TecnoCampus
Escola Superior
de Ciències Socials i de l'Empresa

Centre adscrit a la
Universitat Pompeu Fabra Barcelona

Cost-benefit analysis for the electrification of city bus fleets

Student's name: Joan Antoni Terrassa Bauzà

Academic tutor: Valeria Bernardo, PhD

19/06/2021

FINAL YEAR RESEARCH PROJECT

Course: 4th

Studies: Degree in Logistics and Maritime Business

Acknowledgements

Firstly, I would like to thank my tutor, Professor Valeria Bernardo, whose in-depth knowledge of the research has helped me to put everything on track.

I would like to express my sincere gratitude to my colleagues from my internship at Leclanché who allowed me to conduct this Bachelor thesis. I would particularly like to single out my supervisors Gerardo Gimeno and John Lewis. Thank you for the opportunity you gave me to carry out this paper. Without you, none of this would have been possible.

Finally, I would like to thank my parents, without their unconditional help I would not have been able to complete this stage of my life successfully. Thank you for always being by my side.

Contents

List of figures

List of tables

Abstract

Emissions from transportation have been growing for as long as records have been kept. Urgent measures must be taken to stop this growth. This research aims to take a further step towards the decarbonisation of urban transport. It consists of carrying out a Cost-Benefit Analysis (CBA) of different options for renewing the fleet of city buses in a medium-sized Spanish city. A comparison of zero-emission technologies is made to see which one achieves better values in the CBA. It is concluded that retrofitting old-diesel buses to electrical ones is the most appropriated option given the results of the CBA.

Resumen

Las emisiones del transporte han crecido desde que se tienen registros. Se deben tomar medidas urgentes para detener este crecimiento. Esta investigación pretende dar un paso más hacia la descarbonización del transporte urbano. Consiste en la realización de un Análisis Coste-Beneficio (ACB) de diferentes opciones para la renovación de la flota de autobuses urbanos en una ciudad española de tamaño medio. Se realiza una comparación de tecnologías de cero emisiones para ver cuál de ellas alcanza mejores valores en el ACB. Se concluye que la reconversión de los antiguos autobuses de gasóleo en eléctricos es la opción más adecuada dados los resultados del ACB.

Resum

Les emissions del transport han anat creixent des de que es tenen registres. Cal adoptar mesures urgents per a detenir aquest creixement. Aquesta recerca pretén fer un pas més cap a la descarbonització del transport urbà. Consisteix a dur a terme una Anàlisi de Cost-Benefici (ACB) de diferents opcions per a la renovació de la flota d'autobusos urbans en una ciutat espanyola de grandària mitjana. Es fa una comparació de les tecnologies d'emissió zero per veure quins s'aconsegueixen millors valors en la ACB. S'ha arribat a la conclusió que la adaptació dels autobusos vells de gasoil a elèctrics és l'opció més apropiada donats els resultats del ACB.

Keywords

City bus, retrofit, circular economy, decarbonisation of transport, batteries.

1. Introduction. Scientific relevance of the topic to research.

Since 2011, when the European Commission published the Roadmap 2050, member states and regional governments have started to work to achieve this goal: zero emissions by 2050 and a 55% reduction in 2030. Although it is true that the objective is very ambitious, year after year steps are taken to achieve it.

Of all the most pollutant sectors, transport has been the only one that has increased the emissions since 1990, were the carbon footprints of transport were more than 950Mt of CO_2. In the following years there has been a 27% of increase reaching the peak of emissions in 2008. This increase has been especially significant in land transport of goods, maritime and air.

This paper wants to contribute to the decarbonisation of urban road transport. To reach this objective, we will study how to apply measures to city buses, which, as will be explained in the following sections, is one of the main causes of pollution in 21st-century cities, due to the consumption of non-renewable resources. This process will help to meet the EU objectives mentioned in the first paragraph of this section. To this end, we propose to electrify the city bus fleet but using the circular economy: bus retrofitting, from diesel to electric.
Furthermore, we will see how these measures can save significant amounts of money to the municipal coffers.

The specific measure which will be covered in this study is regarding the public transport of a city: the city bus fleets. And to do this we will compare the different alternatives for the public bus fleet through a cost-benefit analysis: the appropriate tool to assist political decision-making.

It should be borne in mind that buses are the most widespread public mode of transport, where in many cities it is the most recurrent. Particularly in small and medium-sized cities, where mass rapid transit infrastructure is not possible due to the high cost of the infrastructure or that the city's subsoil does not allow this underground work (Gallotti & Barthelemy, 2015).

During the 4 years of the bachelor's degree, through different subjects, we have studied the environmental impact of the different logistics activities, mainly transport. Also, we have studied Cost-Benefit Analysis methodology applied to transportation projects. In this research I focus on one of the main negative externalities that logistics produce: emissions from transport. And what is more important, to find a way to achieve decarbonization of city buses in a shorter time.

As a student placement in Leclanché SA (European battery manufacturer), I have been able to work in this field at first hand, and to learn about the current trends for the decarbonisation of transport.

This research originates from a real need of the company to know the viability of developing a retrofit project for city buses. In addition to this, there are no previous studies that prove the viability of a retrofit project for urban buses as a decarbonisation option.

After this Introduction, the work is structured in the following sections: Section 2 contains the Theoretical Framework, a review of the existing literature. In Section 3 the objectives and their respective hypothesis. In section 4 the methodology used, and the analysis carried out. Finally, section 5 presents the results of the research and the final conclusions and recommendations in section 6 and 7.

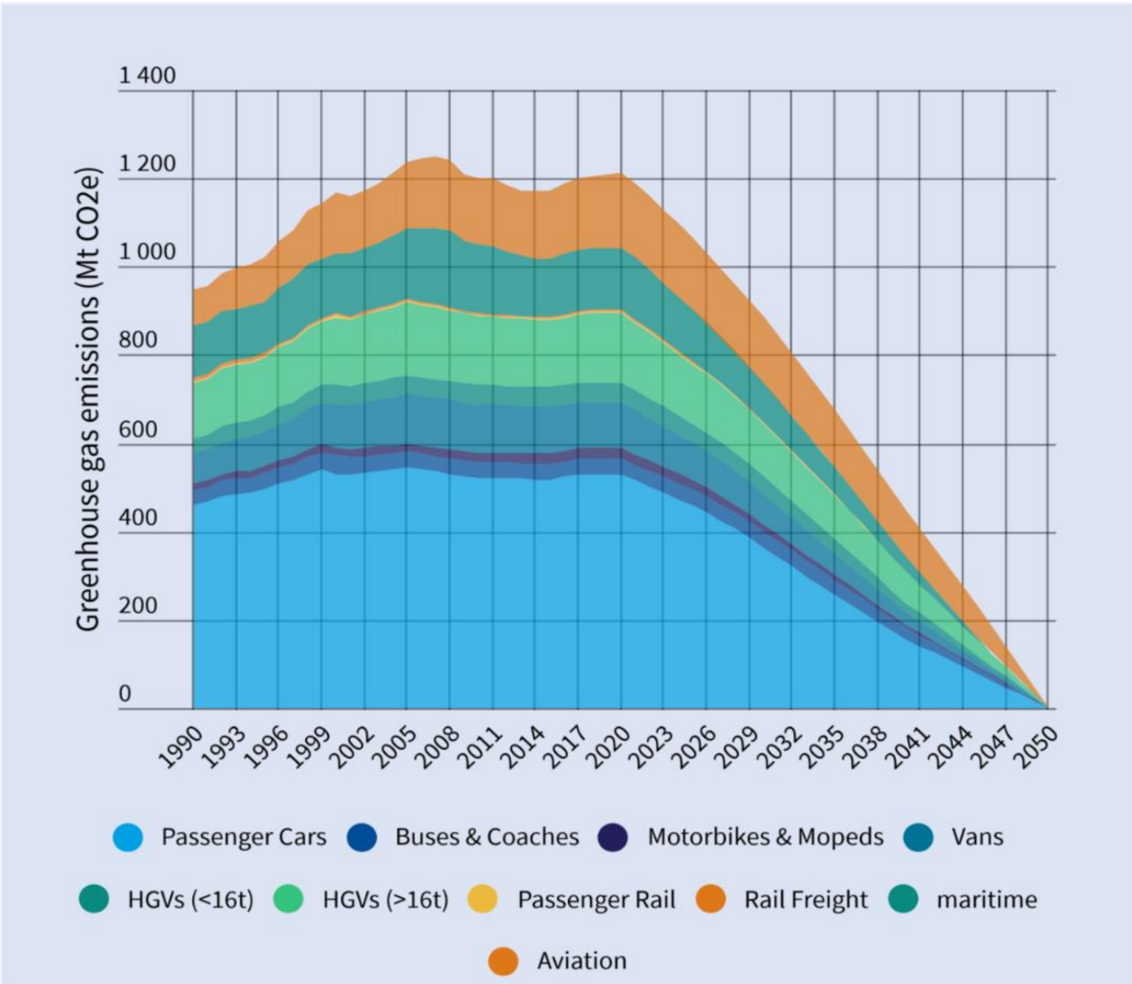
2. Theoretical framework.

In this section, we will expose the set of research, theories, and concepts on which this paper is based. To do this, firstly the impact of the emissions of transport will be analysed. It will be followed by the emissions of the different typologies of fuels used in buses. With all this we will conclude what type of fuels will be the most appropriate for this study. Secondly, we will explain what a Cost-Benefit Analysis (CBA) is and why we are going to use it in this project. We will see some examples of how CBA have been used in other sectors and the importance of this methodology to analyse the viability of a project with different alternatives.

2.1 Emissions

Figure 1 shows how CO_2 transport emissions in Europe increased from 1990 to a peak in 2007. They then steadily reduced until 2014 largely due to the global financial crisis of 2008. To date, 2020, emissions have increased with respect to the low point reached in 2014. The goal of reaching zero greenhouse gas emissions by 2050 seems unattainable. The graph shows the reduction that would have to be made to reach the target.

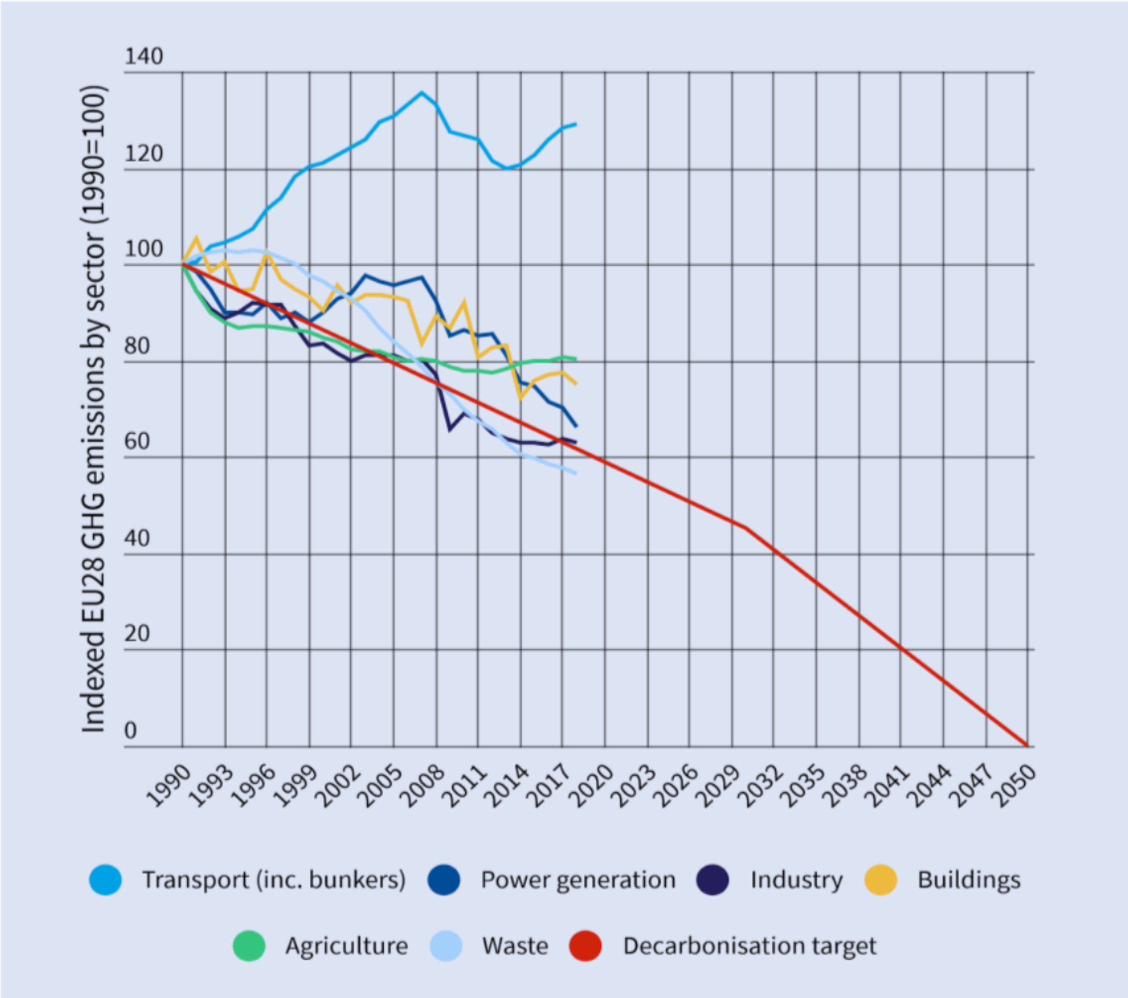
Figure 1. GHG in Europe. Historical data and forecasting according to decarbonization target



Source: Transport & Environment. 2020 (Poliscanova et al., 2020)

As we can see on the figure 2, transport is the only sector that has increased its emissions since 1990. This means that while there have been improvements in other sectors over the last few years to reduce emissions, the opposite has happened in transport. To reach the 0-emission target, quick and effective decisions will have to be taken in the transport sector to reach the target in time.

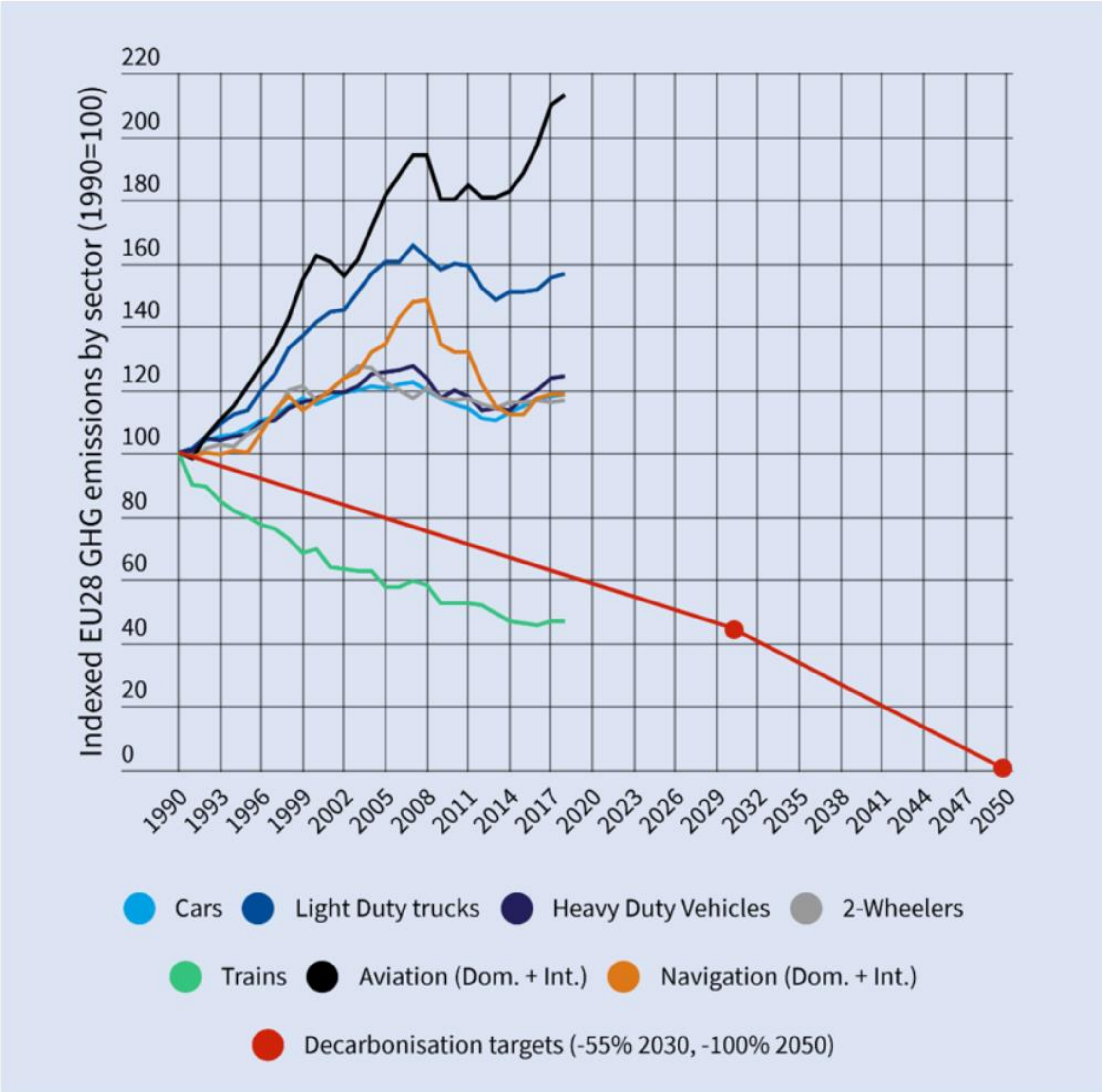
Figure 2. GHG emissions in Europe per sector indexed at 1990 level.



Source: Transport & Environment. (Poliscanova et al., 2020)

Specially aviation which emissions levels have more than doubled (figure 3). On road transport the worst evolution has been experienced by Light Commercial vehicles with more than 56% increase.

Figure 3. Only trains on track to meeting a 55% reduction in emissions by 2030



Source: Transport & Environment. (Poliscanova et al., 2020)

To handle it, on 2013, the European Climate Foundation published the report "From Roadmaps to Reality: A framework for power sector decarbonisation in Europe" it sets out how European energy policies can be improved to achieve decarbonisation (Acke Dries et al., 2013).

Urban passenger mobility must take major steps to achieve the objectives of decarbonisation.

In the following figure (4) we can see how there are only two technologies capable of achieving zero emissions: Battery Electric Vehicle (BEV) and Fuel Cell Electric Vehicle (FCEV).

Figure 4. Emissions comparison

	NOx	PM10(*)	PM10(**)
	(mg/km)	(mg/km)	(mg/km)
Diesel (euro 6)	**74** (306,4)	**0,03** (1,8)	15
Diesel (euro 5)	**137,4** (876,6)	**0,14** (1,8)	15
Diesel (euro 4)	**221,6** (712,7)	**19,4** (36,6)	49,8
Gasoline	**16,6** (48,2)	**0,71** (1,1)	14,3
HEV	**5,8** (12,2)	**0,03** (0,0)	13,1
PHEV	**9,6**	**0**	13,1
BEV	**0**	**0**	13,1
GNC (bifuel)	**16,8** (48,9)	**0** (1,1)	14,3
GLP (bifuel)	**18,4** (48,9)	**0** (1,1)	14,3
FCEV	**0**	**0**	13,1

(*) Only emissions by exhaust pipe.

(**) It includes exhaust emissions and vehicle component wear (frens, tires) and paving.

Type-approval values for vehicles are bold. The rest are the emission values of the Catalan guide for factors of issuance of the *Generalitat* based on the methodology of the European Environment Agency EMEP/EEA derived from numerous experimental vehicle measurements.

Source: Eficiència energètica en gestió de flotes. Generalitat de Catalunya - Institut Català d'Energia (Morer Forns et al., 2015).

Although hybrid technology has very low values, we must emphasize that the objective is zero emissions, so with this technology we cannot achieve the target.

So, to achieve full decarbonisation the local government must acquire one of these two technologies.

However, we must take in account that for a transportation entity is not feasible in the short term or immediately to completely replace existing conventional vehicle fleets by zero emissions ones due to existing fleets assets value.

Anyway, the major problem of the cities councils is how the end up with the existing diesel bus fleets which they acquired in the years 2010 - 2020 and which have not yet reached the end of their useful life. A possible solution to all this is to replace the bus fleet in a staggered manner, and easily adapt to the technological changes as frequent as they are in zero-emissions vehicles.

We must also bear in mind that each of these technologies has drawbacks.

As hydrogen production and distribution network it is not yet sufficiently developed to be implemented for a large-scale fleet vehicles (Thorne et al., 2019), this research will not analyse this option as an alternative.
As well a sudden proliferation of electric vehicles will impose a significant load on the existing power grid, having economic and environmental consequences (Santos et al., 2016). Even so, an overloaded electricity network seems to be only a problem in countries or cities with an energy deficit (e.g., Eastern European cities with a high dependence on thermal energy and those emerging economies that have seen a very rapid increase in population in recent years). It seems that in Western Europe today it is not a big issue.

It must be considered that energy consumption in electric vehicles depends on several factors, and these must be taken in consideration when choosing this type of vehicle. There are three main factors: ambient temperature, as the temperature decreases, the energy consumption increases; parameters correlated to the route type, in city, the energy consumption is more important because of the frequent stop and start driving; and the driving style, the energy consumption is reduced when privileging a calm driving style with smooth pedal motions and constant moderate speed (Younes et al., 2013).

2.2 Cost-Benefit Analysis

To correctly analyse which bus option is the most suitable, we will carry out a Cost-Benefit analysis. The application of the CBA methodology is decisive for the economic assessment of the viability of certain projects. The aim of it is to provide a consistent procedure for evaluating decisions in terms of their consequences (Drèze & Stern, 1987). Furthermore, the purpose of a cost-benefit analysis is to be a way of deciding what society prefers. Where only one option can be chosen from a series of options, CBA should inform the decision maker as to which option is socially most preferred (Ajit K. Dasgupta & D. W. Pearce, 1972). Then we can conclude that Cost-benefit analysis is the best suited methodology to decide which project should be executed, due to is the key economic tool used everywhere for analysing problems of social choice (Mishan, 2007).

The objective of CBA is to maximize the profitability of public resources. Therefore, it allows to decide the preference in comparison with:

- Diverse alternatives
- Diverse alternatives and alternative of doing nothing (current situation)

A cost-benefit analysis proceeds in four stages. Firstly, the identification of cost and benefits and their relevance in the project. Secondly, the valuing of the cost and benefits. Thirdly comparison of the costs and benefits that add up over the life of a project, with the appropriate discount rate. And finally, comparison of the project with the alternatives and the project selection (Nas, 2016).

Government departments and agencies must do a CBA in projects that requires high investment. For instance, in water supply and sanitation (Hutton et al., 2007), to build a high-speed rail (Inglada-López de Sabando & Coto-Millán, 2002), to implement a Medical Emergency Team (Bonafide et al., 2014) or to build a new nuclear power plant (Kennedy, 2007).

Also, CBA methodology has been widely used for evaluation of transport projects due to it allows to allocate scarce resources in a more efficient way (Mackie & Nellthorp, 2001).

For instance, Feng et al. (2016) made a CBA of Hybrid Electric Mining Trucks. This study analysed the feasibility of making hybrid mining trucks via retrofitting them. To perform that retrofit, implies additional costs, such as the added battery ESS (Energy Storage System) and the load capacity loss due to the additional weight of the ESS. Anyway, it brings better fuel efficiency, reduced truck operation cost, and a reduction in emissions. Furthermore, the fast-declining battery cost ensures one year of payback time.

In maritime transport, some studies have also been carried out using this methodology. Glykas et al. (2010) done a cost–benefit analysis for the installation of solar hybrid power on merchant marine vessels. The researchers conclude that the installation of Photovoltaic systems on merchant vessels highly depends on the annual average increase of the fuel oil. The higher the increase, the smaller the payback period of the investment.

Despite all of the above, there are not many articles that conduct a CBA of sustainable technologies to fleet of city buses, and the ones that are found are those of Gerbec et al., Lajunen and Noel & McCormack.

Gerbec et al. (2015) analysed the alternative propulsion systems (CNG and Hydraulic hybrid) and compare the performance in terms of costs and benefits with diesel buses in the public transport of Ljubljana, Slovenia. It concludes that the reliability of the analysis strongly depends on the data applied or on their forecasting. So, the results show how in the future the public transport company shall consider the variability in the performance of technological solutions.

Besides that, Lajunen (2014) also carry out a cost-benefit analysis, but in this case comparing hybrid and electric city buses. This research conclude that the capital and energy storage system costs are the most critical factors for hybrid and electric city buses. Even though hybrid and electric powertrain technology can clearly improve the energy efficiency, it depends also on the operation route and schedule. However, it is difficult to implement without any financial incentives or supporting legislation such as requirements of pollution free zones.

Noel & McCormack (2014) in the journal Applied Energy, published a very remarkable article in this field, a cost-benefit analysis using an electric bus compared to a traditional diesel bus. This analysis was innovative because it focused on public fleet vehicles. And it comes to a clear conclusion: the incorporation of heavy electric vehicles into the public vehicle fleet is not only a reasonable option, but an imperative. The net present value of electric vehicles provided during the service life will greatly reduce the upfront cost of purchasing electric vehicles. In short, electric buses can save thousands of dollars for each public seat during the entire life cycle, while avoiding external factors in health and the environment, and encouraging the further popularization of electric vehicles and the growth of renewable energy.

2.3 Government Franchises

Public administrations are in charge of managing the urban transport service through concessions. The Spanish concession system implies that private bus companies interested in operating in a city compete with each other by offering better conditions to users (like cheaper ticket fares, more frequencies or a higher quality service) in order to obtain an administrative permit to operate in each city. Through this concession, the company obtains the right to provide the service as a monopolist, in exchange for maintaining the conditions it bid to win. Furthermore, concession contracts must be limited in time. It does not set the maximum number of years of a concession, but cannot exceed the time considered reasonable for the concessionaire to recoup the investments made. In any case, as urban buses is an operation of a service, the concession contract may not exceed 25 years. (Law 9/2017, of 8 November, on Public Sector Contracts, transposing into Spanish law the European Parliament and Council Directives 2014/23/EU and 2014/24/EU, of 26 February 2014). A contract term of 7 to 12 years is recommended. This is a reasonable term that allows the authority to improve contractual clauses in successive tenders. It promotes competition compared to long-term contracts, as companies face competition more frequently (Global Green Growth Institute, 2018).

It is noted that, as a general rule, in large cities there is only one public city bus operator, while in small cities the service is provided by a private company. A small city usually has between 13 and 25 lines of buses, with a length less than 400 km. A medium-sized city has between 400 and 1000 km. The big cities have more than 100 lines with more than 1000 km of length. The line length is taken as the sum of the lengths between the line headings in both directions (Monzón et al., 2020).

This system allows to ensure bus transport between points with a lower number of passengers that would not be of commercial interest to the companies. By grouping profitable and unprofitable routes under the same concession, the winning company can use the profits of the profitable routes to cover the losses of the unprofitable ones. The specifications for the concession also state which type of bus have to be used and the money earmarked for the purchase of new vehicles.

2.4 Conclusions

Transport is the biggest polluter, and it has only got worse in recent decades. And urban passenger road transport is not an exception. In order to meet the objectives set by the European Commission, wide strides must be made in a short period of time. Electrifying the vehicle fleet seems to be the most appropriate solution to achieve the objective set out at the beginning of this paper: zero emissions by 2050 and 55% reduction in 2030. That is why we will focus on rechargeable energy storage (batteries). Hydrogen fuel cells are the only other option that ensures zero emissions, but as concluded in the study of Thorne et al. (2019), as the technology is not widely used, it is difficult to apply on a large scale. So electric is the most suitable option despite its limitations.

Previous literature finds that the cost-benefit of using electric buses is positive despite the fact that public subsidies are sometimes needed to sustain it. Even so, the positive externalities that the electric vehicles generate, help the net present value to be higher. Moreover, the concession system allows these technologies to be used even though the initial cost is higher.

But to achieve this in time, it is unfeasible for most municipalities to purchase new electric buses and dispose of their entire old bus fleet, considering that have not reached the end of their useful lives. Therefore, bus retrofitting seems to be a good option given the existing constraints.

That is why this study will consider these two options: buying a new electric bus or retrofitting an old bus to an electric one. After a careful examination of the existing literature, we conclude that this comparison has not been conducted by anyone before, so it's an original contribution to the body of knowledge.

The literature on sustainable alternatives is scarce, particularly for city bus fleet we have found a few contributions analysing electrical option. Therefore, this study contributes to the existing literature by being the first analysis that includes not only the electric option but also the retrofit.

Following this conclusion, a table of the most significant literature used in this section is presented.

Table 1. Relevant literature

Author	**Year**	**Contribution**
Feng et al.	2016	Feasibility of making hybrid mining trucks via retrofitting them. It implies additional costs (the battery and the load capacity loss). Anyway, it brings better fuel efficiency, reduced truck operation cost, and a reduction in emissions.
Gerbec et al.	2015	Compared CNG and hybrid propulsion systems in terms of costs and benefits with the actual diesel buses in the public transport of Ljubljana
Glykas et al.	2010	CBA for the installation of Photovoltaic systems on merchant vessels conclude that highly depends on the annual average increase of the fuel oil.
Lajunen	2014	Comparing hybrid and electric city buses conclude that the capital and energy storage system costs are the most critical factors. However, it is difficult to implement without any financial incentives or supporting legislation.
Noel & McCormack	2014	Electric bus compared to a traditional diesel bus. Electric buses can save thousands of dollars during the entire life cycle, while avoiding external factors in health and the environment.

Source: Own elaboration

3. Research questions

The municipalities must constantly make decisions regarding the city bus fleet in their cities. Especially when choosing the transport operator's and the purchase of the buses. If zero emissions are to be achieved, each local government must make the appropriate decisions despite the fact that it may be the case that the most environmentally sustainable option is the most expensive option in monetary terms. This paper is going to be analysed which option is the most suitable among the options offering zero emissions. The analysis will be focused on a medium-sized Spanish city, that could be the case for many European cities.

The option of buying diesel buses is not analysed in this research because it is not consistent with the emission reduction targets.

The replacement of the ongoing fleet that has arrived at the end of his useful life is a concern that all city councils must decide each certain of time. Each typology of vehicles gives some advantages and disadvantages. In the case of Diesel buses, that are most often, are supposed to depreciate in 10 years. Since the concession period is usually shorter than the depreciation period, it is assumed that the buses will also be used in the next concession period. The municipality can oblige the next concessionaire to buy the buses from the previous concessionaire when taking over the concession, at a cost reflecting the depreciation period. Or the same concessionaire wins the tender for several consecutive periods. It is also often that the owner of the buses is the city council and the transport operators run the use of these buses. In any case, the city council, is faced with a dilemma. Which type of vehicle should choose when renewing the fleet?

On one hand, the life of the diesel could be extended, by spending money on a new diesel traction system. When this is over or not possible, there is the option to buy new diesel buses. On the other hand, there is an environmentally sustainable but expensive solution: switch to electric bus.

Furthermore, it should be noted that there was a massive change in all municipalities and governments that started from the Paris agreements in November 2016. The announcement of the New European Green Deal in 2019 with the new Emissions regulations that entered in 1st Jan 2020 which made the industry and governments to stop thinking on progressive emissions reductions in new vehicles (Euro V and Euro VI norms entered in 2008 and 2012 respectively) and switch to a zero emissions mindset.

Not forgetting the historical sanctions on Volkswagen Dieselgate (it should be recalled that claims for moral damages due to emission fraud are still pending (Fuentes, 2020)).

Indeed, there are more alternatives to these options, such as Natural Gas Vehicle include compressed natural gas (CNG) and liquefied natural gas (LNG), liquefied petroleum gas (LPG), Biodiesel vehicles and all the hybrid and bi-fuel ones.
But in this paper, as mentioned previously, we are going to focus on battery electric bus as it is the only technology, apart from hydrogen, that guarantees zero emissions. And not only that, but we are also going to add a new and unusual option: retrofitting from diesel to electric.
The proposal is going to be raised is innovative; few cities have dared to take this step. Perhaps because of a lack of knowledge about it or a lack of confidence in the solution.

As we have seen above, in the works written so far, there is none that evaluates the viability of making a retrofit project as an alternative to the decarbonisation of the city bus fleet. Although they focus on alternative fuels, the option of retrofitting buses from diesel to electric is not considered despite being a real alternative for the adaptation of the fleet.

That is why in this paper a CBA is going to be developed for comparing the two following options for a medium-sized Spanish city:

Project 1. Retrofitting the buses: from diesel to electric

Project 2. Buy new electric buses.

So, in the next section we will answer the following question:
Which is the best option from the point of view of cost-benefit analysis?

As more than one alternative is evaluated, the decision rule is the following:

- If one of the projects had a positive NPV, the project with the highest NPV would be selected.
- If no alternative had a positive NPV, the best alternative in terms of economic efficiency would be to remain in the situation, not to carry out the project. Continue with old diesel fleet.

After that analysis, we will answer the second question:
Bus retrofitting is a sustainable and efficient solution for bring the bus fleet up to date?

4. Methodology

4.1 Preliminary considerations. CBA structure.

To carry out this research, we will follow the steps mentioned in section 2.2 of how to perform a Cost-Benefit Analysis:

I. Objectives.
II. Alternatives.
III. Identification of cost and benefits.
IV. Valuing the cost and benefits.
V. Comparison of the costs and benefits that add up over the life of a project, with the appropriate discount rate.
VI. Comparison of the project with the alternatives and the project selection.

It´s worth mentioning that this methodology is recommended by the European Union to analyse the feasibility of public projects (Sartori, 2014).

Firstly, define the objectives of the project, considering that the project is addressed to a city council. Furthermore, the consequences of the improvements should be considered, as well as the changes that the project will produce. The objective of this CBA corresponds to the decarbonisation targets set by the EU, as explained in the section 2.1.

Then, as mentioned in the previous section, specify the set of alternatives to the implementation of the project:

Project 1. Retrofitting the buses: from diesel to electric
Project 2. Buy new electric buses.

The third stage requires the identification of the social Costs and Benefits of the project and its economic evaluation. This process is one of the most important stages in analysing the social profitability of a project. That is why it is necessary to observe all the connections between markets, and how individuals (economic agents) change their behaviour by changing incentives (or prices). It is important to note that this is about social costs and benefits, as opposed to a financial analysis that only considers monetary revenues and costs.

Time is also a key variable, so the discount rate should be chosen. One of the most important features of CBA is that it must consider the time frame in which the costs and benefits of a project occur. So, we make the following operation: the social discount rate (r). The r measures the rate at which a society is willing to shift from present consumption to future consumption.

$$Co = \frac{Cn}{(1+r)^n}$$

Where:

$Cn =$ Estimated future capital

$Co =$ Present capital

$n =$ number of periods

It should be noted here that this is not the market interest rate, where only the cost of capital used in the project is reflected. Instead, it is the opportunity cost of the funds used in the project.

When:

r is high, the present is valued more

r is low, the future is valued more

After choosing the discount rate, the profitability of the projects should then be studied. The following formula is used for this analysis:

- **Net Present Value (NPV):** is the difference between the current value of social benefits and the current value of social costs.

$$NPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t}$$

Where:

$B_t = Social\ Benefits\ in\ each\ period$

$C_t = Social\ Costs\ in\ each\ period$

$r = discount\ rate$

$t = period$

In an investment, whether public or private, it depends on when the Costs and Benefits are produced. That is why it is very important to choose an appropriate discount rate (r). For instance, society perceives that the damage that climate change can generate in 50 years' time is worth less because it is so far away. However, the cost of reducing emissions today seems to us to be worth more because they are closer in time.
Therefore, governments tend to be more concerned with short-term problems because society value them more.

Once the results are obtained, the project is compared with the alternatives. Generally, the alternative that generates the highest NPV is chosen, if at least one of the alternatives has a positive NPV. Otherwise, if all the alternatives are negative, the closest alternative to 0 NPV will be chosen.

Finally, the decision or recommendation must be issued. However, given that NPVs are expected values, the project with the highest NPV may not be the best option, given the uncertainty in some of the study variables (Layard & Glaister, 1994).

Despite all the above, this methodology also has weaknesses and present some problematics to decision makers (Beukers et al., 2012). The most remarkable one is that CBA is extremely sensitive to the values used in the different alternatives. A significant error in any of them can cause a bias in the results or even go to the point of changing the result from negative to positive or vice versa (Jones et al., 2014). But because this research uses mobility data, this work does not largely present this problem. As on one hand passenger number data provided by the bus tender is used, and on the other hand the costs of the technology are actual data provided by a company working on it.

4.2 CBA process.

For this research we will consider a medium-sized Spanish city, which can be considered a population of approximately 700,000 inhabitants.
Three different types of buses are mainly used in cities: Short (10 meters of length), Standard (12 meters of length) and Articulated (18 meters of length). In this research we will focus just on standard buses, due to is the most used type of bus in cities.

4.2.1 Variable definition

Following the previous works of Gerbec (2015), Lajunen (2014) and Noel (2014) mentioned on section 2.2, the costs and benefits to be considered are the following:

Table 2. Definition of variables and data sources

Variable definition	Value	Source	Link
Cost of diesel bus	255 000 €	Tender of city buses in Zaragoza	link
Cost electric bus	698 792 €	Zaragoza City Council	link
Cost of retrofit	259 320 €	Leclanché SA	
Cost replace batteries	180 200€	Leclanché SA	
Average journey per year	60 000 km	Tender of city buses in Zaragoza	link
Lifespan retrofit	8 years	Leclanché SA	
Lifespan new electric	16 years	Leclanché SA	
ITV 1° inspection	61.03 €	Revisions de vehicles, S.A.	link
Taxes (IEDMT and IVTM)	N/A	BOE: IEDMT&IVTM	
Insurance	0.07 €/km	Dwarsverband - TIB	link
Fuel price	1.189 €	DieseloGasolina.com	link
Maintenance diesel	0.16 €/km	Dwarsverband	link
Maintenance electric	0.08 €/km	Leclanché SA	
Energy price	0.08 €/km	PROFIELECTRA S.L.	link
Consumption diesel	0.45 l/km	Teknologian tutkimuskeskus	link
Consumption electric	0.8 kWh/km	Sustainable Bus	link
Total fleet Journeys per year	90 000 000	Tender of city buses in Zaragoza	link
Fleet	352	Avanza	link
Average price per ticket	0.62 €	Tender of city buses in Zaragoza	link
Residual value bus	20%	Observatorio costes viajeros	link
European Fund for new electric	15 000 €	Instituto para la Diversificación y Ahorro de la Energía	link

Source: Own elaboration

4.2.2 Social Benefits

Firstly, for the benefits, is considered the direct revenues per user, as established in the concession specifications. In both projects we consider the same revenues. It's calculated in the following table:

Table 3. Total benefit per bus

Journeys per year total fleet	90 000 000	journeys
Fleet	352	buses
Average journeys per bus	255 682	journeys
Average price per ticket	0,62	EUR
Benefit per bus	**158 523**	**EUR**

Source: Own elaboration based on data of Table 2.

In addition to these annual revenues (applicable for both projects), two additional revenues must be added in the year zero of project 2 (new electric bus). Firstly, an incentive from European Regional Development Fund (ERDF) for sustainable mobility (Instituto para la Diversificación y Ahorro de la Energía, 2019) and secondly, the residual cost of the diesel bus, which according to the Ministry of Transport and Infrastructure is 20% of the purchase price (Ministerio de Fomento, 2013) (20% of 255 000€). So total revenue in year zero for the new electric bus project is calculated in the following table:

Table 4. Additional benefit per bus on year 0 of project 2 (new electric bus)

ERDF incentive per bus	15 000	EUR
Residual cost of diesel bus	51 000	EUR
Additional benefit per bus	**66 000**	**EUR**

Source: Own elaboration

In the case of the retrofit (project 1), there is no additional revenue, because according to the principle of the circular economy, the same old buses will be used to develop this project.

4.2.3 Social Costs

The operational expenditures (OPEX) of each project should be calculated in order to proceed with the CBA. For the calculation, we will only focus on the operating costs of the bus itself, ignoring all other costs, which regardless of the technology will be the same. As the technology used in the two projects is the same (Battery Electric Buses), the operating costs are the same for both projects.

Table 5. Total cost per bus

Average journey	**60.000**	**km/year**
Energy price	0,08	eur/kWh
Consumption	0,8	kWh/km
Consumption per year	**3 840**	**EUR**
Insurance	0,07	eur/km
Total insurance per bus	**4 200**	**EUR**
Maintenance	0,08	eur/km
Total maintenance per bus	**4 800**	**EUR**
ITV	**61**	**EUR**
TOTAL OPEX PER BUS	**12.901**	**EUR**

Source: Own elaboration based on data of Table 2.

Then, in the year zero must be added the capital costs (CAPEX), which in the first project is the cost of doing a retrofit (259 320 €), and in the second is the cost of buying a new electric bus (698 792 €).

In the case of the new electric bus, an additional cost must be added to year 8 due to battery replacement. Since the introduction of lithium batteries in vehicles to store electrical energy for propulsion, the price of batteries has been decreasing and their performance has been increasing. Nevertheless, up until now it is still one of the most expensive parts of the electric vehicle. So, the cost of year 8 in project 2 is 180.200€ (battery replacement) plus the yearly OPEX of 12.901€, which gives a total of 193.101€.

4.2.4 Discount rate

For the selection of the social discount rate, we will choose 5% as it is the standard rate (Sartori, 2014).

5. Results

Now we proceed to make the table with the annual costs and benefits for each project. These two data are subtracted to find the annual net benefit. With this we apply the NPV formula and we have the annual result.
Firstly, for the project 1 (as mentioned on Table 2, 8 years of lifespan)

Table 6. Project 1- Retrofit

Year	Costs	Revenue	Benefit	NPV
0	259.320 €		- 259.320 €	-259.320 €
1	12.901 €	158.523 €	145.622 €	138.687 €
2	12.901 €	158.523 €	145.622 €	132.083 €
3	12.901 €	158.523 €	145.622 €	125.793 €
4	12.901 €	158.523 €	145.622 €	119.803 €
5	12.901 €	158.523 €	145.622 €	114.098 €
6	12.901 €	158.523 €	145.622 €	108.665 €
7	12.901 €	158.523 €	145.622 €	103.491 €
8	12.901 €	158.523 €	145.622 €	98.562 €

Source: Own elaboration based on data of Table 2, 3 and 4.

With this table, the annual NPVs are added up to get the total Net Present Value of Project 1, that is 681.864€.

Following, the table for Project 2,

Table 7. Project 2- New electric

YEAR	Costs	Revenue	Benefit	NPV
0	698.792 €	66.000 €	- 632.792 €	- 632.792 €
1	12.901 €	158.523 €	145.622 €	138.687 €
2	12.901 €	158.523 €	145.622 €	132.083 €
3	12.901 €	158.523 €	145.622 €	125.793 €
4	12.901 €	158.523 €	145.622 €	119.803 €
5	12.901 €	158.523 €	145.622 €	114.098 €
6	12.901 €	158.523 €	145.622 €	108.665 €
7	12.901 €	158.523 €	145.622 €	103.491 €
8	193.101 €	158.523 €	- 34.578 €	- 23.404 €
9	12.901 €	158.523 €	145.622 €	93.869 €
10	12.901 €	158.523 €	145.622 €	89.399 €
11	12.901 €	158.523 €	145.622 €	85.142 €
12	12.901 €	158.523 €	145.622 €	81.088 €
13	12.901 €	158.523 €	145.622 €	77.226 €
14	12.901 €	158.523 €	145.622 €	73.549 €
15	12.901 €	158.523 €	145.622 €	70.047 €
16	12.901 €	158.523 €	145.622 €	66.711 €

Source: Own elaboration based on data of Table 2, 3 and 4.

The total Net Present Value of Project 2 is 823.456€.

In order to match the timeline of both projects, another retrofit should be added after finishing the lifespan of the retrofit. So, on year 9 (when the lifespan is over), 259.320€ must be added to the costs of that year in order to have another retrofit and reach a total of 16 years in Project 1. In this way it can be compared with Project 2 as it would have the same project lifespan.

Table 8. Project 1- With Two Retrofit

YEAR	Costs	Revenue	Benefit	NPV
0	259.320 €		- 259.320 €	- 259.320 €
1	12.901 €	158.523 €	145.622 €	138.687 €
2	12.901 €	158.523 €	145.622 €	132.083 €
3	12.901 €	158.523 €	145.622 €	125.793 €
4	12.901 €	158.523 €	145.622 €	119.803 €
5	12.901 €	158.523 €	145.622 €	114.098 €
6	12.901 €	158.523 €	145.622 €	108.665 €
7	12.901 €	158.523 €	145.622 €	103.491 €
8	12.901 €	158.523 €	145.622 €	98.562 €
9	272.221 €	158.523 €	- 113.698 €	- 73.291 €
10	12.901 €	158.523 €	145.622 €	89.399 €
11	12.901 €	158.523 €	145.622 €	85.142 €
12	12.901 €	158.523 €	145.622 €	81.088 €
13	12.901 €	158.523 €	145.622 €	77.226 €
14	12.901 €	158.523 €	145.622 €	73.549 €
15	12.901 €	158.523 €	145.622 €	70.047 €
16	12.901 €	158.523 €	145.622 €	66.711 €

Source: Own elaboration based on data of Table 2, 3 and 4.

The total NPV of project 1 adding the second retrofit is 1.151.734€.

Following, a sum up table of the results of both projects.

Table 9. NPV Projects comparison

	Project 1	Project 2
Total NPV	1.151.734 EUR	823.456 EUR

Source: Own elaboration based on data of Table 7 and 8

Both projects have positive NPV, but project 1 has higher NPV that project 2.

6. Conclusions

Within the framework of the decarbonisation of transport, the European Union has set clear objectives that are important to achieve in order to meet the proposed goals.

Urban mobility occupies an important place within this goal, so this research has analysed viable alternatives to achieve zero emissions for a medium-sized Spanish city, which could be the case for many European cities.

The results of this study show that retrofitting the current diesel buses into electric powered buses is the best option from the point of view of a Cost-Benefit Analysis to decarbonise the bus fleet. The other option analysed (buying electric buses) shows worse results: it is more expensive for the municipal coffers.

So, bus retrofit is a sustainable and a cost-effective solution. On one hand, is based on the concept of circular economy by using the existing bus fleet to extend its life with zero emissions. On the other hand, the results obtained in the cost-benefit analysis show that it is the most cost-effective option to completely decarbonise the urban bus fleet.

The question that now arises given these results is: does Spain have the network of specialised garages to successfully implement this retrofit project on a large scale?

7. Recommendations

Based on the results obtained in the present project, where the available zero-emissions technologies to renew the city bus fleet were assessed, renewing the fleet by retrofitting old diesel buses into electrical ones is the best option that municipalities should consider when faced with the dilemma of which technology to use to make cities zero-emission from an urban passenger mobility point of view.

As this retrofit project would require garages large enough to change the engine and the required parts of a 12-metre bus, the second recommendation to come out of this research is if there are no enough garages available in Spain to perform a retrofit of urban buses in a large scale and if there aren’t the necessary know-how is available to carry it out, it is recommended that the State should generate support programmes for technology development at the national level.

References

Acke Dries, Hill Karla, Hogan Michael, Gaventa Jonathan, Skillings Simon, & Turner Sharon. (2013). *From Roadmaps to Reality A framework for power sector decarbonisation in Europe A contributing study to Roadmap 2050: a practical guide to a prosperous, low carbon Europe*. https://www.roadmap2050.eu/project/roadmap-to-reality

Ajit K. Dasgupta, & D. W. Pearce. (1972). *Cost-Benefit Analysis: Theory and Practice*. Palgrave.

Beukers, E., Bertolini, L., & te Brömmelstroet, M. (2012). Why Cost Benefit Analysis is perceived as a problematic tool for assessment of transport plans: A process perspective. *Transportation Research Part A: Policy and Practice*, *46*(1). https://doi.org/10.1016/j.tra.2011.09.004

Bonafide, C. P., Localio, A. R., Song, L., Roberts, K. E., Nadkarni, V. M., Priestley, M., Paine, C. W., Zander, M., Lutts, M., Brady, P. W., & Keren, R. (2014). Cost-Benefit Analysis of a Medical Emergency Team in a Children's Hospital. *PEDIATRICS*, *134*(2). https://doi.org/10.1542/peds.2014-0140

Drèze, J., & Stern, N. (1987). Chapter 14 The theory of cost-benefit analysis. In *Handbook of Public Economics* (Vol. 2, pp. 909–989). Elsevier. https://doi.org/https://doi.org/10.1016/S1573-4420(87)80009-5

Feng, Y., Dong, Z., Yang, J., & Cheng, R. (2016, August). Performance modeling and cost-benefit analysis of hybrid electric mining trucks. *2016 12th IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications (MESA)*. https://doi.org/10.1109/MESA.2016.7587102

Fuentes, V. (2020, October 14). *Miles de afectados por el Dieselgate en España reclamarán al Grupo Volkswagen hasta 6.000 euros por coche*. https://www.motorpasion.com/industria/miles-afectados-dieselgate-espana-reclamaran-al-grupo-volkswagen-6-000-euros-coche

Gallotti, R., & Barthelemy, M. (2015). The Multilayer Temporal Network of Public Transport in Great Britain. *Scientific Data*, *2*. https://doi.org/10.1038/sdata.2014.56

Gerbec, M., Samuel, R. O., & Kontić, D. (2015). Cost benefit analysis of three different urban bus drive systems using real driving data. *Transportation Research Part D: Transport and Environment*, *41*. https://doi.org/10.1016/j.trd.2015.10.015

Global Green Growth Institute. (2018). *Análisis Comparativo de Modelos de Concesión del Transporte Público*.

Glykas, A., Papaioannou, G., & Perissakis, S. (2010). Application and cost–benefit analysis of solar hybrid power installation on merchant marine vessels. *Ocean Engineering*, *37*(7). https://doi.org/10.1016/j.oceaneng.2010.01.019

Hutton, G., Haller, L., & Bartram, J. (2007). Global cost-benefit analysis of water supply and sanitation interventions. *Journal of Water and Health*, *5*(4). https://doi.org/10.2166/wh.2007.009

Inglada-López de Sabando, V., & Coto-Millán, P. (2002). Introduction of an Innovative Product: the High Speed Train (AVE). In P. Coto-Millán (Ed.), *Essays on Microeconomics and Industrial Organisation* (pp. 29–40). Physica-Verlag HD. https://doi.org/10.1007/978-3-662-11710-1_4

Instituto para la Diversificación y Ahorro de la Energía. (2019). PLAN MOVES. INCENTIVOS A LA MOVILIDAD EFICIENTE Y SOSTENIBLE. *IDAE*. https://www.idae.es/ayudas-y-financiacion/para-movilidad-y-vehiculos/convocatorias-cerradas/plan-moves-incentivos-la

Jones, H., Moura, F., & Domingos, T. (2014). Transport Infrastructure Project Evaluation Using Cost-benefit Analysis. *Procedia - Social and Behavioral Sciences*, *111*. https://doi.org/10.1016/j.sbspro.2014.01.073

Kennedy, D. (2007). New nuclear power generation in the UK: Cost benefit analysis. *Energy Policy*, *35*(7). https://doi.org/10.1016/j.enpol.2007.01.010

Lajunen, A. (2014). Energy consumption and cost-benefit analysis of hybrid and electric city buses. *Transportation Research Part C: Emerging Technologies*, *38*. https://doi.org/10.1016/j.trc.2013.10.008

Layard, R., & Glaister, S. (1994). *Cost-Benefit Analysis* (R. Layard & S. Glaister, Eds.). Cambridge University Press. https://doi.org/10.1017/CBO9780511521942

Mackie, P., & Nellthorp, J. (2001). *Cost–Benefit Analysis in Transport*. https://doi.org/10.1108/9781615832460-010

Ministerio de Fomento. (2013). *Observatorio de Costes del Transporte de Viajeros en Autocar*. https://www.mitma.gob.es/recursos_mfom/comodin/recursos/observatoriocostesviajeros17.pdf

Mishan, E. J. (2007). *Cost-Benefit Analysis*. Routledge. https://doi.org/10.4324/9780203695678

Monzón, A., López, C., Cuvillo, R., Julio, R., Manget, C., & Junio, M. (2020). *Informe Observatorio de la Movilidad Metropolitana-2018*. www.observatoriomovilidad.es

Morer Forns, L., Escobar Mariné, M. A., & Coll Raich, M. (2015). *Eficiència energètica en gestió de flotes*.

Nas, T. (2016). *Cost-Benefit Analysis:Theory and Application, 2nd Edition*.

Noel, L., & McCormack, R. (2014). A cost benefit analysis of a V2G-capable electric school bus compared to a traditional diesel school bus. *Applied Energy*, *126*. https://doi.org/10.1016/j.apenergy.2014.04.009

Poliscanova, J., Murphy, A., Abasov, F., Nix, J., Buffet, L., & Todts, W. (2020). *How European transport can contribute to an EU -55% GHG emissions target in 2030*. www.transportenvironment.org

Santos, D., Kokkinogenis, Z., de Sousa, J. F., Perrotta, D., & Rossetti, R. J. F. (2016, November). Towards the integration of electric buses in conventional bus fleets. *2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC)*. https://doi.org/10.1109/ITSC.2016.7795537

Sartori, D. (2014). *Guide to Cost-Benefit Analysis of Investment Projects*. https://doi.org/10.2776/97516

Thorne, R., Amundsen, A. H., & Sundvor, I. (2019). *Battery Electric and Fuel Cell Trains Maturity of Technology and Market Status*.

Younes, Z., Boudet, L., Suard, F., Gérard, M., & Rioux, R. (2013). Analysis of the main factors influencing the energy consumption of electric vehicles. *2013 International Electric Machines & Drives Conference*, 247–253. https://doi.org/10.1109/IEMDC.2013.6556260

Timeline

The following is the timetable for establishing the tasks to be followed for the proper preparation of the research.