on the kilometers covered (Own source)

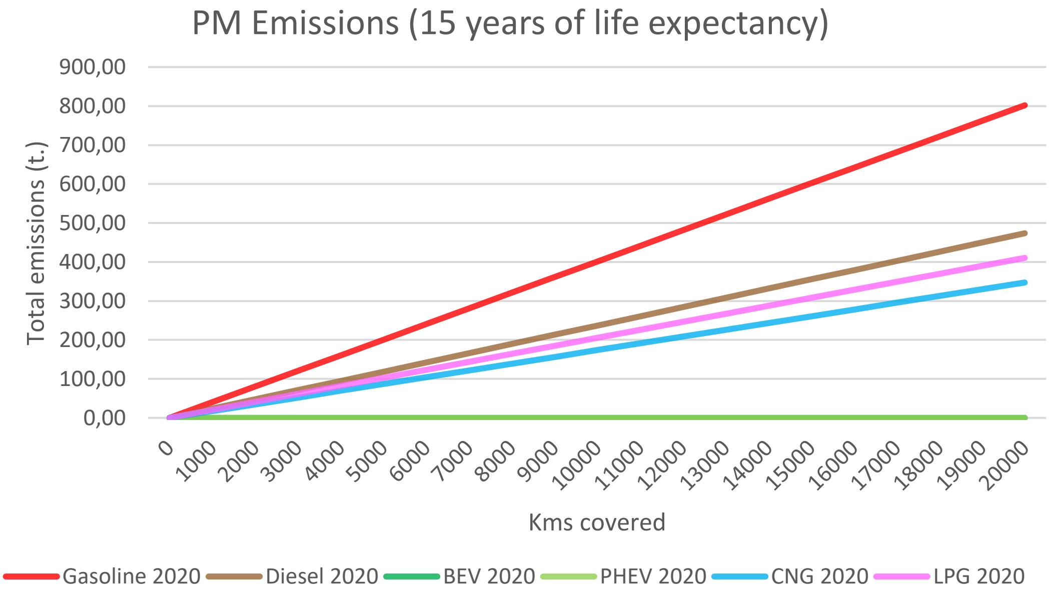

Figure 74: PM emissions per vehicle type purchased in 2020 based on the kilometers covered (Own source)

5.1.3.2 Cost Analysis For a Vehicle Purchased in 2025

In this section an analysis of the total cost associated with a vehicle purchased this year (2025) and with a life expectancy of 15 years. It has been decided not to perform the same analysis as in the previous one, analyzing what happen if are covered more or less than 20,000 km. This decision has been taken because of two reasons, the first one is because it is expected that both, autonomy, and efficiency of new technology (specially BEVs) will improve during these years, enabling to cover at least 25,000 km per year. The second reason is that it is felt that performing that extra analysis will not add any extra value to the thesis, due to main conclusions have already been obtained.

Therefore, *figure 75* will represent the CO_2 emissions per vehicle type purchased in 2025. Despite the improvement of ICE vehicles in terms of pollution, they are still the most damaging choice.

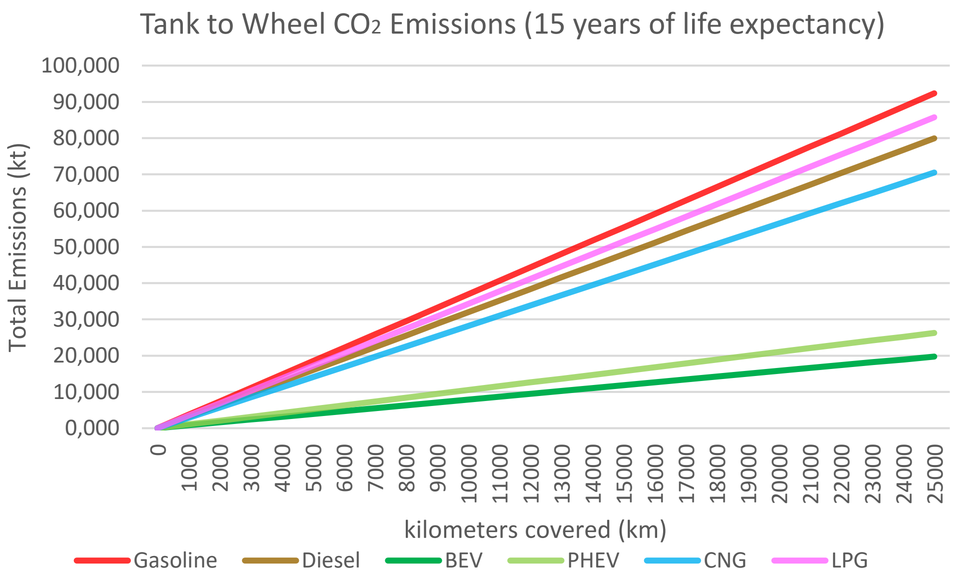

Figure 75: Tank to Wheel CO_2 emissions per vehicle type purchased in 2025 based on the kilometers covered (Own source)

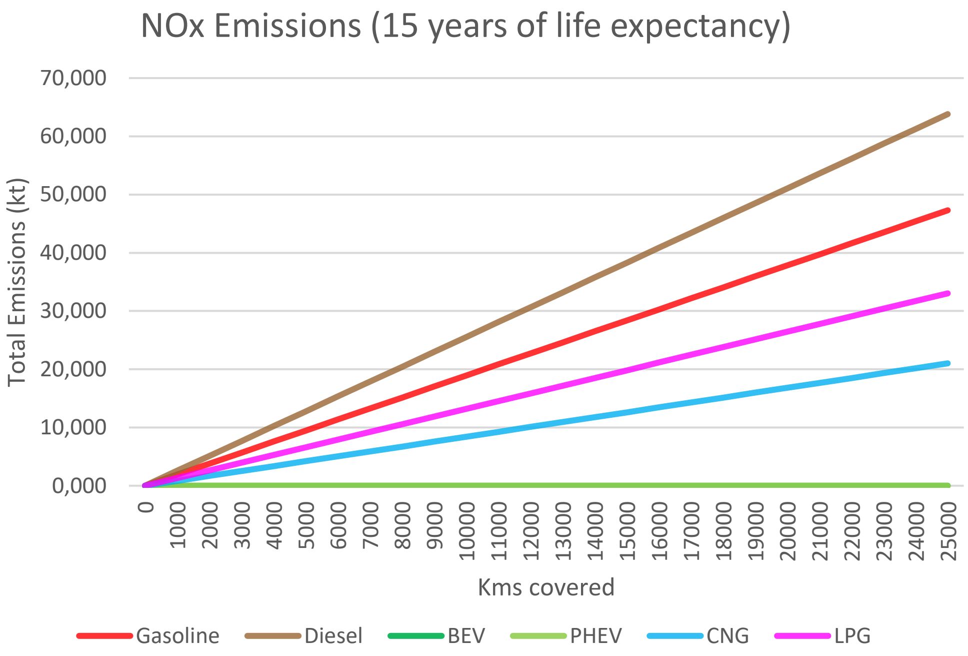

Figure 77: NOx emissions per vehicle type purchased in 2025 based on the kilometers covered (Own source)

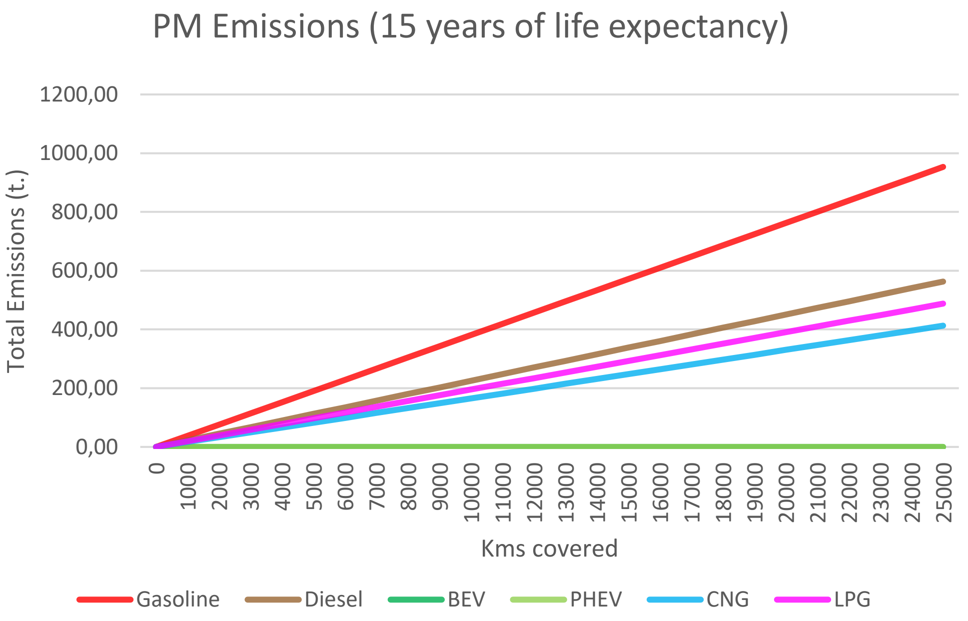

Figure 76: PM emissions per vehicle type purchased in 2025 based on the kilometers covered (Own source)

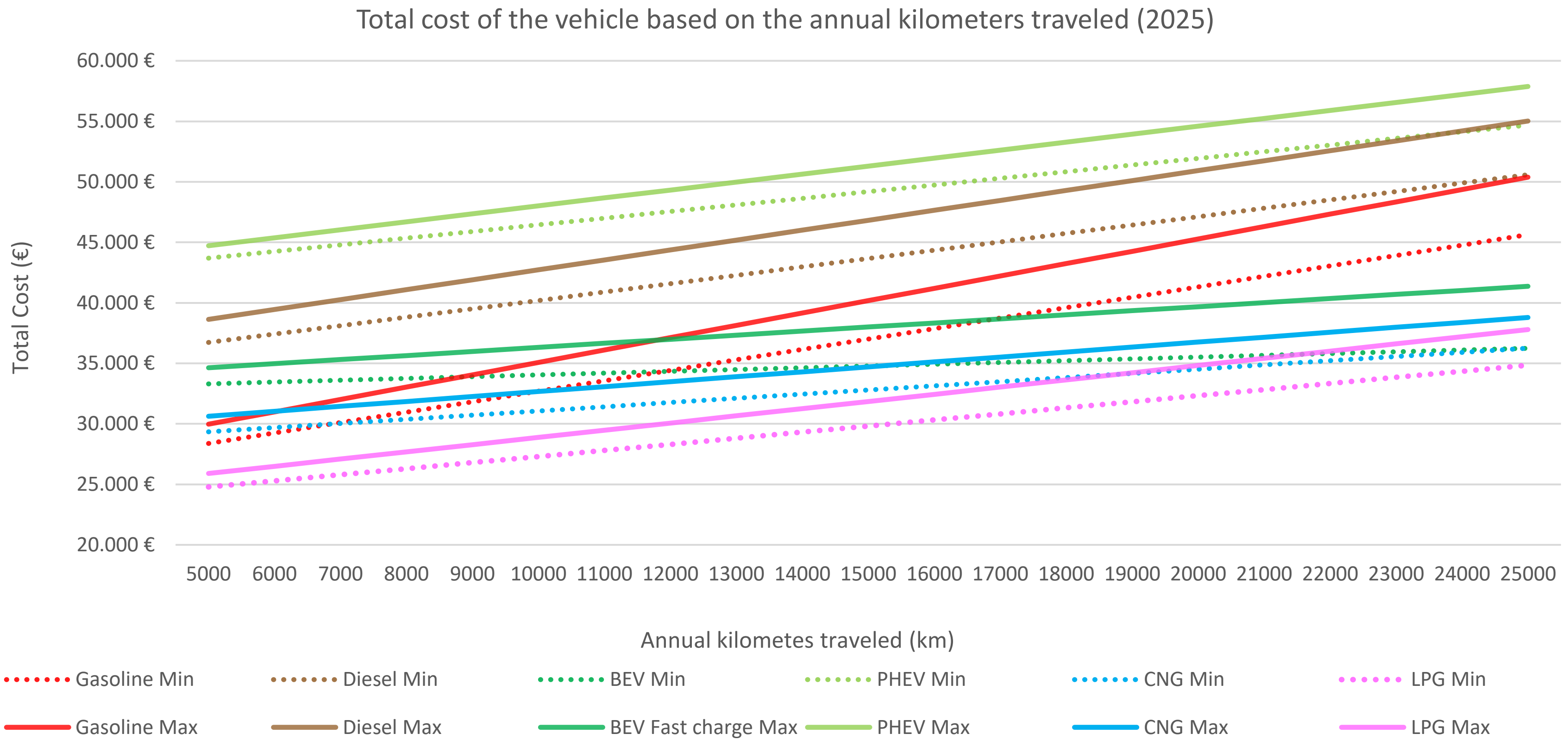

Figure 78:Total Cost per vehicle type purchased in 2025 based on the annual kilometers covered (Own Source)

5.1.3.3 COST ANALYSIS FOR A VEHICLE PURCHASED IN 2030

In this section an analysis of the total cost associated with a vehicle purchased this year (2030) and with a life expectancy of 15 years as in the previous section, only one analysis will be performed. This time, it will be studied assuming that BEVs will be able to cover 30,000 kilometers thanks to the improvement of its autonomy, efficiency and the refueling network.

Figure 79 will represent the CO_2 emissions per vehicle type purchased in 2030, as it can be observed there is not such a great difference with the showed previously. *Figure 80 and 81* represent the homonyms for PM and NO_x, respectively. Regarding the cost of the vehicles (*figure 82*), it can be seen large differences compared to the previous ones. It varies greatly depending on the scenario that occurs (business as usual or decarbonization path). This is

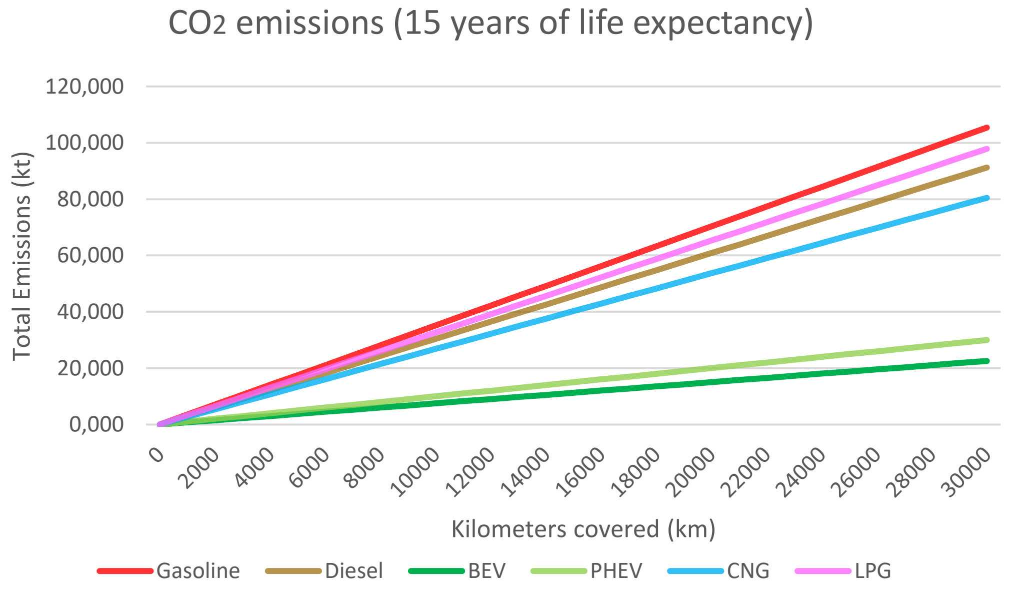

Figure 79:CO2 emissions per vehicle type purchased in 2030 based on the kilometers covered (Own source)

due to the uncertainty about how each type of vehicle will evolve. In the year 2030, the aid provided, and the measures taken have already had time to take effect.

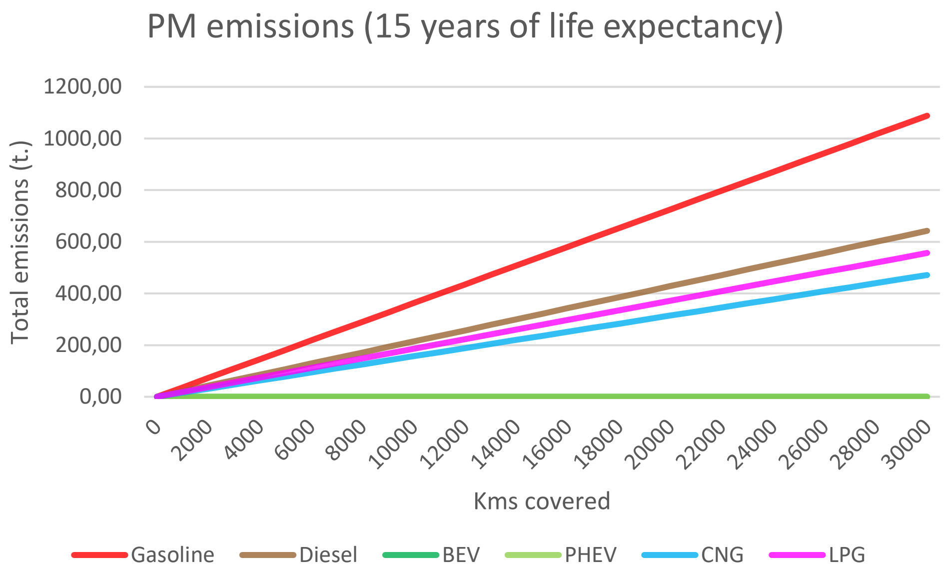

Figure 80: PM emissions per vehicle type purchased in 2030 based on the kilometers covered (Own source)

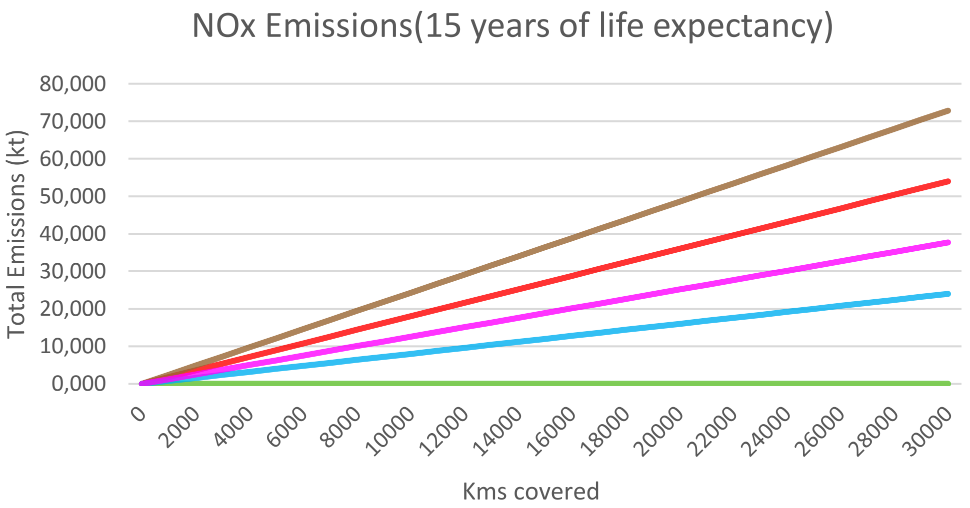

Figure 81: NOx emissions per vehicle type purchased in 2030 based on the kilometers covered (Own source)

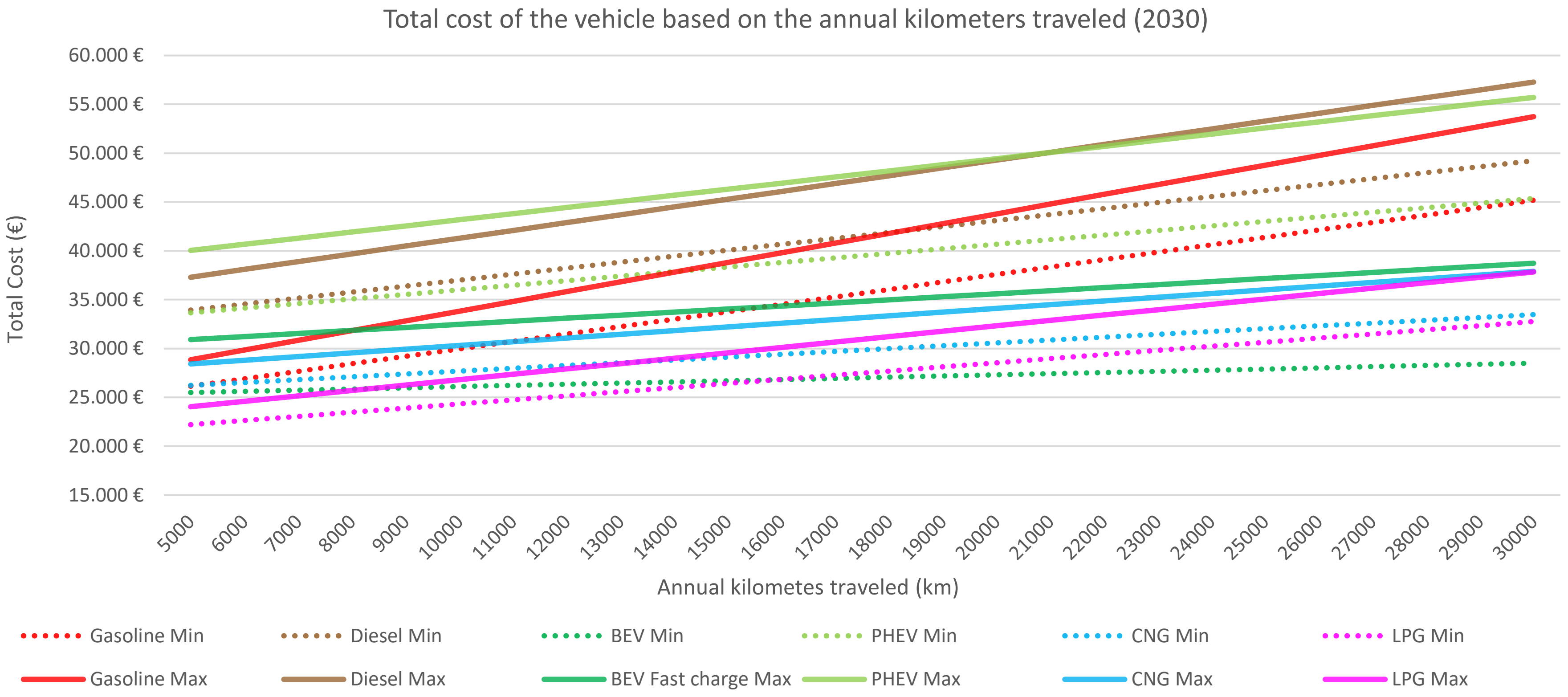

Figure 82:Total Cost per vehicle type purchased in 2030 based on the annual kilometers covered (Own Source)

5.1.3.4 COMPARISON AND CONCLUSION

According to the Ministry for the Ecological Transition [5], it generates approximately 27% of the greenhouse gases (GHG)[18] emitted in Spain and more than 40% of the total nitrogen oxide emissions. That is why trying to reduce the vehicle's emissions has been one of the main concerns for vehicle's manufacturer. Currently, the Spanish fleet is formed mainly by ICE vehicles, alternative fuels represent just a 0.12 %. As it was stated in chapter 3, *Figure 83* shows the average emissions per km of each of the alternatives. In terms of pollution, Electric vehicles without any doubt are the best choice. Gas vehicles improves ICE vehicle talking about NO_x and PM particles, but regarding CO_2 emissions, they have very similar records. Therefore, if what is wanted is to dramatically reduce pollution from the transport sector, it will be required an electrification of the fleet.

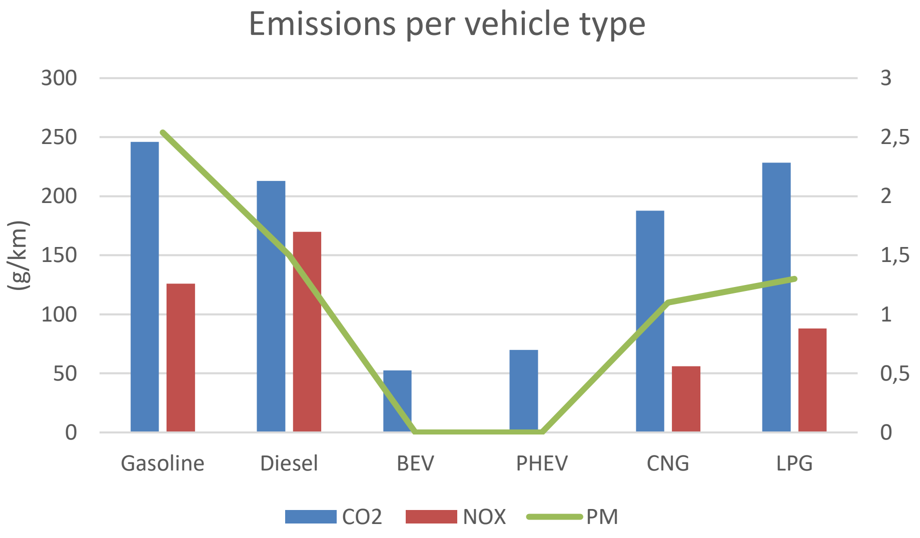

Figure 83: Emissions per km of each type of vehicle (Source: OVEMS [14])

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[18] A greenhouse gas (GHG) is a gas that absorbs and emits radiant energy within the thermal infrared range. The primary greenhouse gases in Earth's atmosphere are water vapor (H2O), carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), and ozone (O3). Without greenhouse gases, the average temperature of Earth's surface would be about −18 °C (0 °F), rather than the present average of 15 °C (59 °F).

It will be calculated how much would it cost switching an ICE vehicle for an electric vehicle or gas vehicle in terms of pollution (€/kt.). Next formulas show the extra cost that it would cost to change a gasoline vehicle for an electric or gas vehicle:

$$Cost\ of\ reducing\ emissions(€/kt.) = \frac{Cost_{gasoline} - \frac{Cost_{PHEV} + Cost_{BEV}}{2}}{Emissions_{gasoline} - \frac{Emissions_{PHEV} + Emissions_{BEV}}{2}} \tag{20}$$

$$Cost\ of\ reducing\ emissions(€/kt.) = \frac{Cost_{gasoline} - \frac{Cost_{CNG} + Cost_{LPG}}{2}}{Emissions_{gasoline} - \frac{Emissions_{CNG} + Emissions_{LPG}}{2}} \tag{21}$$

For calculating the cost of reducing the emissions, it has been decided to use the average prices and emissions of the electric vehicles (BEV+PHEV) and gas vehicles (CNG+LPG). This decision has been taken because that assumption was taken in the scenarios of evolution of the Spanish fleet (chapter 4). *Table 61* present the cost of replacing an ICE vehicle which covers 13,000 km (simulate the Spanish average) and a life expectancy of 15 years old with another electric vehicle or gas vehicle. Some of the data showed in the aforementioned table is very interesting. Replacing an ICE vehicle with a gas natural would not suppose an extra charge for any of the parts, neither the buyer nor the Government. In 2020, it is possible to reduce at the same time the cost of a vehicle and the emissions in case the user decides to purchase a Gas vehicle.

In addition, that table also shows how much would it cost reducing one kt. of the main pollutant in case it would be electrified a vehicle. As, it has been commented previously, electrifying the fleet is the most effective path to reduce GHG emissions, but this involves an expense for the consumer. This expense varies depending on the scenario that occurs (decarbonization path or business as usual). Cost showed in *Table 61*, allow to think whether it is worth paying a little more for a vehicle which pollutes much less, or conversely, stick with a conventional car.

Table 61:Cost of replacing ICE vehicles in terms of GHG emissions (Own source)

		CO2 (€/kg)	**NOx (€/kg)**	**PM (€/kg)**
ELECTRIFY THE VEHICLE FLEET	**Gasoline Min**	-0,224	-0,33	-0,02
	Gasoline Max	-0,240	-0,35	-0,02
	Diesel Min	-0,35	-0,03	-0,003
	Diesel Max	-0,59	-0,05	-0,01
GAS VEHICLE FLEET	**Gasoline Min**	0,55	0,39	0,02
	Gasoline Max	11,80	0,58	0,19
	Diesel Min	0,61	0,43	0,02
	Diesel Max	12,07	0,60	0,19

In addition, replacing an ICE vehicle which covers 13,000 km with a less pollutant technology, would bring a significant reduction in polluting particles, as shown in *table 62*. If it is compared the emissions reduction between making gas the vehicle fleet with electrifying it, it is obtained a much higher reduction when it is electrified. On average GHG would be reduced by a 35 % if the fleet is electrified than if is gasified.

Table 62: Reduction of the emissions in case the vehicle chosen would be gasified or electrified (Own source)

		CO2 (t.)	**NOx (t.)**	**PM (t.)**
ELECTRIFY THE VEHICLE FLEET	**Gasoline**	-36,302409	-30,37515	-414,57975
	Diesel	-32,735381	-30,37515	-414,57975
GAS VEHICLE FLEET	**Gasoline**	-31,915457	-14,7771	-246,285
	Diesel	-28,34843	-14,7771	-246,285

Below are the costs per type of vehicle based on the kilometers traveled for each of the scenarios, as it can be observed there is a significant difference in cost whether or not low polluting alternatives are promoted or not.

Table 63: Total cost per vehicle type depending on the kilometers covered Decarbonization path scenario (Own source)

		5000 km	**10000 km**	**15000 km**	**20000 km**	**25000 km**	**30000 km**
Decarbonization path 2020	**Gasoline**	31.062 €	35.949 €	40.836 €	45.723 €	50.610 €	55.497 €
	Diesel	40.027 €	43.951 €	47.875 €	51.799 €	55.723 €	59.648 €
	BEV	38.148 €	39.046 €	39.944 €	40.842 €	77.887 €	80.780 €
	PHEV	50.026 €	53.257 €	56.488 €	59.719 €	62.951€*	66.182€*
	CNG	33.098 €	35.155 €	37.211 €	39.268 €	41.325 €	43.382 €
	LPG	28.004 €	31.000 €	33.996 €	36.992 €	39.988 €	42.984 €
Decarbonization path 2025	**Gasoline**	28.379 €	32.693 €	37.007 €	41.321 €	45.635 €	49.949 €
	Diesel	36.728 €	40.192 €	43.656 €	47.120 €	50.584 €	-
	BEV	33.299 €	34.034 €	34.769 €	35.504 €	36.239 €	36.974 €
	PHEV	43.691 €	46.440 €	49.188 €	51.936 €	54.685 €	57.433 €
	CNG	29.341 €	31.068 €	32.795 €	34.521 €	36.248 €	37.975 €
	LPG	24.785 €	27.300 €	29.815 €	32.330 €	34.845 €	37.360 €
Decarbonization path 2030	**Gasoline**	26.146 €	29.955 €	33.763 €	37.571 €	41.380 €	45.188 €
	Diesel	33.935 €	36.993 €	40.051 €	43.109 €	46.167 €	49.225 €
	BEV	25.495 €	26.096 €	26.698 €	27.299 €	27.901 €	28.503 €
	PHEV	33.656 €	35.997 €	38.339 €	40.680 €	43.021 €	45.362 €
	CNG	26.226 €	27.676 €	29.125 €	30.575 €	32.024 €	33.474 €
	LPG	22.203 €	24.314 €	26.426 €	28.537 €	30.649 €	32.760 €

*It has been calculated considering the purchase of a BEV and a gasoline vehicle

Table 64: Total cost per vehicle type depending on the kilometers covered Decarbonization path scenario (Own source)

		5000 km	**10000 km**	**15000 km**	**20000 km**	**25000 km**	**30000 km**
Business as usual 2020	**Gasoline**	31.405 €	36.635 €	41.865 €	47.094 €	52.324 €	57.554 €
	Diesel	40.302 €	44.502 €	48.701 €	52.901 €	57.100 €	61.300 €
	BEV	39.063 €	40.876 €	42.689 €	44.503 €	81.737€*	85.258€*
	PHEV	50.251 €	53.707 €	57.162 €	60.618 €	64.074 €	67.530 €
	CNG	33.239 €	35.438 €	37.637 €	39.835 €	42.034 €	44.232 €
	LPG	28.211 €	31.413 €	34.615 €	37.818 €	41.020 €	44.223 €
Business as usual 2025	**Gasoline**	29.972 €	35.074 €	40.177 €	45.279 €	50.381 €	55.484 €
	Diesel	38.631 €	42.729 €	46.826 €	50.923 €	55.020 €	59.117 €
	BEV	34.634 €	36.317 €	38.000 €	39.683 €	41.366 €	-
	PHEV	44.718 €	48.007 €	51.297 €	54.586 €	57.876 €	61.166 €
	CNG	30.626 €	32.667 €	34.708 €	36.749 €	38.789 €	40.830 €
	LPG	25.900 €	28.873 €	31.845 €	34.818 €	37.790 €	40.763 €
Business as usual 2030	**Gasoline**	28.849 €	33.827 €	38.805 €	43.783 €	48.761 €	53.739 €
	Diesel	37.294 €	41.291 €	45.288 €	49.285 €	53.283 €	57.280 €
	BEV	30.916 €	32.479 €	34.041 €	35.603 €	37.166 €	38.728 €
	PHEV	40.043 €	43.176 €	46.310 €	49.443 €	52.577 €	55.710 €
	CNG	28.429 €	30.323 €	32.218 €	34.112 €	36.007 €	37.901 €
	LPG	24.042 €	26.801 €	29.561 €	32.320 €	35.079 €	37.839 €

*It has been calculated considering the purchase of a BEV and a gasoline vehicle

Figure 84 shows the percentage difference between the two scenarios studied in this thesis depending also in the kilometers covered and its fuel type. For obtaining that graph, it has been used the following formula:

$$\%_{vehicle,km,year} = \frac{Cost_{vehicle,km,year,decarbonization} - Cost_{vehicle,km,year,businessasusual}}{Cost_{vehicle,km,year,businessasusual}} \quad (22)$$

The aforementioned figure is quite useful, because it enables to observe the evolution depending the purchase year and the km covered. As the kilometers covered increase, the cost difference between one scenario and another becomes greater. In addition, as time passes, the cost difference between the scenarios also becomes larger, which was intuitive because it will give time to for the aid to show the results.

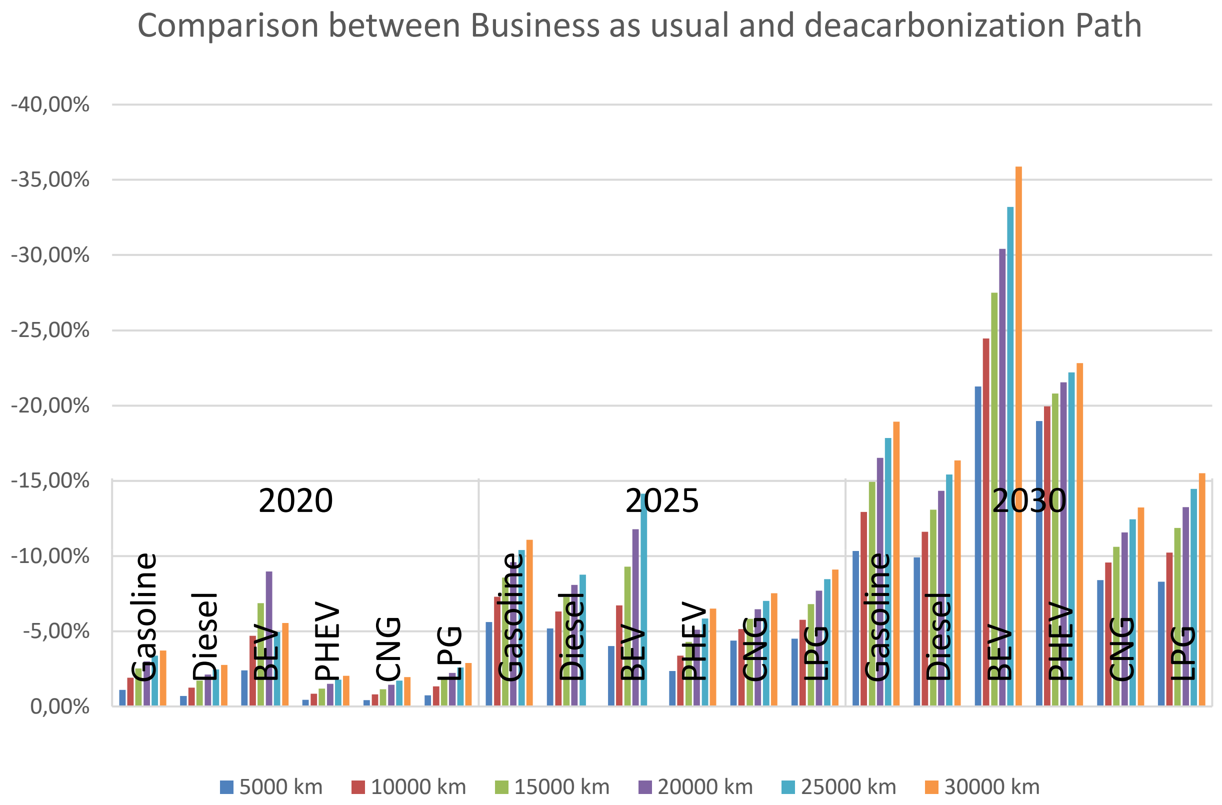

Figure 84: Percentage comparison between the scenarios depending on the purchase year and the km covered per vehicle type (Own source)

5.1.4 COST ANALYSIS FOR A HOUSEHOLD IN 2020

In chapter 4, it was described the current composition of the Spanish fleet, including its motorization rate, 516 passenger car per thousand of habitants, meaning that in many households there is more than just one vehicle. If this is added to the current BEV's limitations in terms of kilometers covered due to their low current range. It seems essential to carry-out an extra analysis for studying some alternatives for a household.

The main advantage of the electric vehicles, as it could be seen in the previous analysis is its low cost per kilometer traveled (electricity prices are cheaper than Gas or conventional fuels). However, their majority of kilometers covered occurred on urban roads. This makes very difficult for them to cover more than 20,000 km a year, at least those cars that have been purchased in 2020. Because of that, in case a household travels more than 20,000 km, it is not feasible to cover it with just one BEV. Therefore, in this section it will be carried out two comparison:

1. Suppose that there is only one vehicle per address, except in the case of the BEV, which would also have a combustion vehicle. The hypothesis has been assumed that half of the kilometers covered per address would occur on urban roads (electric cars) and the other half would be on motorways or highways (gasoline cars).
2. It is supposed that there are two vehicles of the same type per household. It will be studied the total cost of every pair of vehicles, that together with the total emissions emitted by the pair of vehicles, will allow conclusions to be drawn.

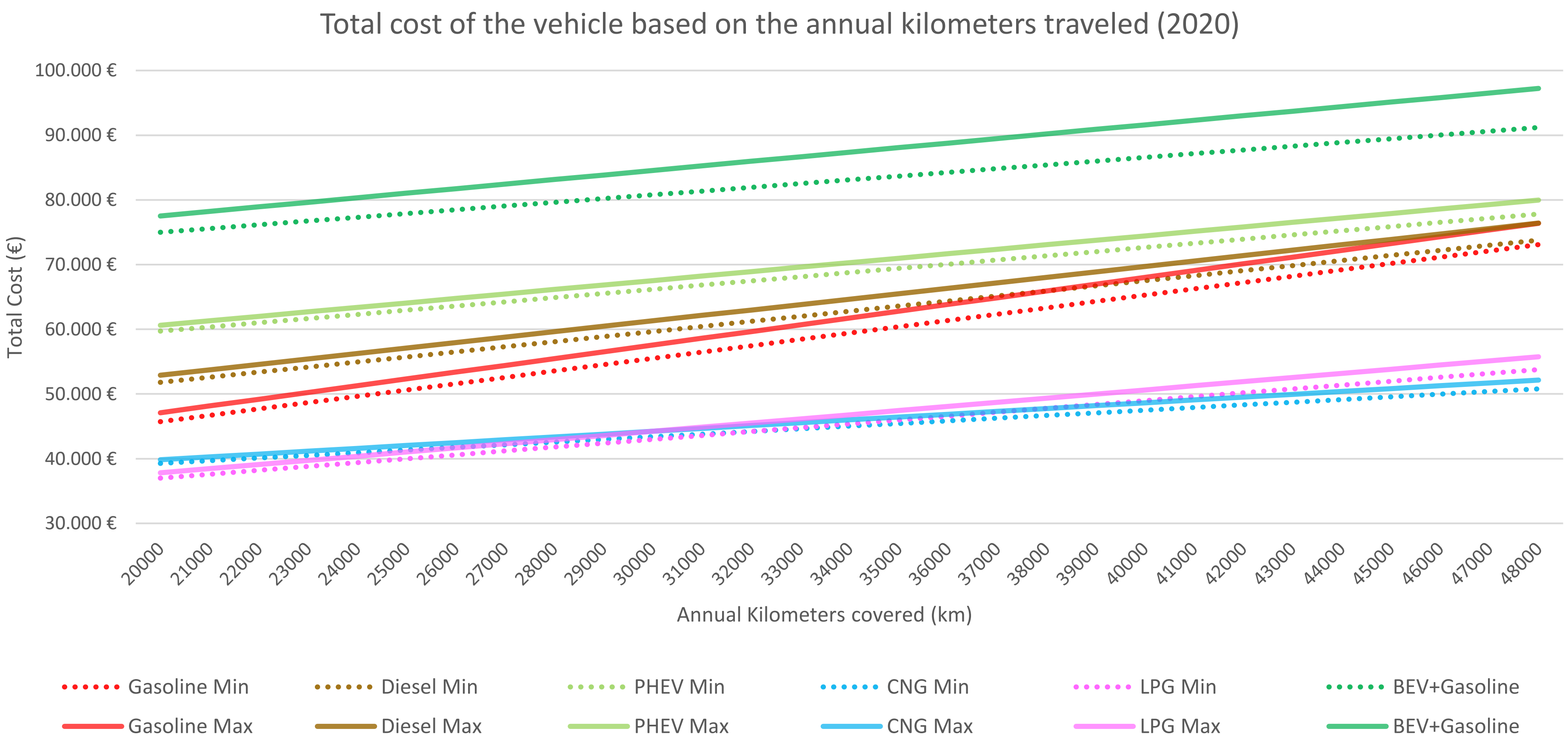

Figure 85:Total Cost of one vehicle per household based on the annual kilometers covered (Own source)

This analysis has been carried out to analyze those households where there is just one vehicle. But since electric cars cannot travel more than 20,000 km, if BEV are chosen as the main vehicle, in case that address covers more than 20,000 per year, it will be forced to buy another car (for example, gasoline).

As it can be observed in *Figure 85*, when comparing the purchase of two vehicles, one electric and the other gasoline, with purchasing just one vehicle per address, it obviously loses out on the comparison. The results presented in the aforementioned figure does not surprise at all. When it is compared the purchase of two vehicles compared to the purchase of a single vehicle, the up-front cost and maintenance cost are doubled, while the fuel cost is the only variable that does not increase.

As previously was anticipated, Plug-in Electric Vehicles are perhaps the ones that benefit the most from this comparison, in addition to being much cheaper than buying a gasoline vehicle and a BEV, it is the least polluting option for those vehicles that travel a lot of kilometers (*Figure 86*).

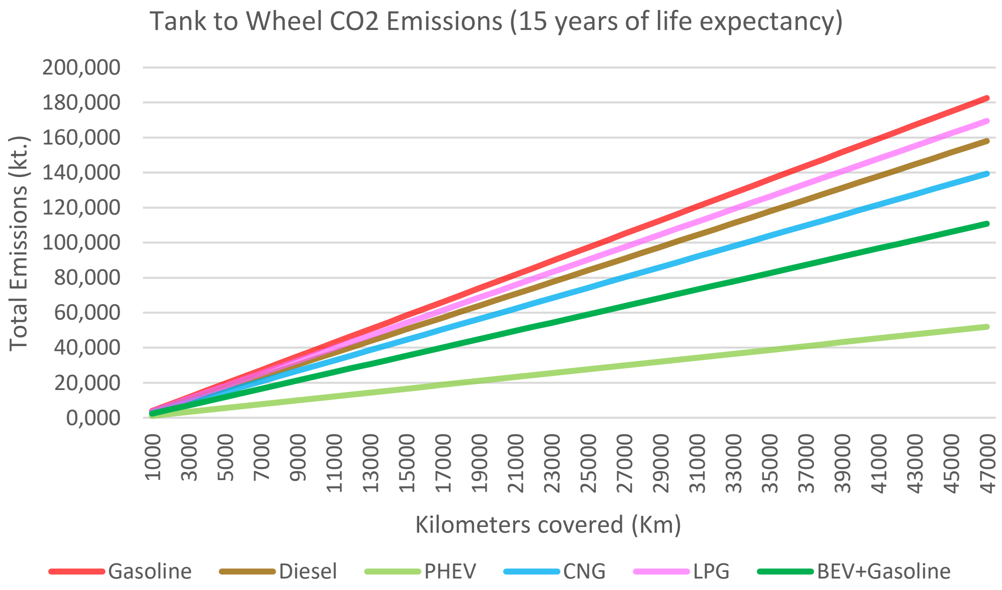

Figure 86: Tank to Wheel CO_2 emissions per vehicle type purchased in 2020 based on the kilometers covered (Own source)

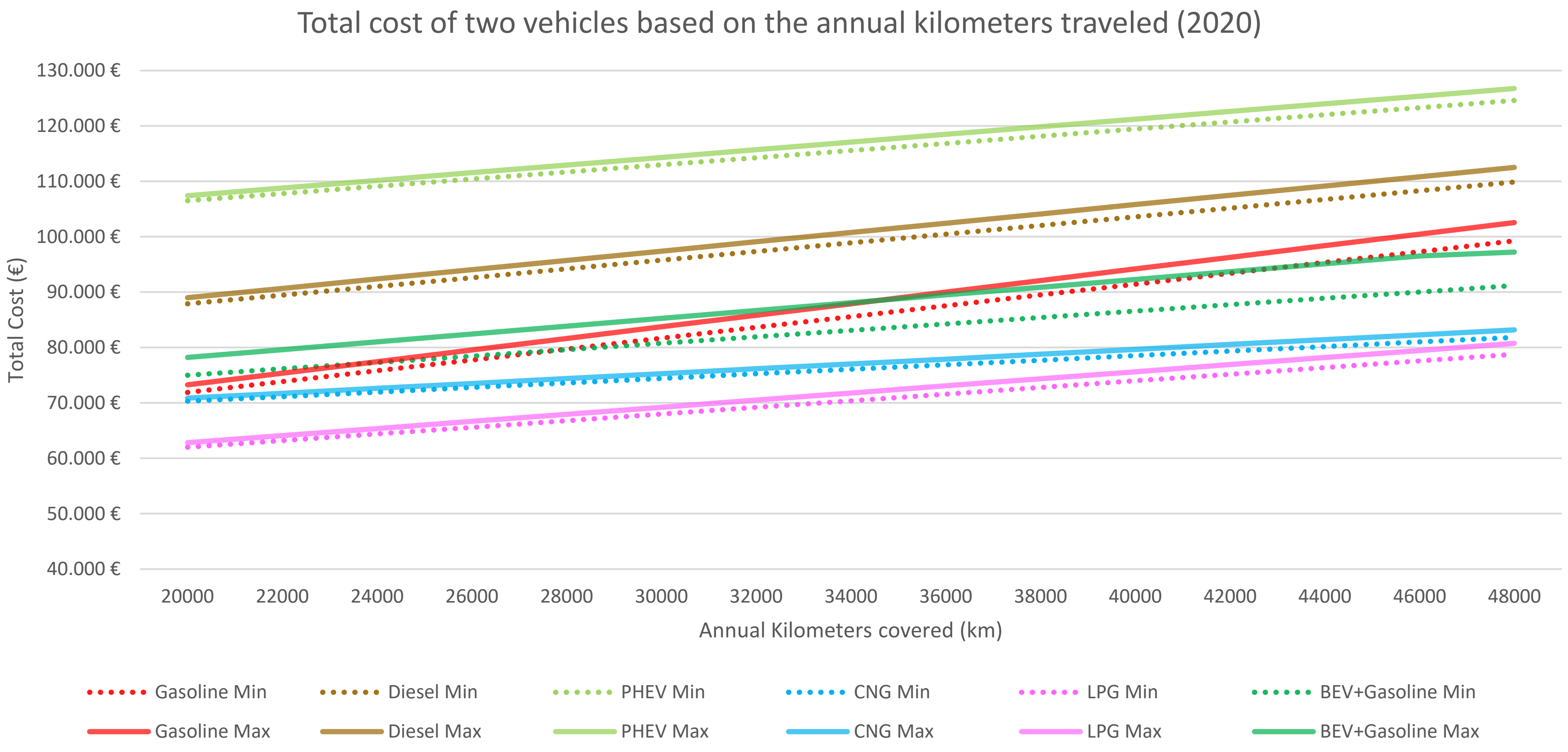

Figure 87:Total Cost of two vehicles per household based on the annual kilometers covered (Own source)

Spain has a motorization rate of 516 passenger car per thousand of habitants. This means that there are probably at least two vehicles per home (especially in places far from the large urban areas such as Madrid or Barcelona).

This makes this analysis very interesting. As shown in *Figure 87*, the domain of the least polluting technologies is overwhelming. The cheapest choice in case it is required two cars per family would be to buy two Gas vehicles. There is a dispute about being the third best alternative in economic terms, and this depends on the kilometers traveled and the scenario that occurs. From the 30,000 km covered between the two familiar vehicles in case the scenario is Decarbonization path happen or 35,000 km in case it is the business as usual scenario.

When it comes to talk about pollution (*figure 88*), there is a clear winner, the combination of BEV + Gasoline vehicle. For this reason, it will be interesting trying to calculate the cost of reducing emissions depending on the scenario. It will allow to check if it is attractive for the Government to give aid to promote sustainable mobility.

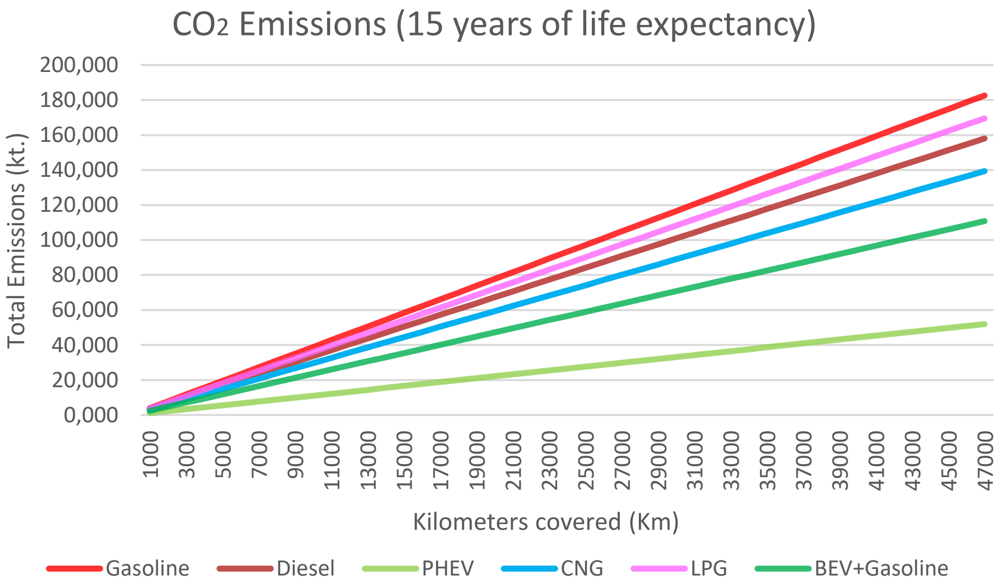

Figure 88: CO2 emissions per vehicle type purchased in 2020 based on the kilometers covered (Own source)

5.2 MACRO LEVEL

The main objective of this section is to carry out an economic analysis at a macro level of the different scenarios of the park. To achieve it, it will be calculated all the cost associated with the fleet scenarios explained in the chapter 4, forecast of the evolution of the Spanish vehicle fleet. Because the scenarios generated in this thesis are opposite each other, it will be quite easy to compare them, taking into account both economic factors and the environmental benefits associated with each scenario.

To calculate the total cost, the cost of implementing the necessary infrastructure, the costs associated with the purchase of the vehicles, the fuel costs associated with transportation and the maintenance costs of the vehicles have been taken into account. In short, the following formula has been used.

$$\begin{aligned} & Total\ Cost\ year_i \\ & = \sum_{j=1}^{6} Purchase\ price_{i,j} * vehicles\ sold_{i,j} \\ & + \sum_{j=1}^{6}\sum_{y=1990}^{i} Manteinance\ cost_{i-y,j} + \sum_{j=1}^{6} Infrastructure\ cost_{i,j} \\ & + \sum_{j=1}^{6}\sum_{y=1990}^{i} Consumtion\ _{y,j} * fuel\ cost_{i,j} * km\ covered_{i,j} \end{aligned} \tag{23}$$

$$Total\ Cost = \sum_{i=2020}^{2050} Total\ cost\ year_i \tag{24}$$

$$Infrastructure\ cost = \sum_{j=1}^{6} Infrastructure\ cost_{i,j}$$

Although the formula shows that only vehicles sold since 1990 have been taken into account, çthis cannot be further from the truth, since all the vehicles of the Spanish fleet have been taken into account. In the previous formula, the year 1990 includes all the vehicles sold before that date. This is because the breakdown of the kilometers covered by the vehicles sold prior 1990 is unknown. Therefore, it appears that the vehicles included in the calculation are those sold from 1990, but because the breakdown of the kilometers traveled in previous years is unknown, in 1990 all vehicles are also included previously sold. Therefore, it is expected that the total cost that comes from the year 1990, is much higher than that of the year 1991 or 1992.

The developed Excel tool has the function of being able to also introduce the subscenarios already mentioned in the Micro analysis. Therefore, in the generation of scenarios for the automobile fleet, it will be used the same sub-scenarios than in the Micro analysis, Business as Usual and Decarbonization Path.

Table 65: Hypothesis in which the maximum and minimum cost of the vehicle is produced (Own Source)

	Min. (Decarbonization Path)			**Max. (Business as Usual)**		
	CONSUMPTION	FUEL COST	PURCHASE PRICE	CONSUMPTION	FUEL COST	PURCHASE PRICE
Gasoline	-1% per year	Const	Const	Const	+1% per year	+1% per year
Diesel	-1% per year	Const	Const	Const	+1% per year	+1% per year
BEV	-1.5% per year	-1% per year	-30% in 2050	Const	Const	-1 % per year
PHEV	-1.5 % per year (electricity) -1% per year (gasoline)	-1% per year (electricity) const (gasoline)	-30% in 2050	Const	Const (electricity) + 1 % per year (gasoline)	-1 % per year
CNG	-1% per year	-1% per year	-1% per year	Const	Const	Const
LPG	-1% per year	-1% per year	-1% per year	Const	Const	Const

As already happened in the macro analysis, a comparison will be made between the costs of each scenario and its emissions due to the great importance of reducing polluting emissions for health.

5.2.1 COST ANALYSIS BASE SCENARIO

This scenario simulates a progressive penetration of electric cars, in which there are 2 million EVs in the Spanish fleet in 2030. It is true that it is more conservative than PNIEC[19] forecasts presented to the European Union, but it is also more realistic since PNIEC intends to have 5 million electric cars by 2030. In chapter 4, in the section Park Evolution forecast, it was explained in detail the park evolution over the years and their emissions. Therefore, this section will focus just on economics aspects. Within this scenario, it has been simulated two sub-scenarios, the Business as usual and the Decarbonization Path, which represent two opposite strategies that the transportation sector could take.

Regarding the cost of the infrastructures, it has been assumed constant (it has not been studied different scenarios of the infrastructures costs). Therefore, both sub-scenarios business as usual and decarbonization path shares the same infrastructure grid.

Figure 90 represent the cost associated with stablishing the recharging grid. It can be observed that the cost per year, follow an uncommon distribution, similar to Poisson's distribution. While *Figure 89*, represent the infrastructures accumulated cost, which it can be matched with a sigmoidal function.

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[19] National Integrated Energy and Climate Plan (PNIEC) 2021-2030: defines the objectives of reducing greenhouse gas emissions, penetration of renewable energy and energy efficiency.

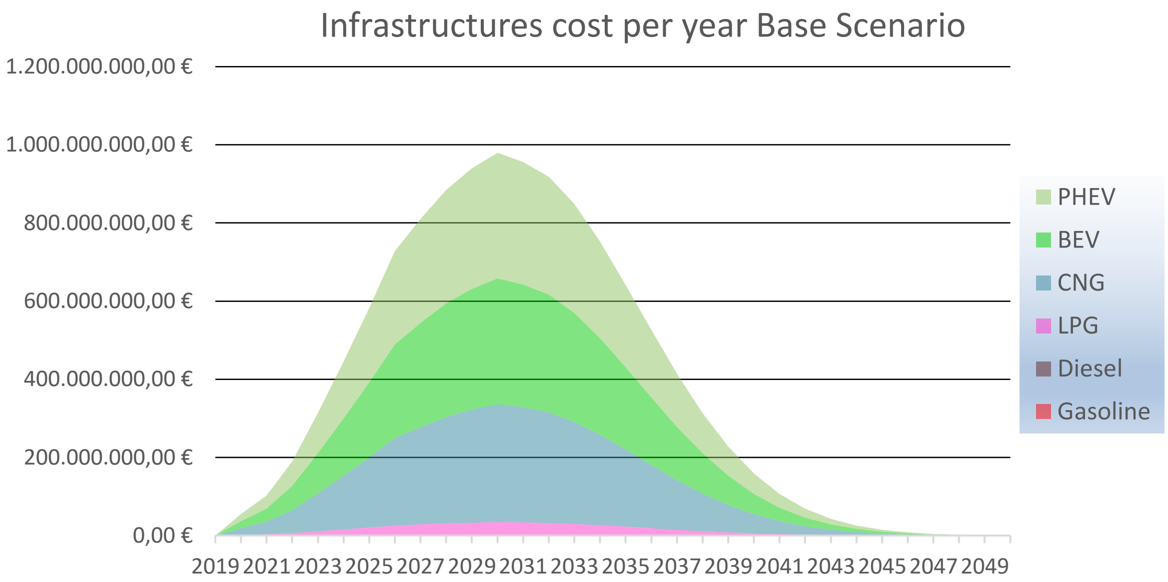

Figure 90:Infrastructures cost per year Base Scenario (Own source)

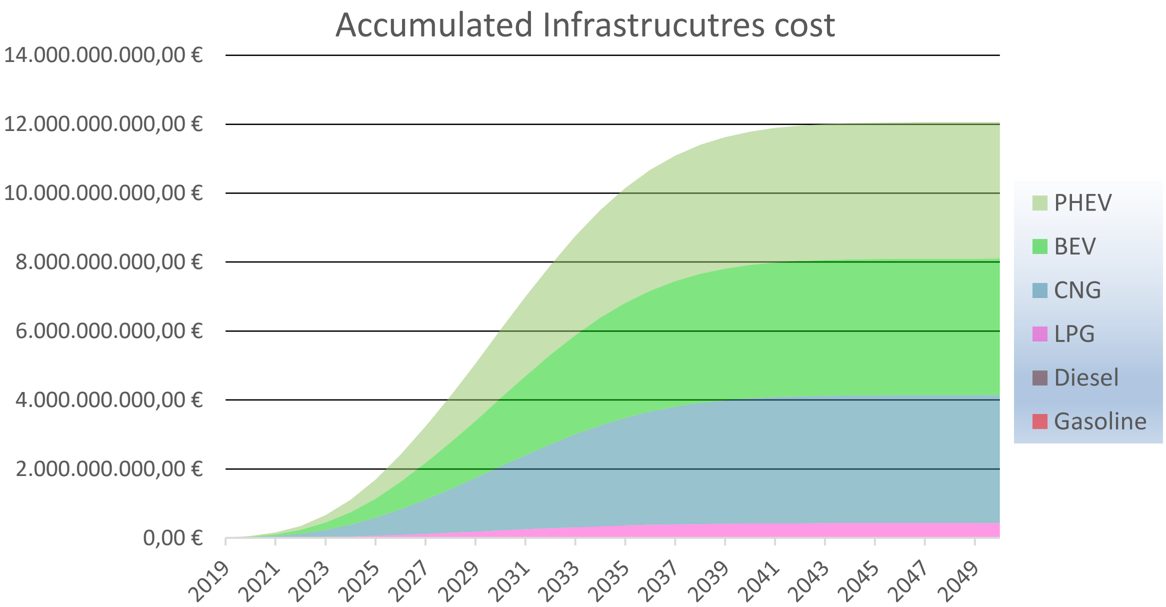

Figure 89:Accumulated Infrastructures costs Base Scenario (Own source)

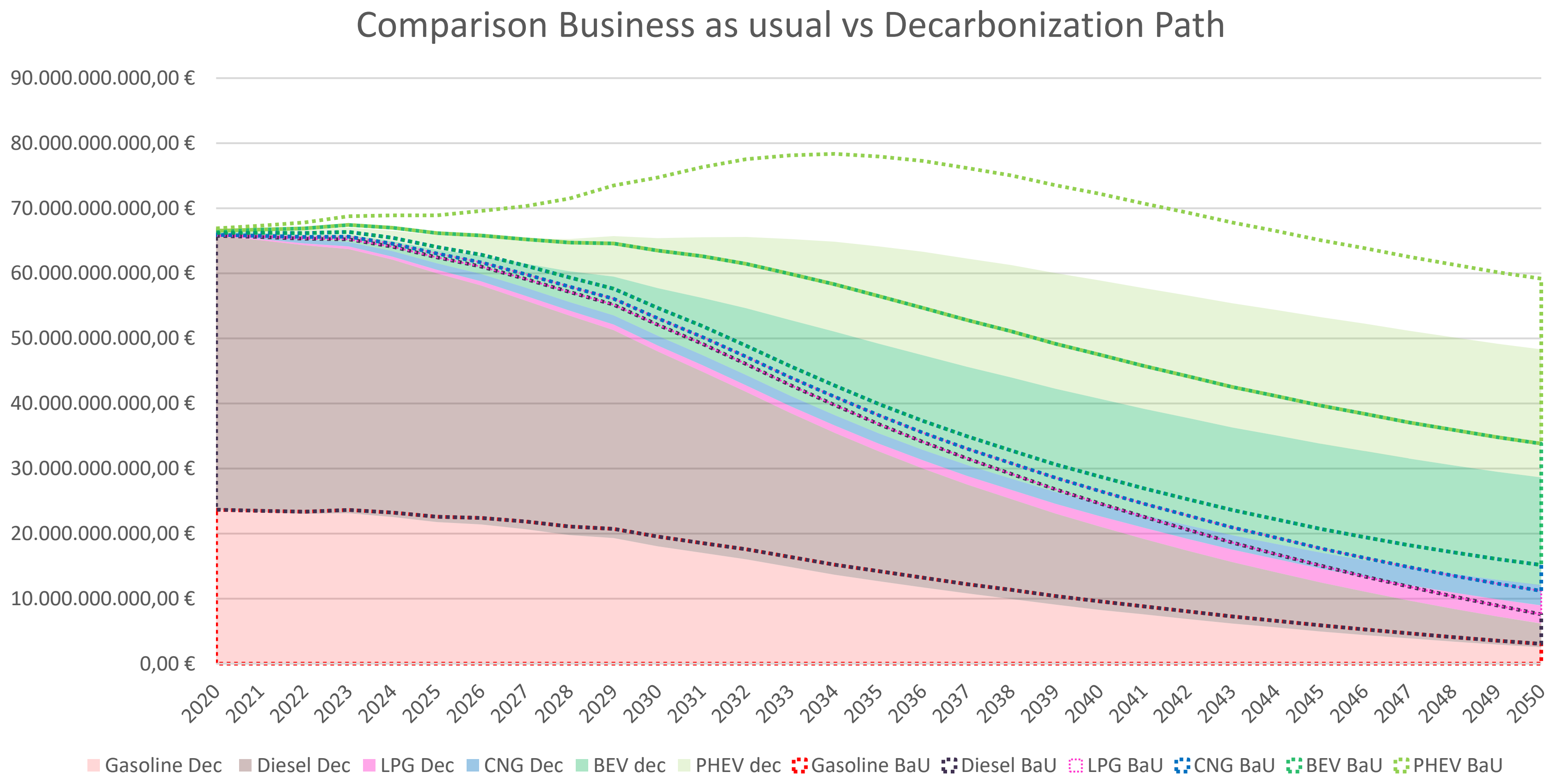

Figure 91: Cost comparison Business as usual vs Decarbonization Path, Base scenario (Own source)

5.2.2 COST ANALYSIS ELECTRIC SCENARIO

As it was commented previously, this scenario is taken up by electric vehicles mainly, in 2050 the park is expected to be fully electrified, having 28 M of electric vehicles (BEV & PHEV). However, to reach that challenged forecast, it is required a great investment for transforming infrastructures. This investment can be compared to a social expense, which includes all the cost associated with the refueling network.

In *Figure 92 & 93*, can be observed that the infrastructures penetration follows the aforementioned distribution, increasing during the first year progressively, and being in 2030 when the largest investment occurs. Moreover, as seen in *Figure 92*, social spending on infrastructures in 2050s tends to zero, but never becomes so. Which makes sense because despite having a solid infrastructure a small investment is always necessary.

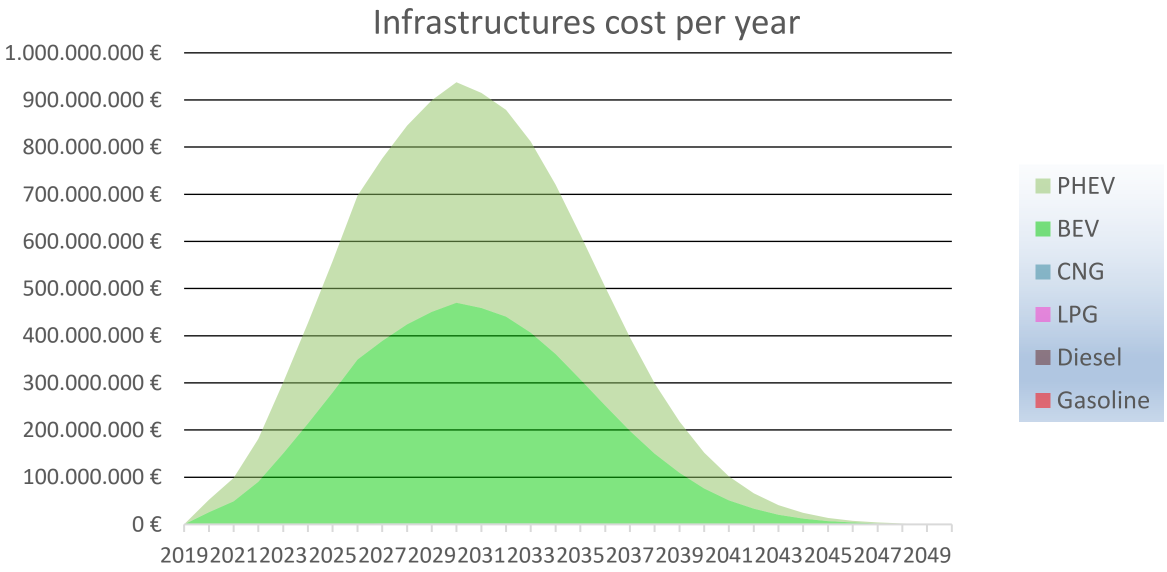

Figure 92: Infrastructures cost per year Electric Scenario (Own source)

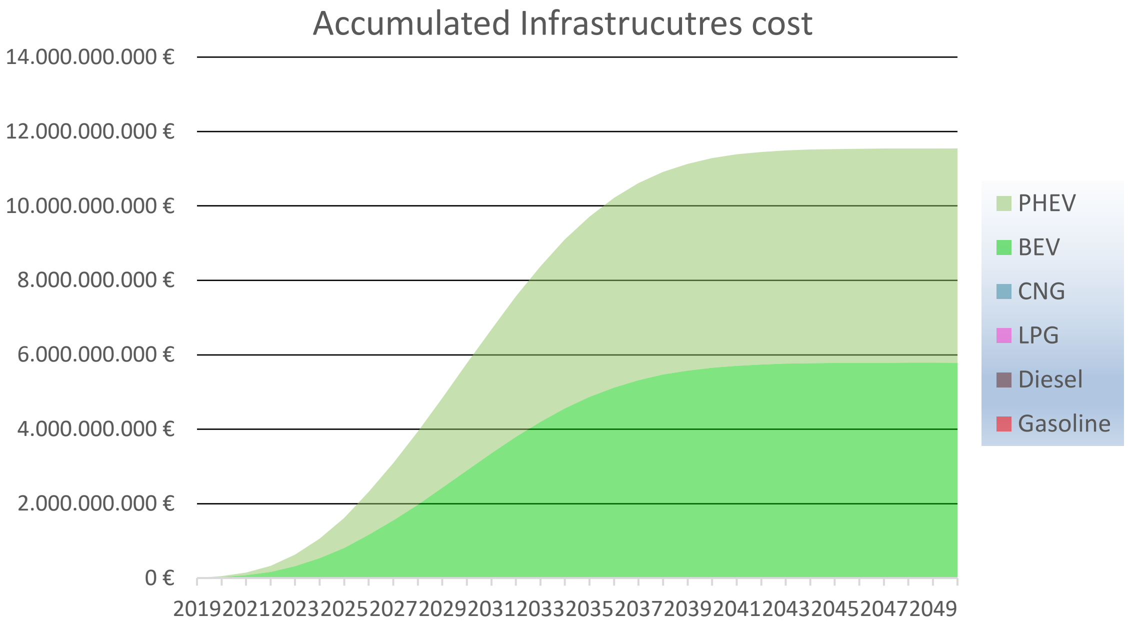

Figure 93: Accumulated Infrastructures cost Electric Scenario (Own source)

It is worth mentioning that the total expenses registered on *Figure 92* is made up by different types of charging post. *Table 66* summarize the number of total posts that would be required to implement in Spain for this scenario. Once again, it is important to highlight that table 64 shows the number of posts nor the number of infrastructures. Moreover, from that table it can be observed that most of the posts are Particular, meaning that practically all of the electric drivers will have a private post on their homes. The charging stations are thought to be used on long haul travels.

Table 66: Number of posts per electric type and cost associated with them in 2050 (Own source)

	Total Posts in 2050	**Cumulative Infrastructures Expenses in 2050**
Particular	12.000.000	9.000.000.000,00 €
Public	40.000	30.000.000,00 €
Semi-fast EV charging station	40.000	350.000.000,00 €
Fast EV charging station	35.473	2.128.402.696,89 €
Fleet	13.243	9.932.545,92 €
Total	**12.128.717**	**11.518.335.242,80 €**

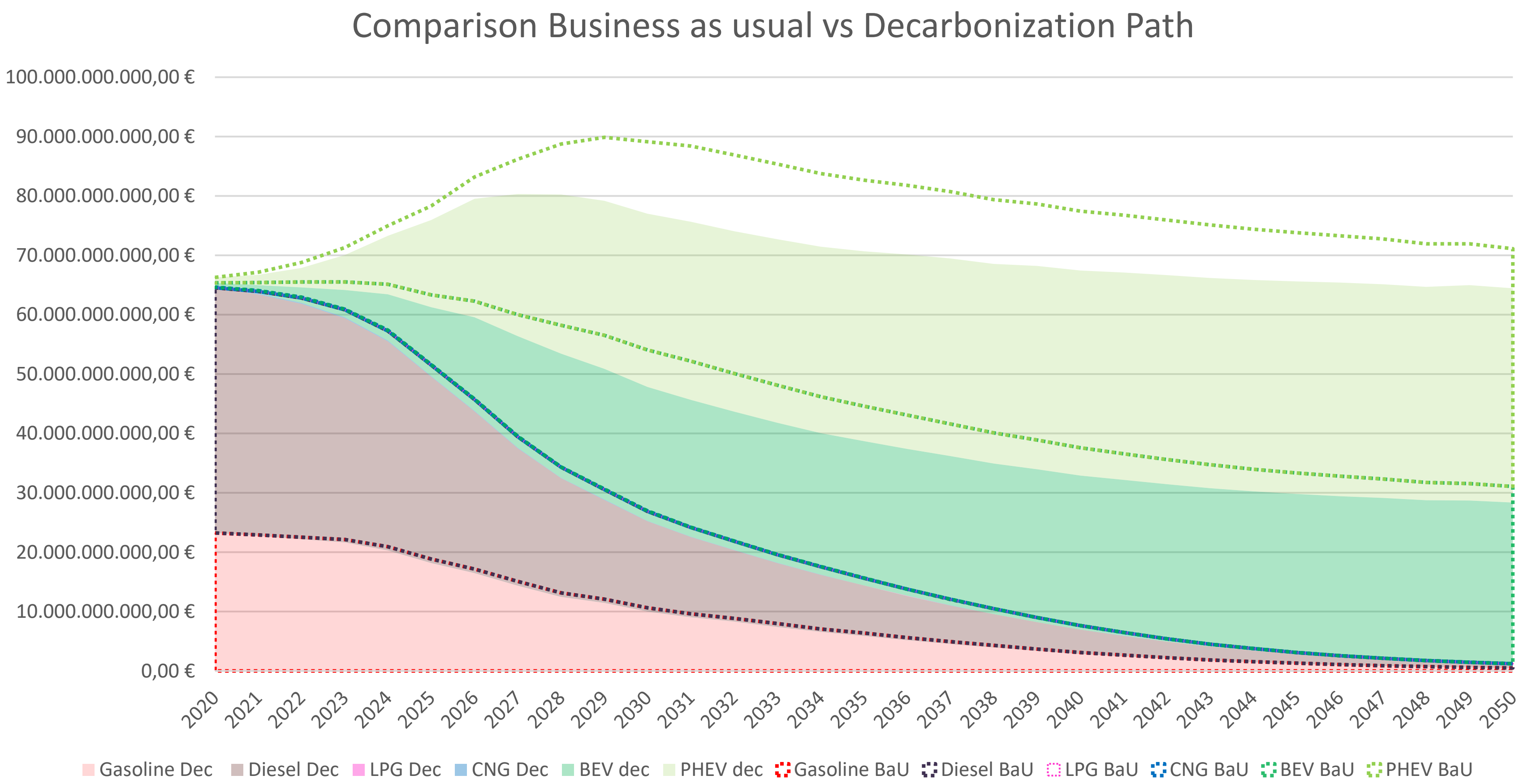

Figure 94: Cost comparison Business as usual vs Decarbonization Path, Electric scenario (Own source)

5.2.3 COST ANALYSIS GAS SCENARIO

This scenario assumes the Spanish fleet to be gasified, meaning that in 2050 there will be 14 M of gas vehicles (LPG & CNG). For reaching that number of gas vehicles on the road, it is required a refueling infrastructure. As it can be observed on *Figure 95 & 96*, despite it has been assumed the same number of CNG and LPG stations, most of the "social expenditure" or infrastructure cost comes from CNG fueling stations. It is because as it was commented on previous chapters, the cost of CNG refueling stations are much higher than LPG stations. Building LPG stations is not a great cost because it takes advantages of the current infrastructure of ICE vehicles.

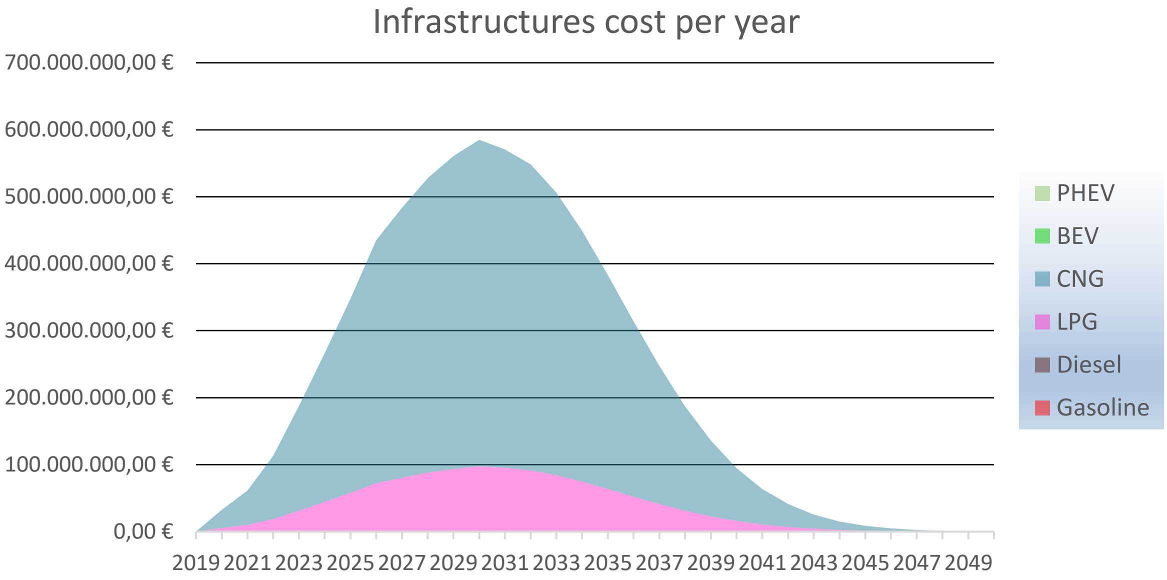

Figure 95: Infrastructures cost per year Gas Scenario (Own source)

Table 67: Number of Gas Infrastrucutres and cost associated with it (Own source)

	Number of Infrastructures in 2050	**Cumulated Infrastructure cost in 2050**
LPG Refueling Stations	12000	1.200.000.000,00
CNG Refueling Stations	12000	6.000.000.000,00

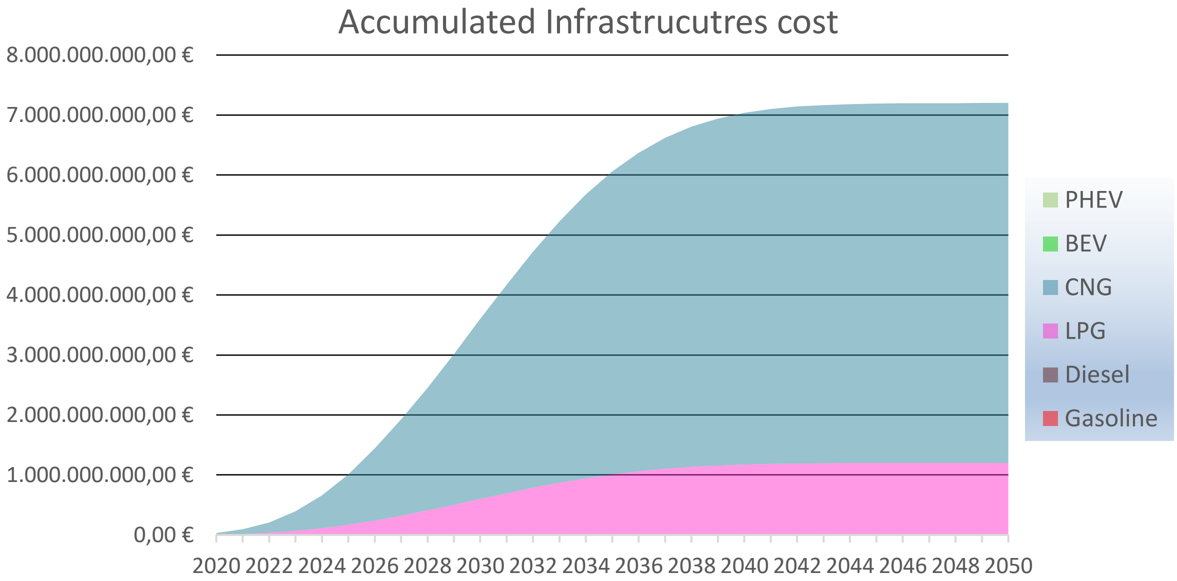

Figure 96: Accumulated Infrastructures cost Electric Scenario (Own source)

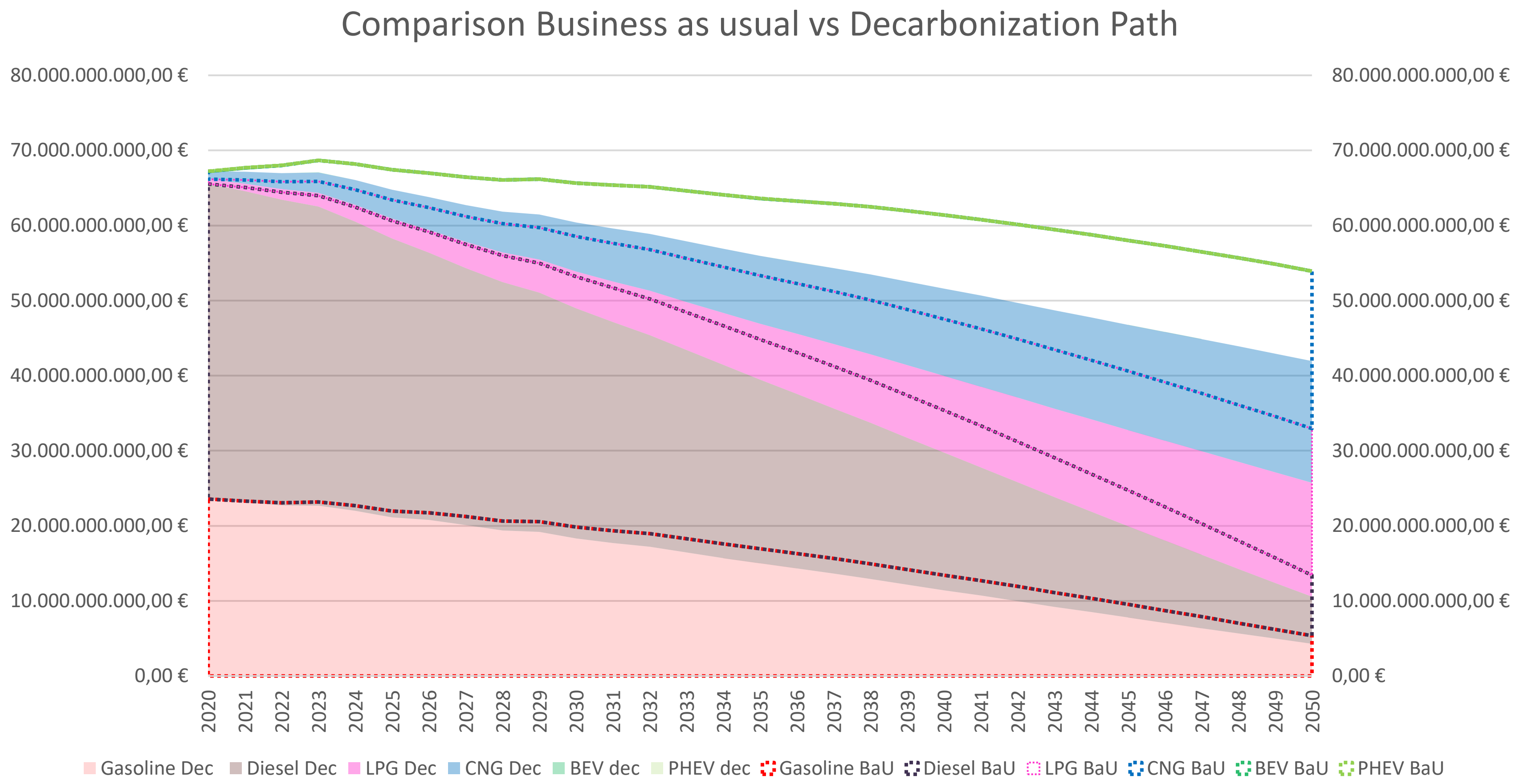

Figure 97: Cost comparison Business as usual vs Decarbonization Path, Gas scenario (Own source)

5.2.4 COST ANALYSIS ICE SCENARIO

In this scenario, it is not produced a notorious expenditure regarding refueling infrastructures because they have already constructed. It is true that it could appear maintenances cost. However, it has not been considered as an infrastructure cost. It is assumed to be included in the cost of the fuel. Moreover, in all of the previous scenarios, have been taken the same assumption so when the scenarios results will be compared, none of them will been harmed. As it can be in *Table 68*, the infrastructure expenses compared to the electric scenario or gas scenario are despicable, and they are occurred during the first years, when alternatives fuels keep appearing.

Table 68:Total Infrastructure costs, ICE Scenario (Own source)

Infrastructure Types	**Total Expenditure**
LPG Infrastructures	188.987,67 €
CNG Infrastrucutres	31.868.288,05 €
Electric Infrastructures	172.259,20 €

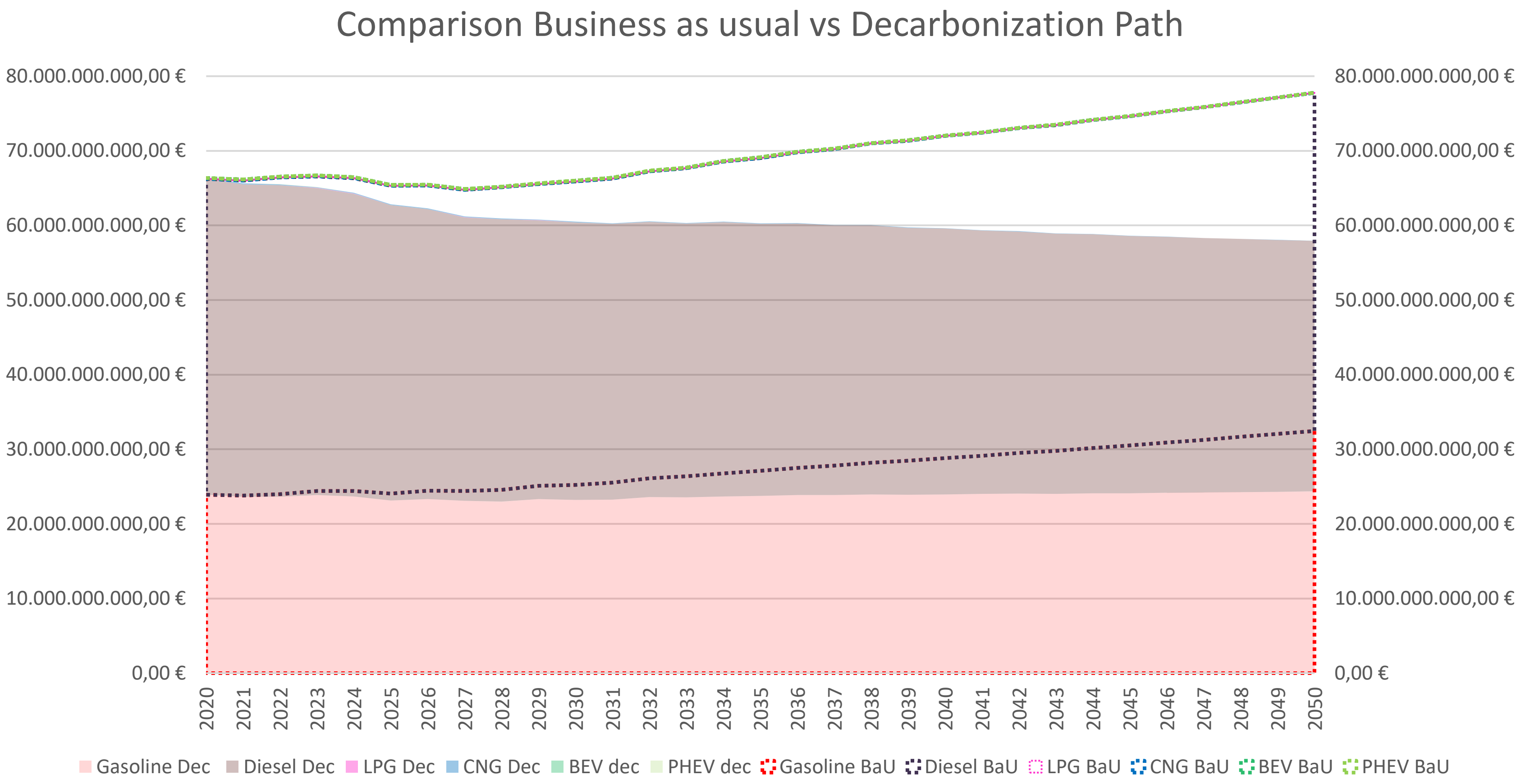

Figure 98: Cost comparison Business as usual vs Decarbonization Path, Gas scenario (Own source)

5.2.5 MACRO ANALYSIS COMPARISON

This senior thesis has attempted to propose a sustainable as well as economically viable way of transforming the Spanish fleet. To achieve this, it has been generated several scenarios with lots of differences between them which makes easier to make conclusions.

While the Micro Analysis discussed previously tries to answer the question Which technology is the best from a consumer perspective, this Macro Analysis tries to answer the same question but from an upper level, it is aimed at a Government level or major players within the Automotive sector.

As it has been stated previously, the 4 scenarios aforementioned differs a lot from each other. It is true that it might seems unlikely that the park evolves to one of these scenarios because in most of them, there is a technology which clearly wins (gas, electricity or ICE), while the reality is that there is no indication of which will stand out over the rest. However, it is not possible to predict what is going to happen regarding the transportation sector, and with these scenarios, it is possible to take conclusion about fuel alternatives.

Throughout the thesis, the importance of sustainability has been made clear at all times. Fortunately, it seems that governments, citizens and large companies are realizing the serious risks that climate change poses for present and future generations, and therefore they are taking action on the matter. And the automotive sector is practically obliged to join such transition, and to produce vehicles that do not harm the environment. Because it is aware of the importance of reducing GHG emissions, this macro analysis will be made around two factors, the emissions of each scenario and their economic impact.

The aim of this section will be to propose some strategies towards a low polluting mobility as well as it is feasible economically. In definite, it will be analyzed all the advantages and disadvantages of each of the scenarios generated.

5.2.5.1 INFRASTRUCTURES COST COMPARISON

First, it will be analyzed the cost of infrastructures of each of the scenarios. For the penetration of the low polluting alternatives technologies, it is required a proper refueling network. To achieve it, it will be need in some cases a great investment from the Government and private entities. It is interesting to analyze the infrastructure cost because it can be resembled with a social cost coming from private or public entities. In this senior thesis has been considered different sources from where the investment comes, more concretely from Public entities (Public infrastructures), private consumers (particular electric posts) and private companies (Charging stations).

Analyzing the total Infrastructures expenditure per scenario (*Figure 99 & Table 69*), it can be observed that there is two scenarios in which is produced a greatest investment, Base Scenario and Electric scenario. Moreover, the graph enable to take another conclusion, electric infrastructures are the most expensive, because if it is compared the three pure scenarios (Park made by mainly just one type of vehicle fuel, Electric, Gas and ICE), the electric one is when is produced the highest expenses. Another conclusion that can be taken from that data is that is better to do an "all-in" to just one of the alternatives technologies rather than a mixed like in Base scenario, because the level of investment is the highest

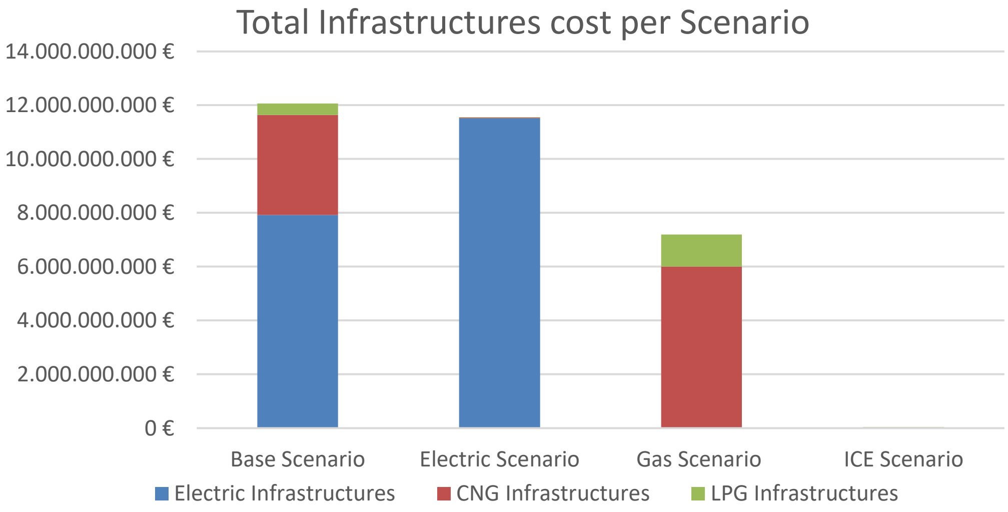

Figure 99:Total Infrastructure cost per Scenario distinguishing by type (Own source)

among the scenarios studied. As it was expected ICE scenario does not require further expenditure.

Table 69: Total Infrastructure cost per Scenario distinguishing by type (Own source)

	Base Scenario	**Electric Scenario**	**Gas Scenario**	**ICE Scenario**
Electric Infrastructures	7.921.646.676 €	11.518.335.243 €	190.969 €	172.259 €
CNG Infrastructures	3.715.716.751 €	27.075.810 €	6.000.000.000 €	31.868.288 €
LPG Infrastructures	424.280.177 €	164.462 €	1.200.000.000 €	188.988 €
TOTAL	**12.061.643.604 €**	**11.545.575.515 €**	**7.200.190.969 €**	**32.229.535 €**

Last, it will be presented *Table 70*, in which it is summarized the number of infrastructures in 2050 and the ratio vehicles per infrastructures in that year. As it can be observed, there is not much difference between the ratio of the scenarios which make this study not biased and more realistic results.

Table 70: Number of infrastructures and ratio vehicle per infrastructure of each of the scenarios (Own source)

	BASE SCENARIO		**ELECTRIC SCENARIO**		**GAS SCENARIO**		**ICE SCENARIO**	
	NºInfrastructures in 2050	**Ratio Vehicles/inf in 2050**	**NºInfrastructures in 2050**	**Ratio Vehicles/inf in 2050**	**NºInfrastructures in 2050**	**Ratio Vehicles/infr in 2050**	**NºInfrastructures in 2050**	**Ratio Vehicles/infr in 2050**
LPG Infrastructures	4.243	302	2	121	12.000	619	2	536
CNG Infrastructures	7.431	174	54	1	12.000	579	64	297
Particular	8.334.888	2	12.000.000	2	185	1	167	1
Public	40.000	429	40.000	710	5	37	5	36
Semi-fast EV charging station	40.000	429	40.000	710	2	93	2	90
Fast EV charging station	21.408	802	35.473	801	0	-	0	-
Fleet	7.992	2.148	13.243	2.145	0	-	0	-

5.2.5.2 TOTAL COST COMPARISON

Second, it has been analyzed the Total cost of each of the scenarios. By saying Total cost, is being referred to any cost incurred regarding the Spanish fleet, which includes from infrastructures or vehicle purchases costs to maintenance or fuel consumption costs. It is important to highlight that for the generation of the Macro analysis scenarios it has been taken zero as the interest rate. This decision has been taken in order to observe in a clearer way the impact of the different scenarios and sub-scenarios compared to the current state.

Figure 100 represents a comparison between all the scenarios distinguishing by the sub-scenarios, business as usual and decarbonization path.

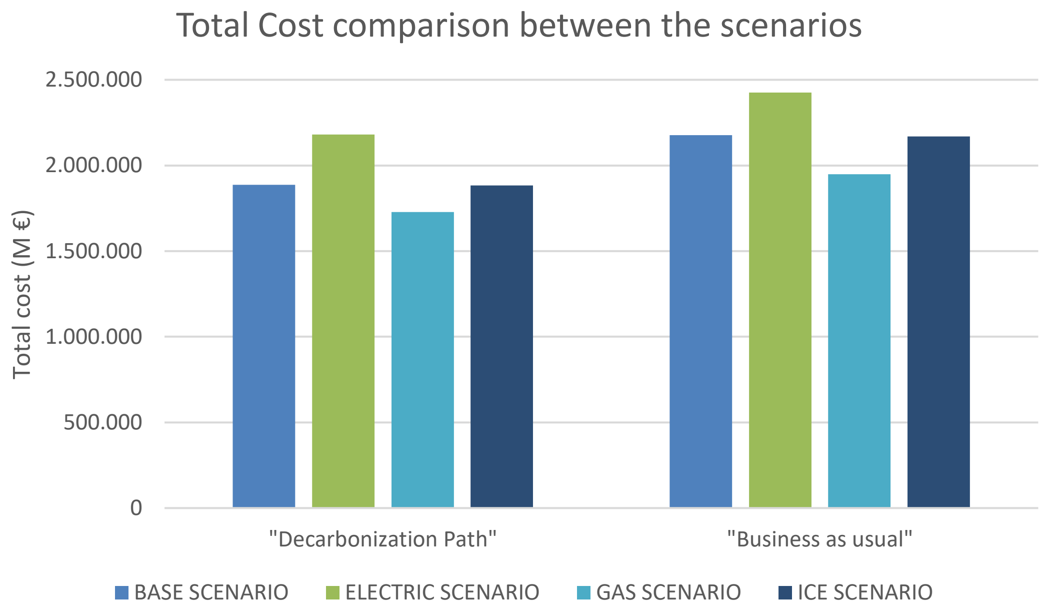

Figure 100: Total Cost comparison between the scenarios (Own source)

In the previous graph, it can be observed that when it is compared the four scenarios, there is a clear winner regarding the Total Cost, the Gas scenario. In both sub-scenarios, business as usual and decarbonization path, the scenario made by gas vehicles is the cheapest one. This may not surprise many, since in micro analysis, LPG and CNG technologies turned out to be very competitive, becoming the cheapest in many of the scenarios studied. In addition, as it could observe above, the cost of necessary infrastructures was quite low compared to the base scenario or the electrical scenario, which makes reasonable that Gas scenario is the cheapest one.

But as previously was commented, not only are economic aspects important for this senior thesis, but GHG emissions are also of great importance. *Table 71* summarizes the economic aspects represented in *graph 102*, and the CO_2, NO_x and PM emissions, measured in kt. It can be observed that in terms of environmental factors, electric technologies are the most efficient.

Table 71: Summary of economic factors and GHG emissions cumulated (Own source)

		Cost (M €)	**CO2 (kt.)**	**NOx (kt.)**	**PM (kt.)**
BASE SCENARIO	"Decarbonization Path"	1.886.923,42 €	1.062.904,69	1.798,457	10,96
	"Business as usual"	2.177.534,74 €			
ELECTRIC SCENARIO	"Decarbonization Path"	2.180.922,39 €	900.676,29	1.505,371	7,54
	"Business as usual"	2.426.091,13 €			
GAS SCENARIO	"Decarbonization Path"	1.728.899,02 €	1.242.791,86	1.887,558	13,96
	"Business as usual"	1.948.706,06 €			
ICE SCENARIO	"Decarbonization Path"	1.883.544,38 €	1.214.926,17	2.165,52	14,99
	"Business as usual"	2.169.346,75 €			

Table 72 represent the same the cost and emissions of each of the scenarios per year, which means it represent the average cost or GHG emissions per year.

Table 72: On average summary of economic factors and GHG emissions (Own source)

		Cost (M €/year)	**CO2 (kt./year)**	**NOx (kt./year)**	**PM (kt./year)**
BASE SCENARIO	"Decarbonization Path"	62.897,45 €	35.430,16	59,949	0,37
	"Business as usual"	72.584,49 €			
ELECTRIC SCENARIO	"Decarbonization Path"	72.697,41 €	30.022,54	50,179	0,25
	"Business as usual"	80.869,70 €			
GAS SCENARIO	"Decarbonization Path"	57.629,97 €	41.426,40	62,919	0,47
	"Business as usual"	64.956,87 €			
ICE SCENARIO	"Decarbonization Path"	62.784,81 €	40.497,54	72,18	0,50
	"Business as usual"	72.311,56 €			

As it happens in the micro analysis, in this section it is also intended to show how much would it cost reducing one kt. of the main pollutant in case it is replaced the ICE scenario by the Base scenario, Electric scenario or Gas scenario. As, it has been commented previously, electrifying the fleet is the most effective path to reduce GHG emissions, but this involves an expense not only for the consumer but for the OEMs, Government and Fueling providers. Therefore, it is very important to analyze deeply *Table 73*, it summaries the cost of replacing ICE scenario by the other scenarios, distinguishing by the two sub-scenarios studied, business as usual and decarbonization. Furthermore, this table also shows the reduction of GHG forecast compared to the ICE scenario.

To know what is the average emissions of a vehicle per year in each scenario (the average of the years simulated by the analysis has been made). Because of that, it is presented *Table 78*.

Table 73:Comparison of vehicle's emissions in a year per scenario (Own source)

	CO2 (kg/vehicle in a year)	**NOx (kg/vehicle in a year)**	**PM (g/vehicle In a year)**
BASE SCENARIO	1.463,63	2,48	15,10
ELECTRIC SCENARIO	1.122,43	1,88	9,39
GAS SCENARIO	1.792,96	2,72	20,13
ICE SCENARIO	1.803,60	3,21	22,25

From *Table 74*, It can be taken several key points which for sure will be very useful when it comes the time to define the strategy of the park evolution forecast. First, by electrifying the fleet, it can be reached a reduction of 25.87, 30.48 and 49.70 %, in CO_2, NO_x and PM respectively. However, for reducing 1 kt. of the GHG, it is required the highest level of investment. For instance, reducing 1 kt. of CO_2 replacing ICE scenario with Electric scenario, would cost between € 946.310,64 and € 817.007,06 while in the Base scenario would cost between € 22.227,45 and € 53.860,73. In case of replacing the ICE scenario with the Gas scenario, as it can be seen in the below table, the CO_2 emissions would increase in a 2.29 % which makes less interest that scenario. In terms of NO_x and PM_x, something striking happens, the number of harmful emissions for our health can be reduced at the same time as costs are reduced, since, as it was observed before, the Gas scenario is the one with the least expense.

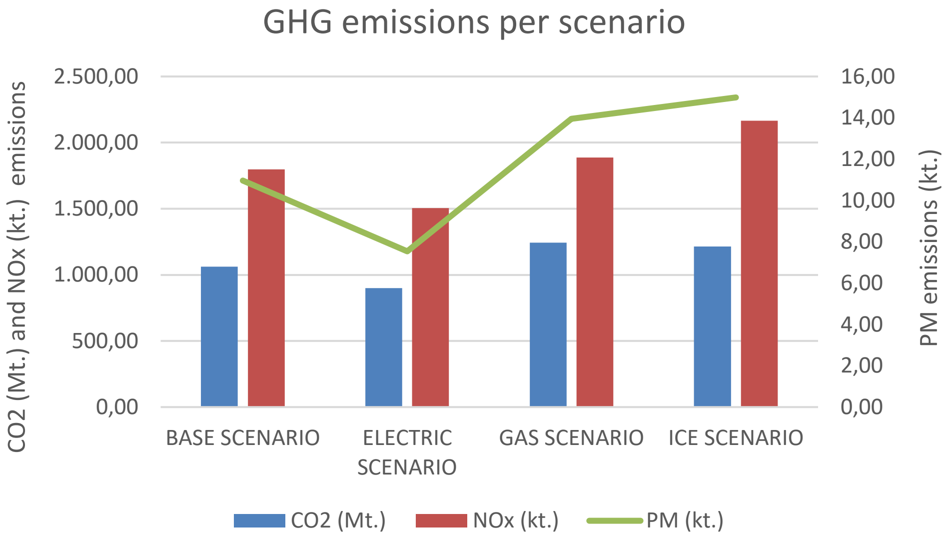

Figure 101: Green House Gases emissions per scenario (Own source)

Table 74:Cost of replacing ICE scenario in terms of GHG emissions and reduction of GHG forecast (Own source)

		% CO_2 reduction	**CO_2 (€/kg)**	**% NOx reduction**	**NOx (€/kg)**	**% PMx reduction**	**PM (€/kg)**
BASE SCENARIO, MIX OF THE LOW ALTERNATIVES TECHNOLOGIES	**"Decarbonization Path"**	-12,51%	0,022	-16,95%	9,21	-26,85%	839,75
	"Business as usual"		0,054		22,31		2.034,84
ELECTRIFY THE VEHICLE FLEET	**"Decarbonization Path"**	-25,87%	0,95	-30,48%	450,47	-49,70%	39,92
	"Business as usual"		0,82		388,92		34,47
GAS VEHICLE FLEET	**"Decarbonization Path"**	2,29%	5,55	-12,84%	-556,36	-6,88%	-150,08
	"Business as usual"		7,92		-793,79		-214,13

CHAPTER 6: RESULTS, CONCLUSIONS AND FUTURE OBJECTIVES

In this section, it will be summarized the work presented on this senior thesis, highlighting the results and conclusions obtained, as well as future objectives/ steps for a low polluting mobility, focusing in the analysis of different scenarios towards a low polluting mobility impacts the economy at a micro and macro levels.

6.1 RESULTS AND CONCLUSIONS

At last, Governments, logistics companies, OEMs, consumers and energy providers (fuel, electricity…) among others, seem to move toward low emissions mobility. There is an accelerating shift toward cleaner but cost efficiency solution in the transportation market, however there is not a clear strategy about how to achieve zero-emissions mobility. As a result, OEMs are working on many different fuel alternatives such as BEVs, FCEVs, PHEVs, CNG/CNG-Bio/LPG/LNG vehicles… and it is yet to be seen which one finally hits the market.

To that end, it has been undertaken an in-depth analysis of the Spanish fleet. The main purpose of that analysis has been to analyze how different scenarios towards a low polluting mobility impacts the economy at a micro and macro level. To achieve it, it has been developed two different analysis the Micro analysis and the Macro Analysis. The first analysis aims to answer from a consumer perspective which vehicle type works better for him, depending on the purchase year, the kilometers covered per year, and the number of vehicles per household (one or two). While the Macro analysis intends to answer the question, which is the best strategy to take as a roadmap for the country. In both analyses, apart from economic factors, environmental ones are also one of the main players for the analysis.

Micro analysis: It is important to stand out that in all the simulations generated, purely economic factors, fixed and variable costs have been taken into account throughout the useful life of the vehicle. In Chapter 5, it was analyzed in detail the results of the scenarios simulated. Bellow it is presented some highlights of the draw conclusions:

- As more kilometers are traveled, electrical technologies become more relevant due to the low cost of fuel, this is because the price of electricity is lower compared to other fuels and its maintenance cost. This suggests that transport sector is likely to end up transforming into electric mobility.
- When comparing the total cost per vehicle over the year there are a clear winner, the emerging technologies. In both scenarios, business as usual and decarbonization path, these technologies, especially the EVs, benefit the most from the passage of time, meaning that as time passes, the total cost reduction of these vehicles is greater than that of conventional vehicles. *Table 75* present the total cost growth of both scenarios (decarbonization path and business as usual) over the years. Appendix D presents a table that shows which top 3 technologies are the less expensive regarding the sub-scenario, the purchase year, and the life expectancy.

Table 75:Total cost decline over the time (Own source)

	Business as usual 2025	**Decarbonization path 2025**	**Business as usual 2030**	**Decarbonization path 2030**	**Business as usual 2035**	**Decarbonization path 2035**
Gasoline	-9,25%	-4,09%	-17,04%	-7,35%	-24,13%	-10,47%
Diesel	-8,71%	-3,86%	-16,12%	-6,98%	-22,89%	-9,97%
BEV	-12,99%	-11,35%	-33,49%	-20,87%	-40,86%	-29,34%
PHEV	-12,95%	-12,05%	-32,55%	-22,18%	-40,15%	-31,10%
CNG	-11,88%	-7,82%	-21,73%	-14,43%	-30,40%	-20,57%
LPG	-12,29%	-8,08%	-22,20%	-14,67%	-30,89%	-20,80%

- For calculating the cost of reducing the emissions, it has been decided to calculate the cost of replacing an ICE conventional vehicle which covers 13,000 km (simulate the Spanish average) and a life expectancy of 15 years old with another electric vehicle or gas vehicle (*Table 76*). As it can be observed from the aforementioned table, replacing an ICE conventional vehicle with a gas natural would not suppose an extra charge for any of the parts, neither the buyer nor the Government. In 2020, it is possible to reduce at the same time the cost of a vehicle and the emissions in case the user decides to purchase a Gas vehicle. That table also shows how much would it cost reducing one kt. of the main pollutant gases in case it would be used an EV. As, it has been commented previously, electrifying the fleet is the most effective path to reduce GHG emissions, but this involves an expense for the consumer. Cost showed in *Table 76*, allow to think whether it is worth paying a little more for a vehicle which pollutes much less, or conversely, stick with a conventional car.

Table 76:Cost of replacing ICE vehicles in terms of GHG emissions (Own source)

		CO_2 (€/kg)	**NO_X (€/kg)**	**PM (€/kg)**
ELECTRIFY THE VEHICLE FLEET	**Gasoline Min**	-0,224	-0,33	-0,02
	Gasoline Max	-0,240	-0,35	-0,02
	Diesel Min	-0,35	-0,03	-0,003
	Diesel Max	-0,59	-0,05	-0,01
GAS VEHICLE FLEET	**Gasoline Min**	0,55	0,39	0,02
	Gasoline Max	11,80	0,58	0,19
	Diesel Min	0,61	0,43	0,02
	Diesel Max	12,07	0,60	0,19

Last, replacing an ICE vehicle which covers 13,000 km with a less pollutant technology, would bring a significant reduction in polluting particles, as shown in *table 77*. If it is compared the emissions reduction between making gas the vehicle fleet with electrifying it, it is obtained a much higher reduction when it is electrified. On average GHG would be reduced by a 35 % if the fleet is electrified than if is gasified.

Table 77: Reduction of the emissions in case the vehicle chosen would be gasified or electrified (Own source)

		CO_2 (t.)	**NO_x (t.)**	**PM (t.)**
ELECTRIFY THE VEHICLE FLEET	**Gasoline**	-36,302409	-30,37515	-414,57975
	Diesel	-32,735381	-30,37515	-414,57975
GAS VEHICLE FLEET	**Gasoline**	-31,915457	-14,7771	-246,285
	Diesel	-28,34843	-14,7771	-246,285

Macro analysis: As in the previous analysis, within this section, all the studies carried out, has taken into all fixed and variable costs throughout the useful life of the vehicle. Below it has been summarized the most important conclusions:

- For the penetration of the low polluting alternatives technologies, it is required a proper refueling network. To that end, it will be needed in some cases a great investment from the Government and private entities. Analyzing the total Infrastructures expenditure per scenario (*Figure 102*), it can be observed that there are two scenarios in which is produced the greatest investment, Base Scenario and Electric scenario. Moreover, the graph enables to take another conclusion, electric required infrastructures are the most expensive, because if it is compared the three pure scenarios (Park made by mainly just one type of vehicle fuel, Electric, Gas and ICE), the electric one is when is produced the highest expenses. Another conclusion that can be taken from that data is that from just budget perspective is better to do an "all-in" to just one of the alternatives technologies rather than a mixed like in Base scenario, because the level of investment is the highest among the scenarios studied. However, it also poses a risk. One of the first thing Finance students learn at college is "Don't put all your eggs in one basket". So, by diversifying it would be reducing the risks, it will have to see what is the most interesting.

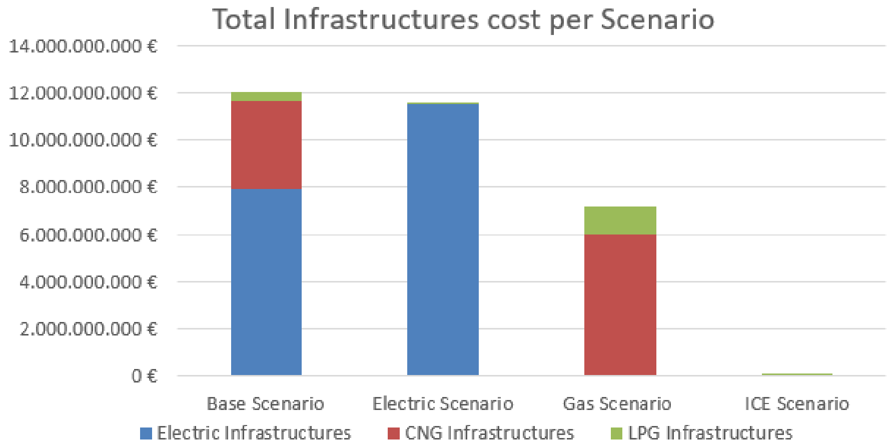

Figure 102: Total Infrastructure cost per Scenario distinguishing by type (Own source)

Last, it will be presented *Table 78*, in which it is summarized the number of infrastructures in 2050 and the ratio vehicles per infrastructures in that year. As it can be observed, there is not much difference between the ratio of the scenarios which make this study not biased and more realistic results.

Table 78:Number of infrastructures and ratio vehicle per infrastructure of each of the scenarios (Own source)

	BASE SCENARIO		**ELECTRIC SCENARIO**		**GAS SCENARIO**		**ICE SCENARIO**	
	NºInfrastructures in 2050	**Ratio Vehicles/inf in 2050**	**NºInfrastructures in 2050**	**Ratio Vehicles/inf in 2050**	**NºInfrastructures in 2050**	**Ratio Vehicles/infr in 2050**	**NºInfrastructures in 2050**	**Ratio Vehicles/infr in 2050**
LPG Infrastructures	4.243	302	2	121	12.000	619	2	536
CNG Infrastructures	7.431	174	54	1	12.000	579	64	297
Particular	8.334.888	2	12.000.000	2	185	1	167	1
Public	40.000	429	40.000	710	5	37	5	36
Semi-fast EV charging station	40.000	429	40.000	710	2	93	2	90
Fast EV charging station	21.408	802	35.473	801	0	-	0	-
Fleet	7.992	2.148	13.243	2.145	0	-	0	-

- Second, it was analyzed the Total cost of each of the scenarios. By saying Total cost, is being referred to any cost incurred regarding the Spanish fleet, which includes from infrastructures or vehicle purchases costs to maintenance or fuel consumption costs. It is important to highlight that for the generation of the Macro analysis scenarios it has been taken zero as the interest rate. *Figure 103* represents a comparison between all the scenarios distinguishing by the sub-scenarios, business as usual and decarbonization path. As it can be seen, the most expensive scenario is the electric one, followed by the Base scenario and ICE conventional one.

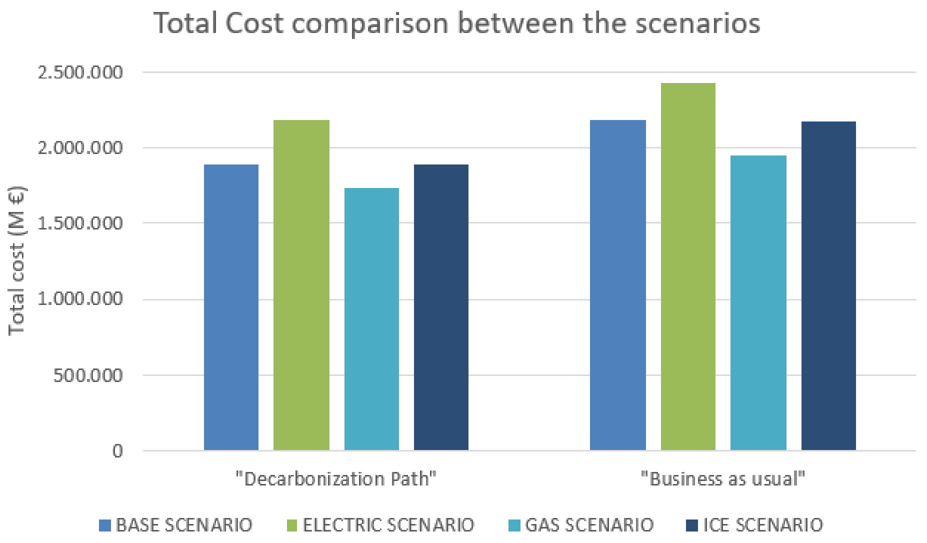

Figure 103:Total Cost comparison between the scenarios (Own source)

In the previous graph, it can be also observed that when it is compared the four scenarios, there is a clear winner regarding the Total Cost, the Gas scenario. In both sub-scenarios, business as usual and decarbonization path, the scenario made by gas vehicles is the cheapest one. This may not surprise many, since in micro analysis, LPG and CNG technologies turned out to be very competitive, becoming the cheapest in many of the scenarios studied. In addition, as it could observe above, the cost of necessary infrastructures was quite low compared to the base scenario or the electrical scenario, which makes reasonable that Gas scenario is the cheapest one.

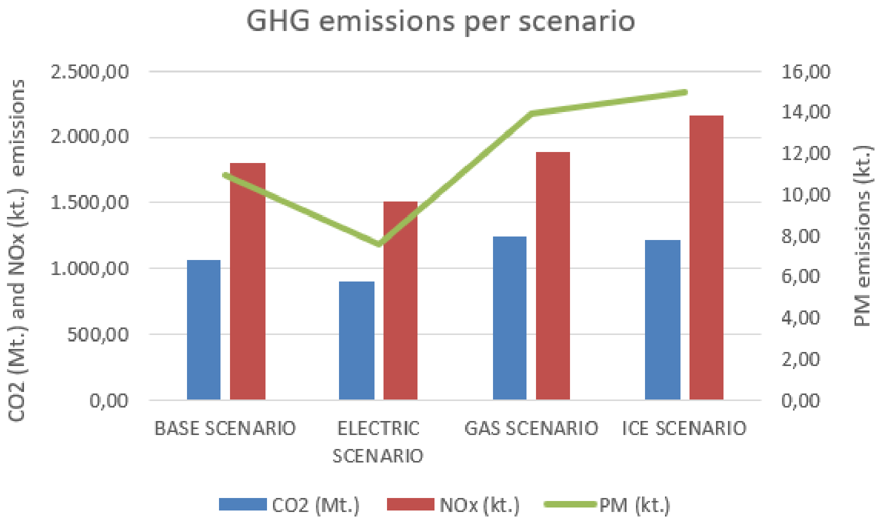

Figure 104: Green House Gases emissions per scenario (Own source)

Moreover, to know what is the average emissions of a vehicle per year in each scenario (the average of the years simulated by the analysis has been made). Because of that, it is presented *Table 79*.

Table 79:Comparison of vehicle's emissions in a year per scenario (Own source)

	CO2 (kg/vehicle in a year)	**NOx (kg/vehicle in a year)**	**PM (g/vehicle In a year)**
BASE SCENARIO	1.463,63	2,48	15,10
ELECTRIC SCENARIO	1.122,43	1,88	9,39
GAS SCENARIO	1.792,96	2,72	20,13
ICE SCENARIO	1.803,60	3,21	22,25

Last, *Table 80* the cost per kt. reduced in case the ICE conventional scenario would be replaced by the other scenarios (Base scenario, Electric scenario and Gas scenario). It can be observed that in the Electric scenario is produced the highest cut of emissions, but it is also when is produced the highest costs. Because of that, to reduce 1 kt. of CO_2, NO_x or PM, it is required the highest expenses.

Table 80:Cost of replacing ICE scenario in terms of GHG emissions and reduction of GHG forecast (Own source)

		% CO_2 reduction	**CO_2 (€/kg)**	**% NOx reduction**	**NOx (€/kg)**	**% PMx reduction**	**PM (€/kg)**
BASE SCENARIO, MIX OF THE LOW ALTERNATIVES TECHNOLOGIES	**"Decarbonization Path"**	-12,51%	0,022	-16,95%	9,21	-26,85%	839,75
	"Business as usual"		0,054		22,31		2.034,84
ELECTRIFY THE VEHICLE FLEET	**"Decarbonization Path"**	-25,87%	0,95	-30,48%	450,47	-49,70%	39,92
	"Business as usual"		0,82		388,92		34,47
GAS VEHICLE FLEET	**"Decarbonization Path"**	2,29%	5,55	-12,84%	-556,36	-6,88%	-150,08
	"Business as usual"		7,92		-793,79		-214,13

Last, it will be analyzed **the three different strategies** that could be taken at a national level (Gas, Electric and Base scenario) to the current situation (ICE conventional scenarios), and its advantages.

1. **Gas scenario:** It is the cheapest alternative to conventional scenario. Indeed, it could be saved on average between 5.157,5 and 7.354,69 million Euros per year, depending on the sub-scenario (Business as usual or Decarbonization path). Regarding the emissions, if the fleet would be gasified, from now on until 2050, it would be cut 277.96 and 1.03 kt. of NO_x and PM, respectively. However, CO_2 emissions are increased in 27.865,69 kt. which let us think that Gasification is not the best way to Decarbonize the fleet.
2. **Electric scenario:** It is the most expensive strategy that could be taken. However, it is produced the biggest reduction in emissions. If it is compared this scenario with the Gas scenario, Electric scenario would be between 15.067,75 and 15.912,84 million Euros more expensive per year than Gas scenario. Regarding the emission, there is a huge difference between Gas and Electric scenarios, due to it could be cut by 11.403,85 kt. of CO_2, 12.74 kt. of NO_x and 0.21 kt. the emission per year.
3. **Base scenario:** This scenario proposes a gradual introduction of all alternative's fuels. Probably, and especially until one fuel alternative takes off and hits the market, the Spanish fleet will evolve in a way similar to this scenario, introducing all fuel alternatives. As it was said in the infrastructure's analysis, it would be better to do an "all-in" to just one technology, it would help to reduce costs. Therefore, despite being the most suitable and realistic scenario, neither economically nor environmentally is the optimal scenario.

6.2 FUTURE OBJECTIVES

Before addressing the points to be developed in the future, it is important to point out that all the calculus made in this thesis are estimations about how vehicles will evolve over the time. Therefore, it could happen that a determined type of vehicle evolve in a very different way to the scenarios that have been carried out in this projects, in terms of emissions, economic aspects, yields or average consumption. The aim of this senior thesis has been to propose a methodology for future studies, but the data should be changed to a more updated sources in order to achieve more accurate results.

- As it has been able to observe, this study has focused on passenger cars with conventional internal combustion engines (ICE) that use diesel and gasoline as fuel, on electric vehicles (PHEV and BEV) and on vehicles ran by gas (CNG and LPG). Despite, it has been explained briefly, another fuel alternatives, such as Hydrogen, Natural liquified gas or Hybrid vehicles. These alternatives have been left out of the study, but nobody today could affirm that none of them is not the one that finally take up the full market share, specially Fuel Cell vehicles. This is a personal opinion, and I wouldn't like it was taken as a statement, but I deeply believe FCVs (Hydrogen) have an enormous potential, and as it can be seen on recent days, there are many companies and Governments investing and trusting in this technology, a clear example of that is the National Hydrogen Strategy[20] taken by the German Federal Government. Therefore, it is recommended that in future studies, all the technologies are carefully reviewed again.

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[20] In the fight against climate change, German Government announced the National Hydrogen Strategy (06/2020) Germany has set out to become a global leader in the associated hydrogen technologies, and the government has penned a National Hydrogen Strategy to fulfil these ambitions. This plan includes the followings initiatives: Develop a "home market" for hydrogen technologies in Germany and pave the way for imports, establish hydrogen as an alternative energy carrier, Make hydrogen as a raw material for industry sustainable, Enhance the transport and distribution infrastructure and Support research and train qualified personnel among others.

- It would be convenient to review all the hypotheses made in this work for the generation of the scenarios carried out. Because all the variables undergo a temporal evolution.
- Another limitation of this study is that it does not cover the entire car park. Despite the fact that the passenger car represents around two thirds of the polluting gases of the transport sector, about a third would remain to be studied. For this reason, it would be convenient for the next studies to also analyze Heavy duty vehicles and light commercial vehicles.
- It would also be interesting to introduce in the calculus, the residual value of the vehicle once it exceeds its useful life in both micro and macro analysis. It is not the objective of a study like this, the analysis of the sale and purchase of second-hand vehicles in Spain. However, it would be of special interest to calculate the residual value of those vehicles that exceed their useful life, that is, they are de-registered and taken to the waste. Since that expense also impacts the automotive sector.
- In this study, an insurance quote for the same vehicle (Volkswagen Golf) ran by gasoline, diesel, BEV, PHEV and CNG has been obtained. Because the Volkswagen Golf LPG version was not available in the catalog, it was compared to the Opel Corsa LPG. Despite the fact that there were budgets for different degrees of coverage, the study was only carried out with basic coverage for third parties. It would be interesting to expand it in future jobs to full coverage with or without franchise, as well as other possible expenses
- In addition, no hypotheses have been made about the evolution of the cost of infrastructure over time, since it has been assumed to be constant (It costs the same to build a connection pole for an electric car in 2020 as it does in 2050). Perhaps it would be convenient to do in future sub-scenarios projects to predict the evolution of infrastructure costs.
- Because Excel tools have been developed with variable real interest in mind, it would be nice to introduce recession periods into the model. As explained in Chapter 4, Spanish car fleet, from time to time there are economic crises or recessions that

directly affect the automotive sector. For this reason, it would be interesting to take into account these variations in the economy in subsequent works.

- It is also recommended to make an analysis of the impact that the substitution of the rest of the sectors, mainly the transport of goods, by cleaner technologies, for example, the railroad, would have.
- This is a personal belief, and again I wouldn't like that it will be taken as an statement, but I would encourage to study Autonomous vehicles in future studies. It is no longer a question of it but when self-driving vehicles will hit the road. Today, there are many companies that are investing vast amount of money to develop this technology, it is being commercialized SAE level 2[21] of automation, an example of it is the Tesla's Autopilot mode. In addition, companies such as TuSimple, Waymo (Google) or Volvo are testing SAE level 4 vehicles. It enables to think that in next years self-driving vehicles will hit the market. Driverless cars will disclose completely new ways to deal with transportation as well as business models. In addition, autonomous vehicles offers potential benefits such as more efficiency and safer journeys.
- In addition, in case of choosing electric vehicles as the definitive alternative to ICE vehicles, it would be of special interest to make an exhaustive analysis of where the electricity used came from, if they come from renewable energies or coal, since the emissions of BEVs vary in function of this.

Despite the fact that this work has covered most of the economic and polluting aspects related to passenger vehicles, it is aware that there are still many aspects to improve and to be studied. Therefore, all the points mentioned have defined the following steps to consider in subsequent studies.

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[21] SAE levels of Automation: The Society of Automotive Engineers (SAE) defined a classification for autonomous vehicles according to the level of autonomy. There are 6 levels, from level 0 to level 3 are considered Human-centered conduction, and level 4 and level 5 are considered fully autonomous vehicles. These levels have been adopted worldwide including the European Union and the United States.

APPENDIX A: SDG REFLECTION

“The future of our planet requires immediate action — in real time. That is why I am calling on all those involved in the ecological transition and the modernization of the economy to join forces at once to mend our fragmented economies and societies. This is because the ecological transition and modernization of the economy are a matter of concern to all of us. (…) And because this ecological transition will not be a smooth, pain-free ride, we are also working to ensure that workers have effective social protection to help them adapt to change, that young people are well trained in the skills required by the jobs of tomorrow, in particular in green technologies and the digital sector, and that farmers have the means to implement environmentally friendly and climate-friendly practices thanks to the support of a modernized common agricultural policy.”

The previous speech has been quoted from Jean-Claude Juncker, President of the European Commission during the Juncker Comission’s contribution to the One Planet Summit in the Juncker Commission’s contribution to the One Planet Summit, December 12, 2017 [23].

There is no doubt that everything is changing for everyone by leaps and bounds, and pretending to deny it is an abdication of common sense. Because of that reason, two alternatives appear, the first one, being a victim of that change, while the second one would be embracing that change and try to guide it. Everyday not only in Europe but worldwide, people have to face challenges such as climate change, demographic transition, gender equality or migration. These challenges, what they really represent are our prosperity, our living standards, our freedom, and our health.

The United Nations were aware of this issue, and that was why in 2015 it was decided to create a common agenda, formed by developing and developed countries and which goal was to transform the world. In that year it was provided a shared blueprint for peace and prosperity for people around the world, not just for today but for the future. That agenda is best captured by the 17 Sustainable Development Goals (SDGs).

Figure 105:Sustainable Development Goals, 17 goals to transform our world

Figure 105 represent not just a checklist but a realistic approach to transform our world. Within the agenda there are five critical components, on which the 17 development goals depend. These five Ps or critical components are according to the video “Understanding the Dimensions of sustainable development” [24]:

- People: End poverty and hunger in all forms and ensure dignity and equality.
- Prosperity: Ensure prosperous and fulfilling lives in harmony with nature.
- Peace: Foster peaceful just and inclusive societies.
- Partnership: Implement the agenda through a global partnership.
- Planet: Protect our planet’s natural resourced and climate for future generation

The SDGs are the main global consensus agenda for the integral progress of our societies, and this agenda requires the support of every single citizen, especially those who belong to the scientific community. Because of this reason, it feels required that this senior thesis should be aligned with the international commitment of transforming our world towards a better one.

In compliance with the commitment to the sustainable development goals by 2030, this thesis has been developed. The SDGs addressed in the thesis "HOW DIFFERENT SCENARIOS TOWARDS LESS POLLUTING MOBILITY IMPACT IN SPAIN AT A MICRO AND MACRO LEVEL" are showed in figure 106:

Figure 106: Sustainable Development Goals addressed in this thesis

Next, a table will be presented where the SDGs taken into account will be specified.

Table 81: Sustainable Development Goals addressed in this thesis based in the presentation [25]

SDG Dimension	***SDG Identified***	***Role***	***Goal***
Biosphere	SDG 13: Take urgent action to combat climate change and its effects (noting the agreements adopted in the forum of the United Nations Framework Convention on Climate Change)	Secondary	Propose a viable plan which enables to reduce the GHG emitted by passenger vehicles in Spain
	SDG 7: Expanding infrastructure and upgrading technology to provide clean and more efficient energy in all countries will encourage growth and help the environment.	Secondary	Even though it is not the main goal of the project, certain points have been touched on renewable energy at work, since the origin of the electricity used in recharging the BEV directly affects the emissions of these vehicles
Society	SDG11: Making cities and human settlements inclusive, safe, resilient and sustainable	Secondary	Implementing a low polluting vehicle as an alternative to ICE vehicles, will provoke a reduction of the local emissions, making urban cities cleaner

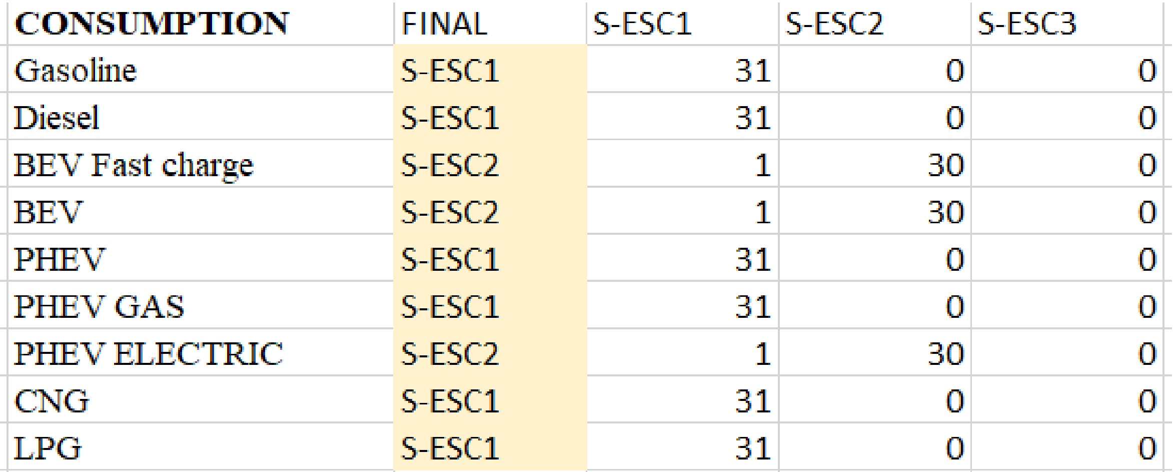
Economy	SDG8: The SDGs promote sustained economic growth, higher levels of productivity and technological innovation.	Primary	This has been the aim of this project, due to it has been carried out the scenarios looking for an economic growth while it was being promoted new technological alternatives with lower emissions.
	SDG9: Develop resilient infrastructure, promote inclusive and sustainable industrialisation, and encourage innovation	Secondary	One of the main purposes of this project was implementing infrastructures needed for the penetration of the new alternatives to ICE vehicles.

As it has been observed through the entire thesis, all the aforementioned Sustainable development goals has been approached. An example of that is table 90, which addresses most of them:

Table 82: Cost of replacing ICE scenario in terms of GHG emissions and reduction of GHG forecast (Own source)

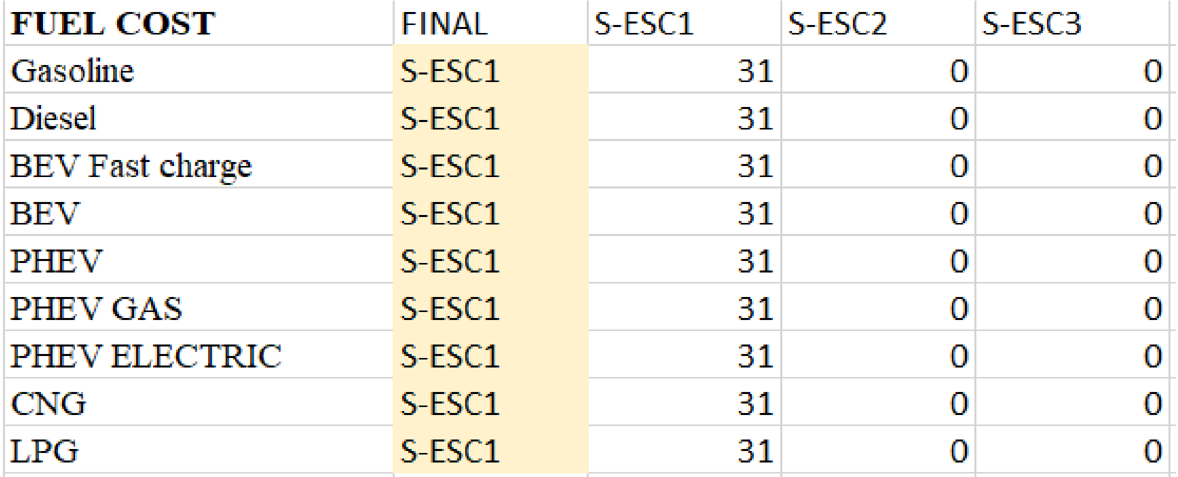
		% CO2 reduction	**CO2 (€/kt.)**	**% NOx reduction**	**NOx (€/kt.)**	**% PMx reduction**	**PM (€/kt.)**
BASE SCENARIO, MIX OF THE LOW ALTERNATIVES TECHNOLOGIES	**"Decarbonization Path"**	-12,51%	22.227,45	-16,95%	9.205.712,47	-26,85%	839.746.148,98
	"Business as usual"		53.860,73		22.306.943,89		2.034.841.984,42
ELECTRIFY THE VEHICLE FLEET	**"Decarbonization Path"**	-25,87%	946.310,64	-30,48%	450.473.210,58	-49,70%	39.924.742.681,12
	"Business as usual"		817.007,06		388.920.697,09		34.469.438.781,76
GAS VEHICLE FLEET	**"Decarbonization Path"**	2,29%	5.549.668,73	-12,84%	-556.360.968,93	-6,88%	-150.079.032.111,52
	"Business as usual"		7.918.005,40		-793.789.570,72		-214.125.679.417,34

APPENDIX B: DECARBONIZATION PATH SCENARIO



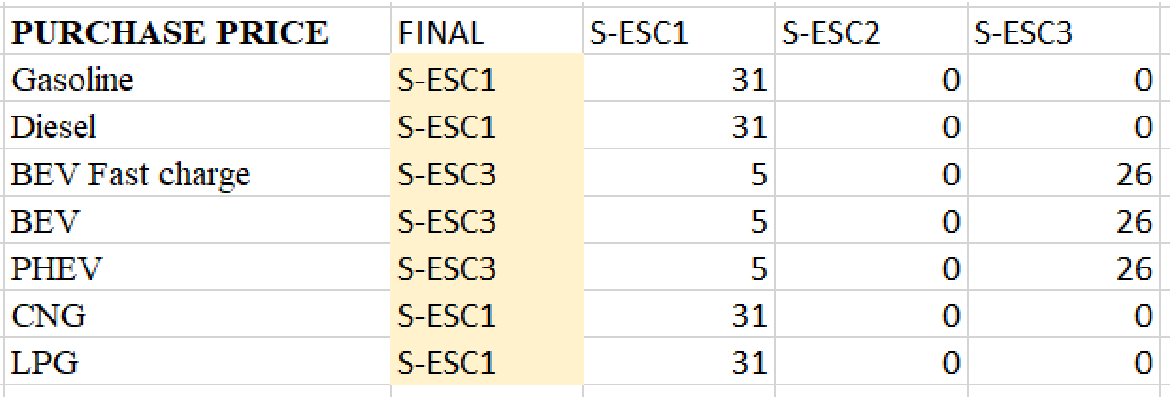
CONSUMPTION	FINAL	S-ESC1	S-ESC2	S-ESC3
Gasoline	S-ESC1	31	0	0
Diesel	S-ESC1	31	0	0
BEV Fast charge	S-ESC2	1	30	0
BEV	S-ESC2	1	30	0
PHEV	S-ESC1	31	0	0
PHEV GAS	S-ESC1	31	0	0
PHEV ELECTRIC	S-ESC2	1	30	0
CNG	S-ESC1	31	0	0
LPG	S-ESC1	31	0	0

Figure 107: Number of years in which a sub-scenario reaches the lowest consumption (Own source)



FUEL COST	FINAL	S-ESC1	S-ESC2	S-ESC3
Gasoline	S-ESC1	31	0	0
Diesel	S-ESC1	31	0	0
BEV Fast charge	S-ESC1	31	0	0
BEV	S-ESC1	31	0	0
PHEV	S-ESC1	31	0	0
PHEV GAS	S-ESC1	31	0	0
PHEV ELECTRIC	S-ESC1	31	0	0
CNG	S-ESC1	31	0	0
LPG	S-ESC1	31	0	0

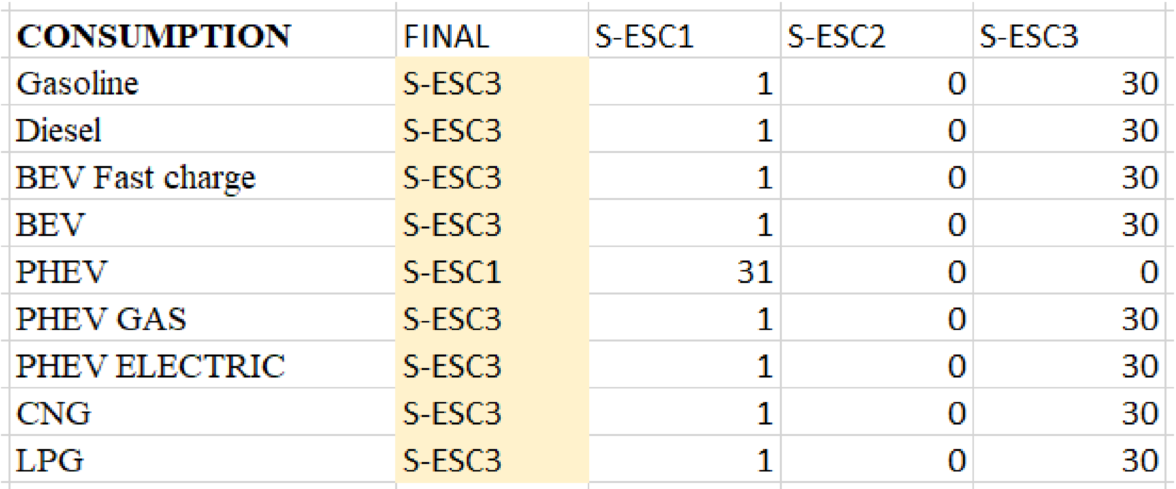
Figure 108: Number of years in which a sub-scenario reaches the cheapest fuel cost (Own source)



PURCHASE PRICE	FINAL	S-ESC1	S-ESC2	S-ESC3
Gasoline	S-ESC1	31	0	0
Diesel	S-ESC1	31	0	0
BEV Fast charge	S-ESC3	5	0	26
BEV	S-ESC3	5	0	26
PHEV	S-ESC3	5	0	26
CNG	S-ESC1	31	0	0
LPG	S-ESC1	31	0	0

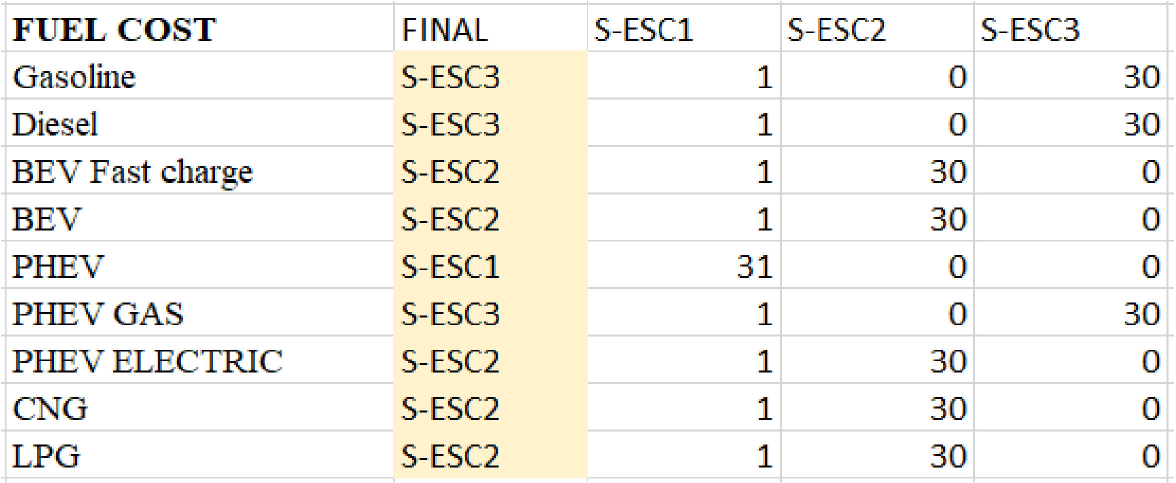
Figure 109: Number of years in which a sub-scenario reaches the cheapest purchase price (Own source)

APPENDIX C: BUSINESS AS USUAL SCENARIO



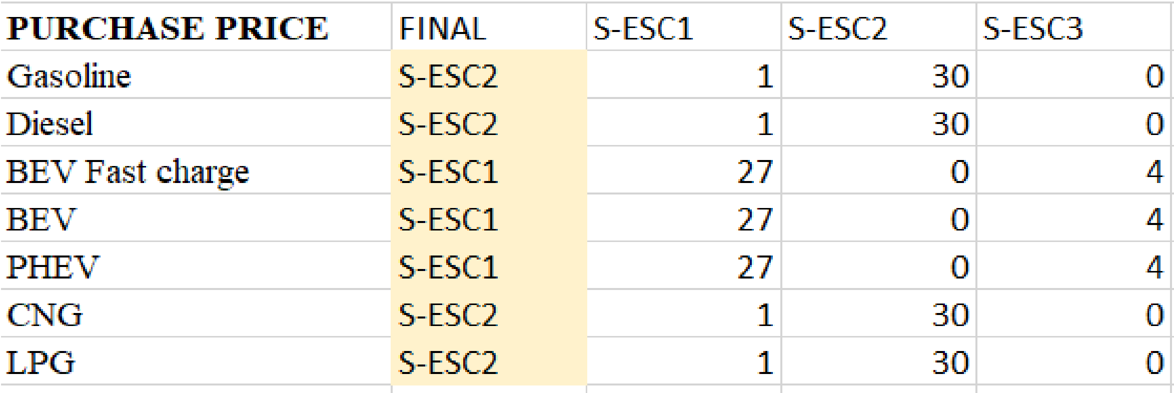
CONSUMPTION	FINAL	S-ESC1	S-ESC2	S-ESC3
Gasoline	S-ESC3	1	0	30
Diesel	S-ESC3	1	0	30
BEV Fast charge	S-ESC3	1	0	30
BEV	S-ESC3	1	0	30
PHEV	S-ESC1	31	0	0
PHEV GAS	S-ESC3	1	0	30
PHEV ELECTRIC	S-ESC3	1	0	30
CNG	S-ESC3	1	0	30
LPG	S-ESC3	1	0	30

Figure 110: Number of years in which a sub-scenario reaches the highest consumption (Own source)



FUEL COST	FINAL	S-ESC1	S-ESC2	S-ESC3
Gasoline	S-ESC3	1	0	30
Diesel	S-ESC3	1	0	30
BEV Fast charge	S-ESC2	1	30	0
BEV	S-ESC2	1	30	0
PHEV	S-ESC1	31	0	0
PHEV GAS	S-ESC3	1	0	30
PHEV ELECTRIC	S-ESC2	1	30	0
CNG	S-ESC2	1	30	0
LPG	S-ESC2	1	30	0

Figure 111:Number of years in which a sub-scenario reaches the most expensive fuel cost (Own source)



PURCHASE PRICE	FINAL	S-ESC1	S-ESC2	S-ESC3
Gasoline	S-ESC2	1	30	0
Diesel	S-ESC2	1	30	0
BEV Fast charge	S-ESC1	27	0	4
BEV	S-ESC1	27	0	4
PHEV	S-ESC1	27	0	4
CNG	S-ESC2	1	30	0
LPG	S-ESC2	1	30	0

Figure 112: Number of years in which a sub-scenario reaches the most expensive purchase price (Own source)

APPENDIX D: TOP 3 ALTERNATIVES

Table 83: Top three options for the Business as usual scenario and its purchase year (Own source)

		Business as usual 2020	**Business as usual 2025**	**Business as usual 2030**	**Business as usual 2035**
15 Years & 20,000 km	Best choice	1.LPG	1.LPG	1.LPG	1.BEV
	Second Best choice	2.CNG	2.CNG	2.BEV	2.LPG
	Third Best choice	3.BEV	3.BEV	3.CNG	3.CNG
12 Years & 20,000 km	Best choice	1.LPG	1.LPG	1.LPG	1.LPG
	Second Best choice	2.CNG	2.CNG	2.CNG	2.BEV
	Third Best choice	3.BEV	3.BEV	3.BEV	3.CNG
15 Years & 15,000 km	Best choice	1.LPG	1.LPG	1.LPG	1.LPG
	Second Best choice	2.CNG	2.CNG	2.BEV	2.BEV
	Third Best choice	3.BEV	3.BEV	3.CNG	3.CNG
12 Years & 15,000 km	Best choice	1.LPG	1.LPG	1.LPG	1.LPG
	Second Best choice	2.CNG	2.CNG	2.CNG	2.BEV
	Third Best choice	3.Gasoline	3.BEV	3.BEV	3.CNG
15 Years & 10,000 km	Best choice	1.LPG	1.LPG	1.LPG	1.LPG
	Second Best choice	2.CNG	2.CNG	2.CNG	2.BEV
	Third Best choice	3.Gasoline	3.Gasoline	3.BEV	3.CNG
12 Years & 10,000 km	Best choice	1.LPG	1.LPG	1.LPG	1.LPG
	Second Best choice	2.Gasoline	2.CNG	2.CNG	2.CNG
	Third Best choice	3.CNG	3.Gasoline	3.BEV	3.BEV

Table 84:Top three options for the Decarbonization Path scenario and its purchase year (Own source)

		Decarbonization Path 2020	**Decarbonization Path 2025**	**Decarbonization Path 2030**	**Decarbonization Path 2035**
15 Years & 20,000 km	Best choice	1.LPG	1.LPG	1.LPG	1.BEV
	Second Best choice	2.CNG	2.CNG	2.CNG	2.LPG
	Third Best choice	3.BEV	3.BEV	3.BEV	3.CNG
12 Years & 20,000 km	Best choice	1.LPG	1.LPG	1.LPG	1.LPG
	Second Best choice	2.CNG	2.CNG	2.CNG	2.BEV
	Third Best choice	3.BEV	3.BEV	3.BEV	3.CNG
15 Years & 15,000 km	Best choice	1.LPG	1.LPG	1.LPG	1.LPG
	Second Best choice	2.CNG	2.CNG	2.CNG	2.BEV
	Third Best choice	3.Gasoline	3.BEV	3.BEV	3.CNG
12 Years & 15,000 km	Best choice	1.LPG	1.LPG	1.LPG	1.LPG
	Second Best choice	2.CNG	2.CNG	2.CNG	2.BEV
	Third Best choice	3.Gasoline	3.Gasoline	3.BEV	3.CNG
15 Years & 10,000 km	Best choice	1.LPG	1.LPG	1.LPG	1.LPG
	Second Best choice	2.CNG	2.CNG	2.CNG	2.BEV
	Third Best choice	3.Gasoline	3.Gasoline	3.Gasoline	3.CNG
12 Years & 10,000 km	Best choice	1.LPG	1.LPG	1.LPG	1.LPG
	Second Best choice	2.CNG	2.CNG	2.CNG	2.BEV
	Third Best choice	3.Gasoline	3.Gasoline	3.Gasoline	3.CNG

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