Life cycle CO_2 footprint reduction comparison of Hybrid and Electric Buses for Bus Transit Networks

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Abstract

To control the global warming by ensuring the greenhouse gas emissions reduction of the automotive sector, the standards or norms are getting ever stricter globally, specifically in the past few years. In view of this, great emphasis is currently being given to the shift towards electric vehicles. However, it is very important to critically evaluate the overall life cycle of different powertrain technologies. In this study, such analysis has been carried out for the bus rapid transit networks in the 4 largest cities of Spain: Madrid, Barcelona, Valencia and Seville. Ten different lines were selected from each city and their driving-cycles were designed by extracting real time data from GPS used for simulating 3 different bus powertrains (diesel, hybrid and electric) for real-life results of the vehicles on each route. A life cycle analysis of the different bus configurations was done considering a wide perspective from manufacturing, use, maintenance to end-of-life stages, to compare the CO_2 footprints of the 3 evaluated powertrains using the database of the software GREET. The CO_2 footprints of the electric bus was also estimated for the years 2030 and 2050, using the predictions for cleaner electricity grids for future perspective. Compared to the standard diesel bus results, the overall results for hybrid and electric bus show 40% decrement and 30% increment of CO_2 well-to-tank emissions, respectively, 40% and 60% decrement of CO_2 life cycle emissions; 30% increment and 60% decrement of the buses' driving range and, 2.5% and 30% addition in the life cycle cost.

Keywords

Bus Rapid Transit; Diesel; Hybrid; Electric; Carbon footprint; Life Cycle Analysis

Nomenclature

Greek symbols	
$\sum$	Summation
Subscript and superscripts	
C_{eff}	Charging efficiency
C_E	Cost of Electricity
C_F	Cost of the fuel
C_{LCA}	Life cycle cost
C_{Main}	Maintenance cost
C_T	Cost per trip
CO_{2ADR}	CO_2 emissions from Assembly, disposal and recycling phase
$CO_{2\,Main}$	CO_2 emissions from Maintenance
$CO_{2\,P}$	CO_2 emissions from Production
$CO_{2\,TTW}$	Tank-to-Wheel CO_2 emissions
$CO_{2\,WTT}$	Well-to-Tank CO_2 emissions
$CO_{2\,WTT\,Elec}$	Well-to-Tank CO_2 emissions of the electric vehicle
$CO_{2\,WTT\,Fuel}$	Well-to-Tank CO_2 emissions of the fuel powered vehicle
$CO_{2\,WTT\,Elec\,2030}$	Well-to-Tank CO_2 emissions of the electric vehicle in 2030
$CO_{2\,WTT\,Elec\,2050}$	Well-to-Tank CO_2 emissions of the electric vehicle in 2050
$CO_{2\,WTW}$	Well-to-Wheel CO_2 emissions
EC_E	Energy Consumption of electricity
EC_F	Energy consumption of the fuel
F_{ADR}	CO_2 Footprint for the ADR phase
F_{comp}	CO_2 Footprint for a component
F_{DC}	CO_2 Footprint for diesel combustion
F_{EP}	CO_2 Footprint for the electricity production
F_{FP}	CO_2 Footprint for the fuel production
LCD_{comp}	Life cycle distance of a component
N_{main}	Number of maintenance times
W_{comp}	Weight of a component
$W_{vehicle}$	Weight of the vehicle
Abbreviations	
ADR	Assembly, Disposal, and Recycling
BRT	Bus Rapid Transit
BS	Bharat Stage
DB	Diesel Bus
EB	Electric Bus
ECU	Electronic control unit
EU	European Union
EV	Electric Vehicle
GHG	Greenhouse gases
GPS	Global positioning system
GREET	The Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies
HB	Hybrid bus

LCA	Life cycle analysis
LCD	Life Cycle Distance
TTW	Tank to Wheel
WTT	Well to Tank
WTW	Well to Wheel

1. Introduction

Air pollution from the automotive sector has been a topic of utmost concern and discussion to find a solution for its abatement from the automobile tailpipes [1]. Since automotive tailpipe emissions include several pollutants (soot, NOx, CO etc.) and greenhouse gas emissions (CO_2), which are among the main contributor to global warming, the automotive sector has been focusing on reducing the fuel consumption and consequently the emissions as much as possible over the years [2][3]. For which, across the world, different countries have set their own standards or laws, which must be complied with for every vehicle before going out in the market for sale, including: United States Emission Standards, European Emission Standards (Euro), Bharat Stage Emission Standards (BS), etc. [4]. In the past few years, these standards have been constantly upgraded and reframed by setting the future targets to ensure stricter regulations for CO_2 emission reductions as shown in Figure 1. This is primarily due to the ever-increasing awareness about global warming leading to climate change all around the globe [5]. Therefore, different alternative fuels and energy sources are being investigated constantly to address these challenges of global warming, climate change, etc. [6][7].

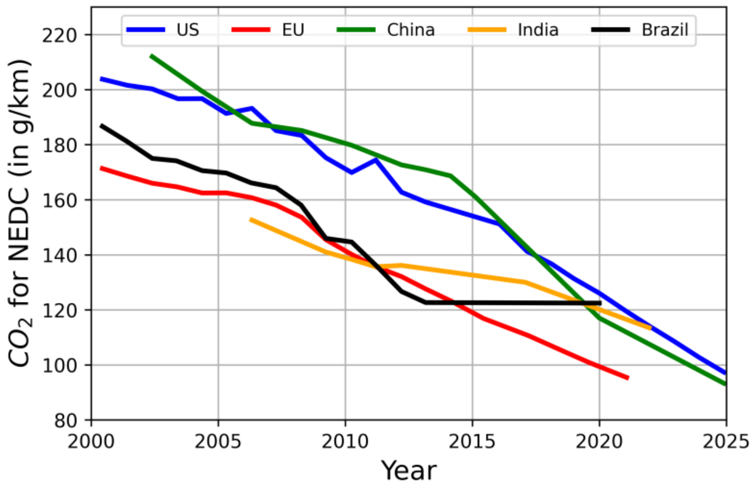


Figure 1. Timeline of Automotive Emission Legislations and Targets for Passenger Cars over the years around the world (normalised to NEDC) [8].

Due to these challenges and constraints, recently there has been a great push towards switching to Electric Vehicles (EVs) as a solution for reducing automotive emissions [9][10]. The pioneers in the field of EVs have been using taglines such as "Zero Emission Vehicle", with a view to attract policymakers to revise the standards with an emphasis on EVs. However, it is to be realized that before using taglines, a thorough examination of the life cycle emissions must be considered for EVs [11][12]. There are several processes/phases involved in the overall EV life cycle which gives out carbon emissions [13]. Whether a diesel, hybrid or an electric vehicle, its emissions should not only be monitored while it is in use (well-to-wheel) or just during running on the roads (tank-to-wheel), but it should also consider the stages of its manufacturing, maintenance as well as its disposal, for the vehicle as well as the fuel, separately [14][15]. The current transportation sector is more than 90% powered by ICE, which means that for movement of raw materials during the manufacturing of any item, there will surely be carbon emissions [16]. So, even in the transportation for the development of the electric infrastructure and vehicles, there are surely going to be carbon emissions. Also, the current state of global electricity production is not emission-free [17]. Barring a few countries like Norway, Iceland, Sweden, Austria and Denmark; all the other countries have majority of their electricity production coming from the non-renewable energy sources [18][19]. Moreover, the production of the large battery packs for EVs is a major source of its carbon emissions too [20][21]. In addition to all this, the increase in the demand for electricity generation to power the new electrified fleet of buses will be too high to be satisfied with the renewable energy generation supply [22][23]. Hence, it is especially important to do an overall life cycle analysis of each powertrain technology [24], considering all its relevant characteristics to assess its impact correctly [25][26].

Life cycle assessment for transportation sector can be found in the literature in large numbers [27] [28]. This approach has been used to quantify the impact of new fuels [6] and powertrains [13] on the CO_2 emissions in a comprehensive manner [29]. Several works have been done in passenger cars and heavy-duty vehicles [30][20]. Similarly, bus rapid transit networks were also subject of interest in the recent years due to their large contribution towards CO_2 emissions for both local and global perspective. In the past, a lot of work related to the life cycle of buses in different cities with different bus types as well as different fuel sources, have been done [31][32]. Ercan et al. [11] have evaluated the life-cycle impact of using alternative fuel options and also Ercan et al. [31] have discussed the CO_2 emission reduction potential together with several alternative fuel options with optimised bus fleet. Their paper also shows the result of the effect of different powertrains in high traffic scenarios. Similarly, Islam et al. [29] have carried out the evaluation for assessing the real GHG emission reduction potential of replacement of the conventional bus fleet with the electric buses. The study shows that a fleet comprising of 79% battery electric buses and 21% Diesel hybrid buses will lead to the most optimal solution in terms of cost as well as environmental constraints. In the same line, Song et al. [13] have done similar bus fleet replacement study, specific to the city Macau. Their study evaluates the emissions from different type of buses: light-duty, medium-duty and heavy-duty buses. Also, Lajunen et al. [33] have performed a detailed evaluation considering full electric buses and their impact compared to conventional powertrains. Their study shows the difference in the reduction of CO_2 emissions from hybrid and electric buses as well as their cost competitiveness with the conventional diesel or natural gas-powered buses. Further, Pathak et al. [9] have also done a related study to have the impacts on sustainability of the environment by using electric buses in Singapore. A comparison is done mainly for the cost competitiveness and GHG emission reduction of a 6 m autonomous electric bus with a 12-meter diesel bus. Despite the number of works presented in the literature, most of them do not account real driving scenarios of the bus routes in those cities [25][9]. Additionally, real time traffic and passenger numbers may influence the overall CO_2 contribution of these vehicles.

This paper evaluates the buses in real drive cycles, representative of their original routes, to have a realistic evaluation of the impact of each powertrain technology for their CO_2 emissions. Lifecycle CO_2 footprint of the three bus models (diesel, hybrid and electric) for different BRT network lines in the 4 mega cities of Spain: Madrid, Barcelona, Valencia, and Seville are traced by combining 0- D simulation and detailed carbon footprint databases. This enables a new and advanced way to evaluate bus routes for any bus transport company, globally, with respect to the dedicated bus model operating in that route, avoiding real life tests while having an approximation of the emissions just with simulations through a 0D numerical approach. It is worth to remark that the combination of real-driving conditions obtained from GPS and full vehicle simulation as inputs for life cycle assessment provide an edge over conventional methods since it can deal with the real conditions that are found in transportation. Additionally, the methodology proposed in this work is aligned with the future legislation to be introduced, where real driving conditions must comply with the imposed restrictions. Finally, the change in the electricity grid in future [22] is also considered by using estimations for 2030 and 2050 CO_2 footprint predictions for the electricity. This approach is intended to bring out the true picture of hybrid and electric buses with the changing state of the electricity grid in the future years. It is to be remarked that the presented methodology can be extended to any country just by adjusting the model's inputs according to the scenario in analysis. Hence, this paper discusses a practical and novel way for analysing buses on real drive cycles specific to different routes, operated by the Bus transit network company of any city around the world. As with the drive cycle information (route, stops, etc.), carbon emission intensity of the electricity generation-mix specific to that country and the corresponding prices for fuel, electricity and the evaluated bus models the performance of the powertrains can be evaluated for real traffic scenario on real drive cycles. Thus, this evaluation of the different bus powertrains can be done for an estimation of the emissions and fuel consumption on a specific bus route as a substitute to real world tests.

2. Methodology

The methodology is divided into five main steps: (1) selection of the cities and the BRT lines, (2) GPS based drive cycle designing, (3) bus models and specifications, (4) life cycle analysis and (5) predictions for 2030 and 2050. The first part justifies the choice of the cities and their selected BRT routes. The second part explains the method used for making GPS based drive cycles for the respective routes. The third part discusses the specifications of the bus models used for the evaluation and their respective 0D simulation models. The fourth part highlights the methodology and steps used in the life cycle analysis. Finally, the last part explains how the forecast is done for 2050 footprints.

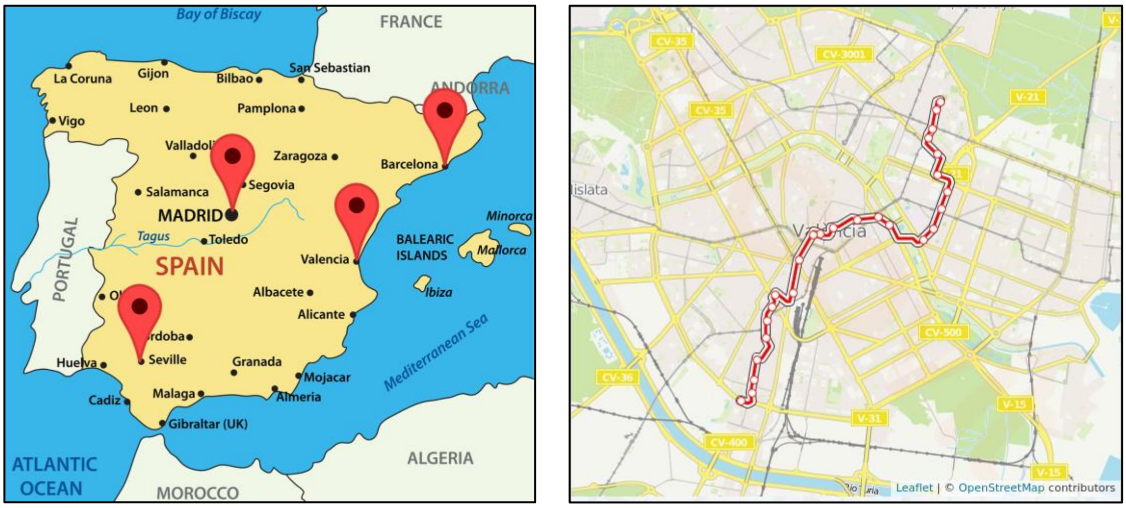
2.1. Selection of the Cities and the BRT lines

This study is done for the four largest cities of Spain: Madrid, Barcelona, Valencia, and Seville. Due to the largeness of these cities, the BRT networks are quite extensive too, with large fleet of buses running on the roads. Also, due to the high population, there will be more demand in the frequency of the lines as well as much bigger routes with length of about 15-20 km are operated. This makes these cities a perfect case to study the impact of electrification on carbon footprint reduction as they contain cases of extreme CO_2 emissions. Hence, ten BRT lines (routes), most frequently used by the citizens, in each city, were selected to generate an overall picture of the carbon footprint. The selected lines in the four Spanish cities are tabulated in Table 1.

Table 1: Selected BRT lines in different cities.

S. No.	Barcelona [34]	Valencia [35]	Seville [36]	Madrid [37]
1	B4	9	2	34
2	B12	10	27	27
3	B14	19	32	70
4	B18	70	C2	C1
5	B20	89	C1	C2
6	B21	90	13	21
7	B25	92	LE	31
8	B34	93	LN	28
9	M6	95	EA	35
10	N5	99	5	38

Figure 2 represents the different cities that were selected in this evaluation as well as their position in the map of the country (Figure 2 (a)) and an example of a bus line with the respective stop schedule for Line 10 in the city of Valencia (Figure 2(b)). The stop schedules for all these lines were extracted from the moovitapp.com to have the exact route in the drive cycles for the simulations [38].

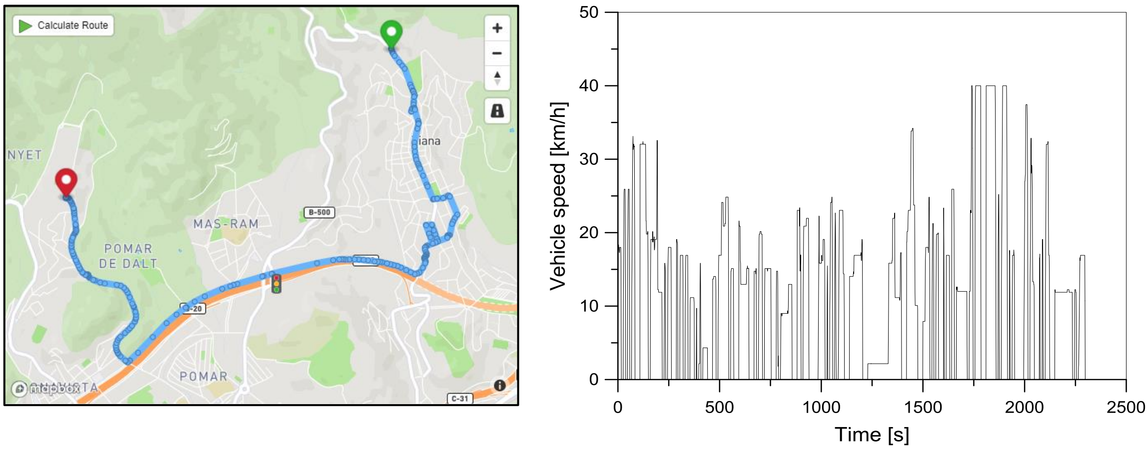


(a) (b)

Figure 2: Selection of (a) different cities in Spain and (b) Bus route of Line 10 in Valencia [38].

2.2. GPS based Drive Cycle designing

For designing the driving cycles, the GT RealDrive feature (ProfileGPSRoute), of the GT-Suite commercial software (v2021, Gamma Technologies) was used. Through this, the GPS based data for vehicle speed is directly extracted by providing the start and end point of each route. The driving cycles for each one of the bus lines were defined by a dedicated methodology. Considering a given line, their corresponding individual drive cycles (n-1) were designed, where n is the number of stops (n). For example, a line with 3 stops (A, B, C) will have 2 GT RealDrive cycles, A to B and B to C. These drive cycles are used to run the 0D GT model of the diesel bus to obtain the overall velocity-time profile as output for each bus line (as shown in Figure 3(a)). The obtained velocity-time profile (Figure 3(b)) was then used as an input to run the other two bus models of hybrid and electric bus, using the general ProfileTransient option, for their respective evaluation with the similar velocity-profile.



(a) (b)

Figure 3: GT-RealDrive; (a) GPS Based Drive cycle (b) Velocity-Time Profile for M6 Line in Barcelona [39].

This feature of the GT suite software basically imports the stored vehicle speed data from the GPS devices installed in the vehicles, on the cloud server, running in those specified routes for the intended GT Realdrive study. Using these values, a linear drive cycle is framed on the GT suite platform considering the speed profiles obtained from the Realdrive that already considers the traffic congestions, the turns as well as the topology of the drive cycle. Also, to have a real like scenario, a gap of 15 seconds is added between each stop as a stop condition for passenger loading/unloading, using a MATLAB code. This is done for every bus stop according to the number of stops involved in each specific bus route. The distance covered by the GT Realdrive based drive cycles and the time taken to have the route completed by the bus was matched with real data reported by the transport companies for each of the specified routes, as the data was found to be very much in accordance the approach was followed ahead for its further application. The distinct speed profiles of each specific GT Realdrive route are then used as an input for different cases to evaluate the three different bus models targeted in this study corresponding to each specific routes evaluated for this study. The assumptions considered in this methodology such as the sum of the parts of the cycle as well as the passenger loading/unloading were developed from previous works that can be found in the literature [40][41].

2.3. Bus Models and Specifications

Three different bus models were examined: (1) MAN Lion's City Diesel Bus (DB), (2) Volvo 7900 Hybrid bus (HB), and (3) BYD 12m Electric Bus (EB). The equivalent 0D model of these three buses were made, and validated on the GT suite software according to their respective specifications, and configurations [3][42]. The specifications for the three bus types used in this study are shown in Table 2.

Table 2: Specifications for the different Bus types.

Parameter	Diesel (DB)	Hybrid (HB)	Electric (EB)
Bus			
Model Name	MAN Lion's City [43]	Volvo 7900 Hybrid [44]	BYD 12m eBus [45]
Engine Type	D1556 LOH, Euro6	Volvo D5K 240, Euro6	Electric
Passenger Capacity	83	95	80
Approximate Cost (Euros)	250000 [32]	400000 [46]	550000 [32]
Gross Weight (kg)	19000	19500	19500
Rated Power - Engine/Motor (kW)	265/0	180/150	0/150x2
Maximum Torque – Engine/Motor (Nm)	1600/0	918/1200	0/550x2
Battery Capacity (kWh)	-	19	348
Length (mm)	12185	12000	12200
Width (mm)	2550	2550	2550
Height (mm)	3060	3280	3370

The 0-D longitudinal vehicle model was built in GT-Drive for each powertrain. Figure 4 depicts the GT-Drive model for the hybrid bus model, where the blocks used to model battery, internal combustion engine, transmission, etc., can be evidenced. The model includes different experimental maps to describe the fuel consumption and emissions during drive cycles evaluated on the test bench. For the battery modelling resistance-capacitance branches are used and the electric motor is modelled by using the power-speed maps based on the motor power rating. For each time-step the torque demand and the speed of the wheels from the driving cycle is calculated. Both values are used to determine the operating condition for the electric motor and ICE, resulting in the energy consumption and the formation of the emissions. This approach has shown accurate results in different investigations [42][3]. More details about the modelling approach can be found at [39]. The fuel energy consumption by the three bus models with full passenger loading capacity for all the 40 BRT drive-cycles were then used to calculate the "well-to-wheel" emissions for its LCA.

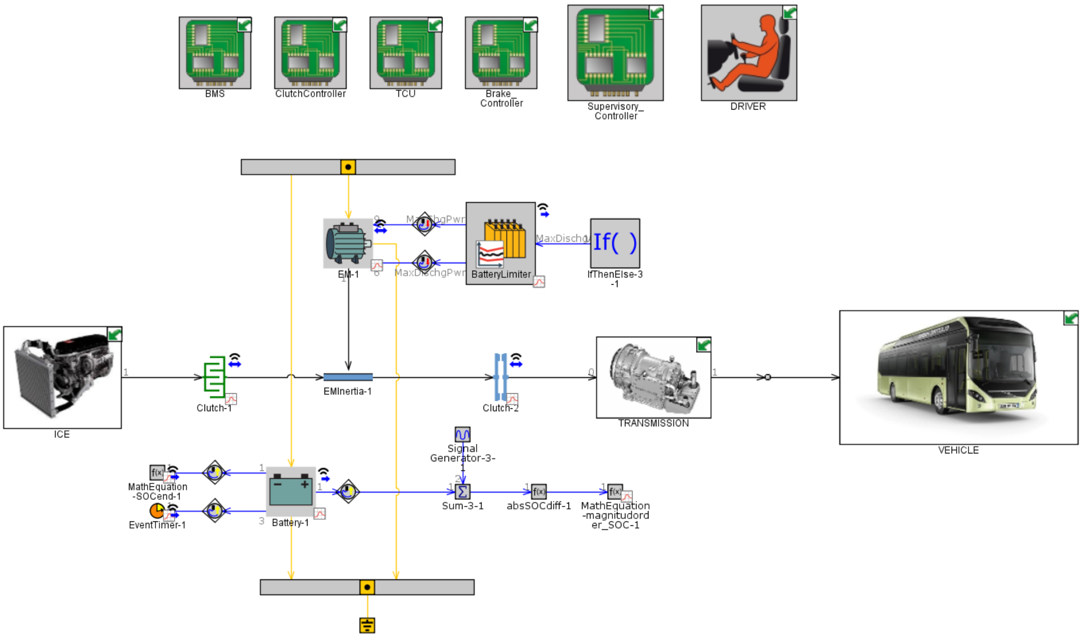


Figure 4: Example of a GT-Drive model developed for this work illustrating the different components considered in the hybrid powertrain.

2.4. Life Cycle Analysis

To have a complete assessment of the different powertrain technologies, it is first needed to identify the distinct parts (bill-of-materials) involved in the development of the different powertrains and then evaluate their footprint cumulatively [47]. Main parts of a standard bus are chassis, powertrain, transmission, and body. The electric components must be added for the hybrid and electric bus architectures based on their capacity and design (i.e., battery, motor, power electronics, etc.). The different parts considered in the three different bus types are presented in Table 3. The weight distribution of the different bus types should be considered to have the impact of each component on the CO_2 emissions [48].

Table 3: Bill-of-Materials relevant for the different Bus types.

Part	Diesel	Hybrid	Electric
Chassis	×	×	×
Powertrain	×	×	×
Transmission	×	×	×
Body	×	×	×
Power Electronics		×	×
Generator		×	
Motor		×	×
Battery		×	×
Engine Oil	×	×	
Tyres	×	×	×
Coolant	×	×	×

The life cycle analysis is done using Argonne National Laboratory's automotive LCA software GREET, to gather the dataset for the overall CO_2 footprint evaluation (i.e., for the raw materials, production and end-of-life cycles) [49]. The software has been validated to be quite accurate for the predictions of the greenhouse gas emissions and has dedicated automotive related information for LCA calculation [7][50]. The life cycle kilometres for each bus (before its disposal) is taken to be 800,000 km [48]. Table 4 presents the different CO_2 footprint values taken from the GREET database for this study.

Table 4: Carbon Footprint dataset for the different Bus types[49].

Part	DB	HB	EB
Chassis (Kg per Kg)	2.63	2.61	2.6
Powertrain (Kg per Kg)	2.51	2.52	3.96
Transmission (Kg per Kg)	3.75	3.26	3.26
Body (Kg per Kg)	8.63	8.97	9.48
Power Electronics (Kg per Kg)	-	2.41	2.41
Generator (Kg per Kg)	-	2.57	-
Motor (Kg per Kg)	-	2.57	2.57
Battery (Kg per Kg)	-	58.84	42.13
Engine Oil (Kg per Kg)	3.12	3.12	-
Tyres (Kg per Kg)	3.59	3.59	3.59
Coolant (Kg per Kg)	1.66	1.66	1.66
Assembly, Disposal & Recycling (Kg per Kg)	0.99	0.99	0.99
Fuel/Electricity-Well to Tank (gm per MJ)	18.6	18.6	89.53
Diesel Combustion-Tank to Wheel (Kg per Kg)	3.17	3.17	-

The above-mentioned datasets were used to calculate the overall CO_2 footprint of the three different bus models in a step-by-step process. The GREET software contains data on fuel cycles and vehicle operations evaluating the energy and emission effects associated to vehicle material recovery and production, vehicle component fabrication, vehicle assembly, and vehicle disposal/recycling [47]. The GREET model provides a comprehensive, lifecycle-based approach to compare the energy use and emissions of conventional and advanced vehicle technologies (e.g., hybrid electric vehicles and fuel cell vehicles). The software includes datasets for the following powertrain systems: internal combustion engine, internal combustion engine with hybrid configuration, fuel cell with hybrid configuration as well as full electric powertrains [51]. The model calculates the energy use and emissions that are required for vehicle component production; battery production; fluid production and use; and vehicle assembly, disposal, and recycling [52]. The step-by-step processes followed in this study to have the life cycle assessment is explained below:

(i) Production

The first step for the Life Cycle Analysis is to consider all the CO_2 emissions from the production phase of the vehicles [53]. For this, it is very important to identify the main parts of the vehicle to be considered during the vehicle manufacturing, i.e., chassis, body, transmission, powertrain, power electronics, generator, motor as well as the battery. The next important step is to find the weight distribution of the vehicle for each of these parts, as the GREET gives CO_2 footprint in kg of CO_2/kg of these parts. Using the average weight distribution (from Table 5) as in GREET for automotive vehicles, the CO_2 footprint was calculated for the production phase.

Table 5: Weight breakdown (in %) considered for the three Bus types [52].

Part	DB	HB	EB
Chassis	26.6	29.1	36.1
Powertrain	30.9	20.8	1.8
Transmission	5.7	7.6	3.5
Body	36.8	36.5	44
Power Electronics	-	1.8	6.8
Generator	-	2.1	-
Motor	-	2.1	7.8
Battery	-	0.6	17.8

Keeping this weight breakdown into account, the CO_2 footprint for the production phase was calculated for all the three busses using equation (1)[49]. The calculation considers the respective weight of the parts, produced for the specific vehicle configuration. Then, it is multiplied by the footprint value of that specific part obtained from the GREET database. This is done for all the parts included in the production of each bus model, and a sum of the all the parts emission values is done to compute the total emission value of each bus type.

$$\mathrm{CO_{2\,P}} = \sum(\mathrm{F}_{comp})*(\mathrm{W}_{comp}) \tag{1}$$

(ii) Use

The next step is to calculate the footprint of the vehicles during their operation. This consists mainly of WTW emissions, which is divided into two phases: Well to Tank (WTT) and Tank to Wheel (TTW). The WTT phase basically considers the fuel/electricity production for the buses that are to be filled/charged at the refilling/charging stations. And the TTW phase considers running of the buses and depends on the tailpipe emissions. For this, the efficiency of the charging stations (close to 93%) is also kept in account to have a more accurate value to the real consumption value. The well-to-tank emission for the ICE buses is calculated using equation (2)[33], which considers the fuel consumption obtained from the ICE buses and multiplied by the values obtained from the GREET database for the respective fuel. In case of EVs, there is no TTW emission, but only WTT emission, which is calculated using equation (3), which includes the Well to tank electricity consumption, obtained from the GT simulations, multiplied by the footprint of the electricity production from the GREET dataset, whole divided by the charger efficiency. The tank-to-wheel emissions is calculated by using the equation (4)[54] that involves the 0D GT simulation results of the ICE buses and multiplying it with the GREET footprint value for the emissions from the diesel combustion. Finally, the well-to-wheel emissions were calculated using the equation (5)[55], i.e., by simply adding the WTT emissions with TTW emissions.

$$CO_{2\,\mathrm{WTT\ Fuel}} = \mathrm{F}_{FP} * EC_{F} \quad (2)$$

$$CO_{2\,\mathrm{WTT\ Elec}} = \frac{EC_{E} * F_{EP}}{C_{Eff}} \quad (3)$$

$$CO_{2\,\mathrm{TTW}} = \mathrm{F}_{DC} * EC_{F} \quad (4)$$

$$CO_{2\,\mathrm{WTW}} = CO_{2\,\mathrm{WTT}} + CO_{2\,\mathrm{TTW}} \quad (5)$$

(iii) Maintenance

During the lifespan, buses also require maintenance during their use phase. In this phase, some parts of the bus are repaired, or consumables replaced as per the requirement. Hence, the footprint of the parts replaced should also be added for the life cycle assessment of the CO_2 footprint. Main items that are most frequently replaced during this phase includes engine oil, tyres and coolant. The battery packs are also changed during this phase. However, in the evaluated case, the EBs were free from battery maintenance as they last more than the lifetime of the buses [30][45]. The CO_2 footprint for the maintenance phase is calculated using the equation (6)[49], which includes the production emission footprint (calculated using equation (1)) of each specific part replaced during maintenance. The number of times maintained is calculated by using the equation (7), which led to the number of times replaced to be 80, as the lifecycle span of each part maintained is found to be 10,000 kms. For the tyres, it was calculated for each single tyre and was then simply multiplied with the total number of tyres in each respective bus type.

$$\mathrm{CO}_{2\,main} = \sum(\mathrm{F}_{comp} * \mathrm{N}_{main}) \quad (6)$$

$$\mathrm{N}_{main} = \frac{LCD}{\mathrm{LCD}_{comp}} \quad (7)$$

(iv) Assembly, Disposal and Recycling (ADR)

This phase is considered only once in the entire lifetime of a bus. It includes the assembly of all the parts manufactured during the production phase, disposal of the bus at the end of its life, and recycling of the recyclable materials used in the vehicle. The CO_2 footprint for this phase is calculated using the equation (8)[49], the emission footprint from GREET for this phase was multiplied by the overall weight of the vehicle/bus. Each vehicle type has its own emissions from this phase based on the components involved in the respective vehicles.

$$\mathrm{CO}_{2\,ADR} = (F_{ADR} * W_{vehicle}) \quad (8)$$

2.5. Prediction of the CO_2 emissions for 2030 and 2050

It is important to consider the changing state of the electricity grid infrastructure while calculating the CO_2 footprint of the EB for the future years to have a valid life cycle study. Hence, using CO_2 emission targets for the year 2030 and 2050 from the electricity grid, the LCA CO_2 emissions were estimated. Based on the European Union (EU) report, the targets for 2030 and 2050 are to reduce the CO_2 footprint approximately by 15% and 71.5%, respectively, compared to the 2020 emissions levels [57]. This decrement is considered in the WTT phase of the EB using the equation (9) for the 2030 values and using equation (10) for the 2050 values. Both the equation uses the TTW electricity consumption for the Electric buses obtained using GT simulations multiplied by the projected footprint for the electricity generation in the specific years of 2030 and 2050, and by dividing the whole by the effective efficiency of the charger.

$$CO_{2\,\text{WTT Elec 2030}} = \frac{EC_{E} * (0.85 * F_{EP})}{C_{Eff}} \tag{9}$$

$$CO_{2\,\text{WTT Elec 2050}} = \frac{EC_{E} * (0.285 * F_{EP})}{C_{Eff}} \tag{10}$$

These WTT emissions were considered as the WTW emissions for 2030 and 2050 and were correspondingly used in the LCA CO_2 emission estimation for 2030 and 2050. Based on the above-mentioned methodology and assumptions the life cycle assessment was carried out for tracing the carbon emission footprint of the different bus models. The Figure 5 shows the summary of all the steps and processes considered for this detailed evaluation on the emissions of the bus models.

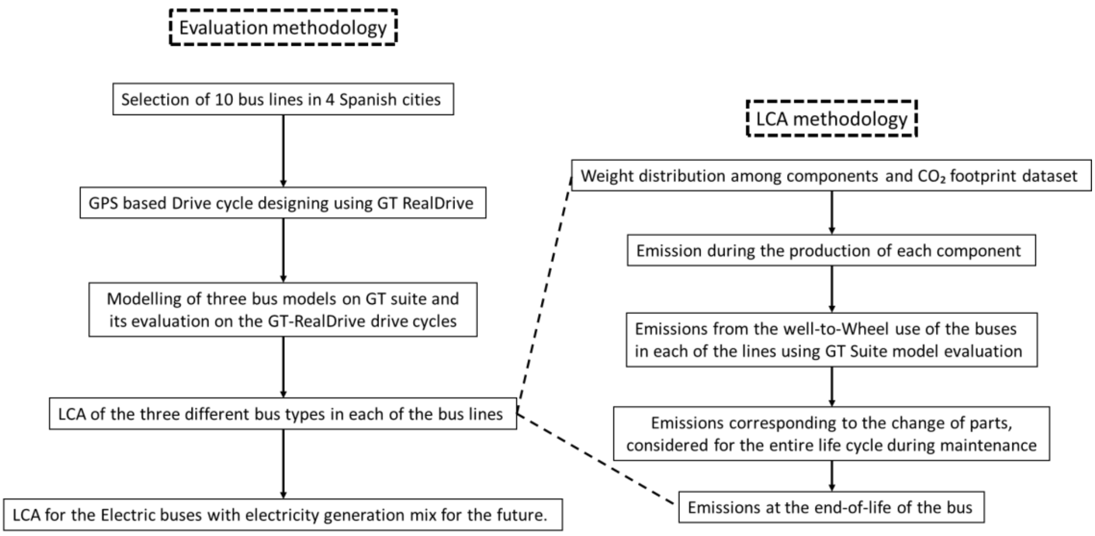


Figure 5: Hierarchy of different steps and processes included in this study.

Thus, key assumptions or considerations considered in this study can be highlighted as the following:

- Weight of the three bus types: Diesel-19000kg, Hybrid-19500kg and Electric-19500.

- Battery capacity: Hybrid-35kWh and Electric-348 kWh.
- Passenger capacity: Diesel-83, Hybrid-95 and Electric-80.
- Electricity generation Carbon emission: 89.53gm/MJ [49].
- Parts considered during maintenance: Diesel and Hybrid-Engine oil, Tires, Coolant and Electric: Tires and coolant.
- Total number of times the maintenance occurs is calculated by the total life cycle kilometers of the vehicle (800,000) divided by the life cycle kilometers of the respective part maintained.
- Cost considered in the study for the different bus types: Diesel-250000, Hybrid-400000 and Electric-550000.
- The GPS based drive cycles were designed at the different times, i.e., while designing one drive cycle there could be a different traffic scenario for that drive cycle, while for the other drive cycle it could be free of traffic based on the varying traffic congestions along the day.
- The geographic topology of the cities is also very distinct, which will have a significant impact on the performance of the powertrains even if they might have similar average speed along the trip.
- For the life cycle emissions' predictions for 2030 and 2050, it is only considered that the well-to-tank emissions are reduced for the EVs' assessment as per the target set by the EU for carbon emission intensity reduction for the respective years.
- The battery replacement for the Electric bus is not considered, as the selected electric bus is equipped with a Lithium Iron Phosphate battery which has a very long-life cycle more than that of a conventional Lithium-ion battery used widely. As, the bus battery's life cycle (1.2 million) is higher than that considered of the buses (800000), its replacement is not considered.

3. Results

Based on the methods explained above, here are the obtained results for our comparative powertrain analysis.

3.1. Validation of the obtained results

Based on the methodology adopted in this study the obtained results were validated against the literature data. The validation was done by matching the values obtained in this study for different parameters and looking for related values reported by other researchers in the literature. It is to be mentioned that no available study in the literature have focussed exactly on the same parameter as in this study, so different papers are considered for different powertrains and for its different parameters. As most of the study only focuses on tailpipe emissions or well-to-well emissions, there are a lot of data for TTW validation or even for WTT emissions but not for the overall LCA of the buses. Yet the LCA emissions were validated against the available literature data. Hence, in Table 6, we can find the different literature available data that have reported similar values for the well to tank and well to wheel emission values as well as LCA emissions. The LCA emission validation is shown in Figure 6 with the most similar available results.

Table 6: Literature data considered for the validation

Source	LCA emissions			WTT Emissions			TTW Emissions		
	Diesel	Hybrid	Electric	Diesel	Hybrid	Electric	Diesel	Hybrid	Electric
Paper 1	[16]	[16]	[58]	[15]					
Paper 2	[59]	[31]	[7]	[60]					

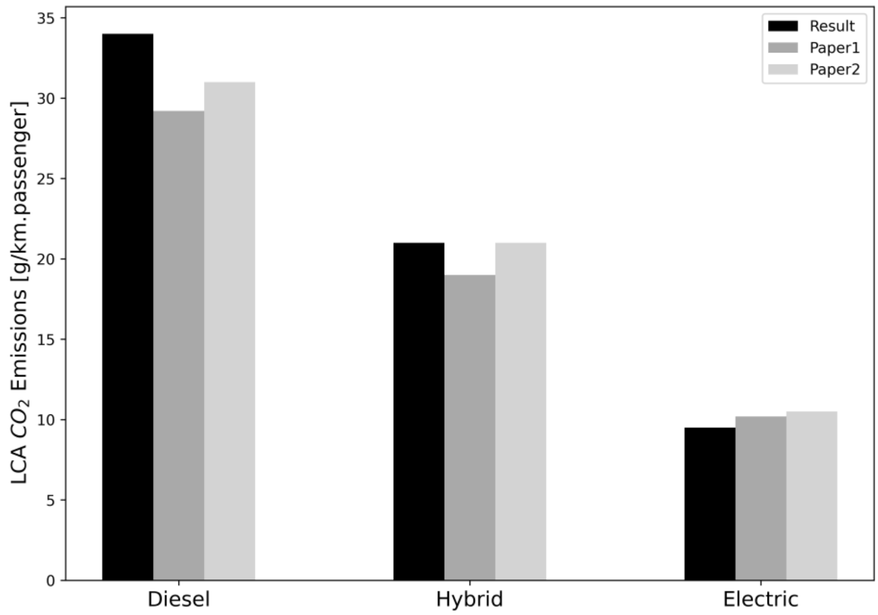


Figure 6: Validation of the LCA emissions of the different powertrain types with literature data.

Based on the results obtained in the literature, it was seen that the order of magnitude for the results obtained in our study is similar in terms of range. However, as the behaviour of the powertrains very much dependent on the drive cycles and the powertrain specifications it is not exactly matching the values from the reported literature data. Further, it is very important to realize that the dataset for the life cycle assessment can vary in different publications. Hence, the data is not exactly matching in the literature as well. Also, some of the studies are carried out in US, so it is dependent on the electricity production in the US which is much higher than that in the EU[15]. Thus, it is important to understand that the exact validation of the obtained data can be done only with the exact configurations of the powertrain and the steps that the authors include in their analysis. This variation in the powertrain's performance is explained by researchers already in their work [61][62].

3.2. Average Speed Variation of the BRT networks

The average operational speed of all the 40 lines in the 4 cities are shown in Figure 7. The lines in Madrid and Seville have quite low average speed as compared to that in Barcelona and Valencia. Further, the variation in the average speeds among the lines in each city shows maximum deviation in the cities, Barcelona and Valencia. This could be directly related to the performance of the lines presented here ahead in the results section as Madrid and Seville have the lowest deviations for the parameters evaluated in the Results section in contrast to that in Barcelona and Valencia.

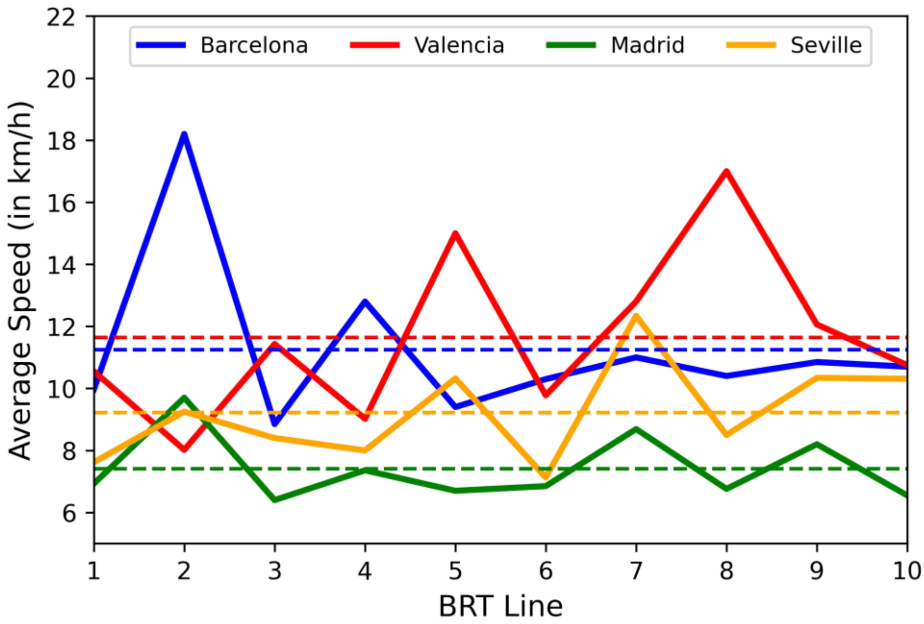


Figure 7: Average Speed variation (in dotted lines) in the 4 cities (10 BRT lines in each city).

The velocity-time profile for each BRT Line is very specific and unique (see Figure 7). So, it is presumed that the efficiency/performance of the bus will vary accordingly. For example, considering the line 89 and 90 of Valencia, both have almost the same distance covered (5.8 km and 5.7 km), but different number of stops (22 and 19). Despite the higher number of stops and a relatively higher distance travelled in the line 89, the fuel consumed was higher in the line 90. This could be attributed to the fact that the areas covered in the line 90 have denser traffic as well as greater frequency of traffic congestions (average speed 10 km/h). While the line 89 is related with more fluent traffic or better driving conditions (average speed 15 km/h). This is very important as the efficiency of the powertrain is very strictly dependent on its operating conditions.

At low speeds and with more stop conditions, the ICE powertrains will be less efficient as compared in high speed or cruise-like conditions. If the powertrain is operating more in transient conditions like in the line 90, the performance of the powertrain will be low, but in steady-like conditions with less stops as in the line 89, the powertrain will perform more efficiently. It could be seen here that the deviation in the results for Madrid is quite less as compared to the other cities. This is dependent on several parameters including: terrain of the city, area covered by the bus routes, lengths of the bus routes, no. of stops in the route, etc. [63][64].

For example, in Barcelona, there is a high deviation as the city has a mixed terrain. Similarly, in Valencia the deviation is quite high too mainly due to the selection of city-based lines (variation in the average speed), for the evaluation. Consequently, in Madrid there are least deviations, mainly due to similar range of average speeds (less deviations) for all the lines. Moreover, at low engine speeds, the diesel engines emit higher pollution, so it could be seen that the hybrids as well as the electric buses are performing much efficiently in Seville and Madrid, which have lower average speeds. The cycle-to-cycle variability in the results are presented more in detail in the APPENDIX section.

3.3. Energy Consumption

Energy consumption is one of the main parameters for any powertrain related study. Figure 8 shows the reduction in the fuel energy consumed as compared to the standard diesel bus. Both electric energy from batteries of the electric buses and fuel energy for the hybrid buses are normalised in MJ/km and represented as % reduction compared to the conventional diesel bus. Results shows an average decrease of about 75% from electric buses and around 30% from hybrid buses.

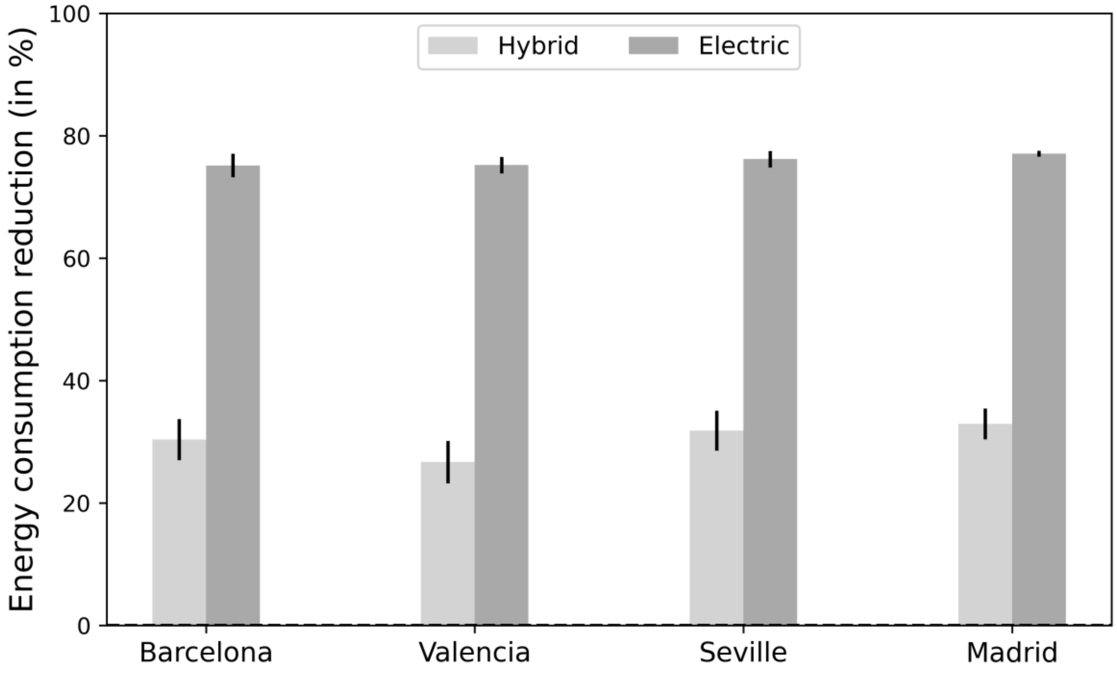


Figure 8: Energy consumption reduction in the 4 cities by Hybrid and Electric buses.

Here, the variation in energy consumption of the same bus model with respect to changing routes reflects the importance of the drive cycle conditions for the efficient functioning of the powertrains [65]. As the drive cycles have different lengths (km), number of stops, as well as different localities covered by the lines, the efficiency of the powertrains change due to these changes in the driving conditions. Moreover, the velocity-time profile for each drive cycle (BRT Line) is very specific and unique. So, it is presumed that the efficiency/performance of the bus will vary accordingly. This can be seen in the results presented in the section

3.2 that shows the variation in the average speed of the different lines. For a bus route with lower average speed, the efficiency of the different bus models will be surely poor compared to the efficiency in a route with much higher average speed. Consequently, in the low-speed routes, the electrification of the powertrains will be very advantageous in enhancing the efficiency, this can be seen as the higher energy consumption reduction percentage by Hybrids and Electric buses in Seville and Madrid.

3.4. Driving range

Other particularly important parameter that needs to be considered while evaluating the electric and hybrid powertrains is the driving range of the powertrain. The hybrid buses (about 500 km) show an average increase in driving range by about 30% and act as range extenders due to the lower fuel consumption. Although the energy consumption with electric buses is almost half of that consumed by hybrid buses, the hybrids still are range extenders. The electric buses are way below them due to the vast difference in the energy density of the battery pack as compared to that in a fuel tank. Hence, an average decrease in driving range by about 60% is experienced by electric buses in these cases (Figure 9).

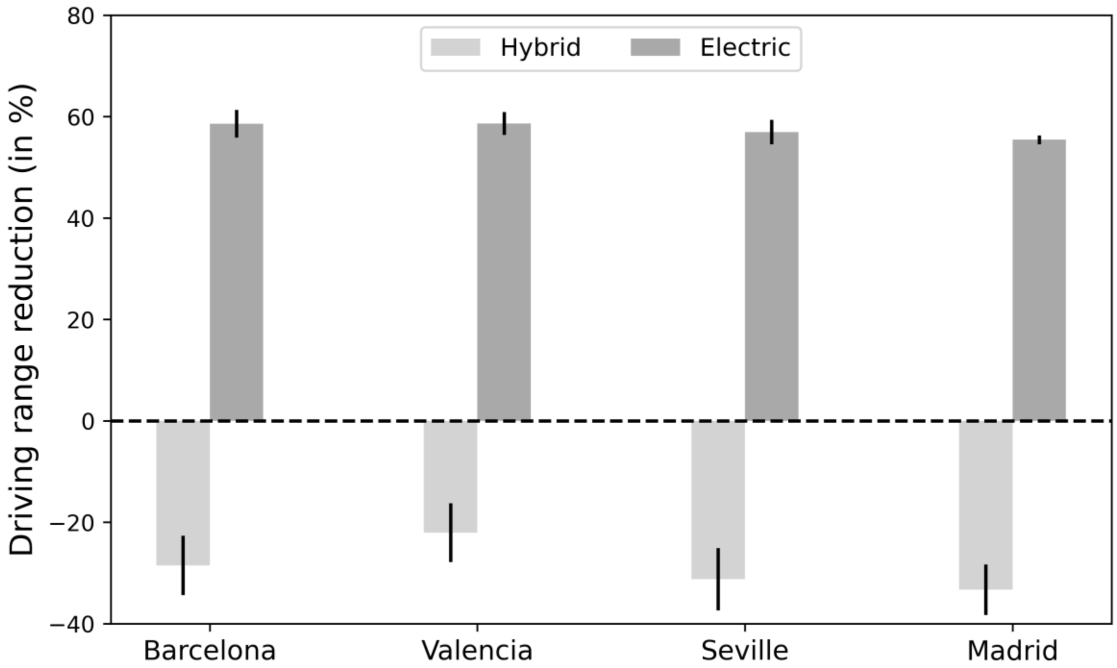


Figure 9: Change in driving range in the 4 cities by hybrid and electric buses.

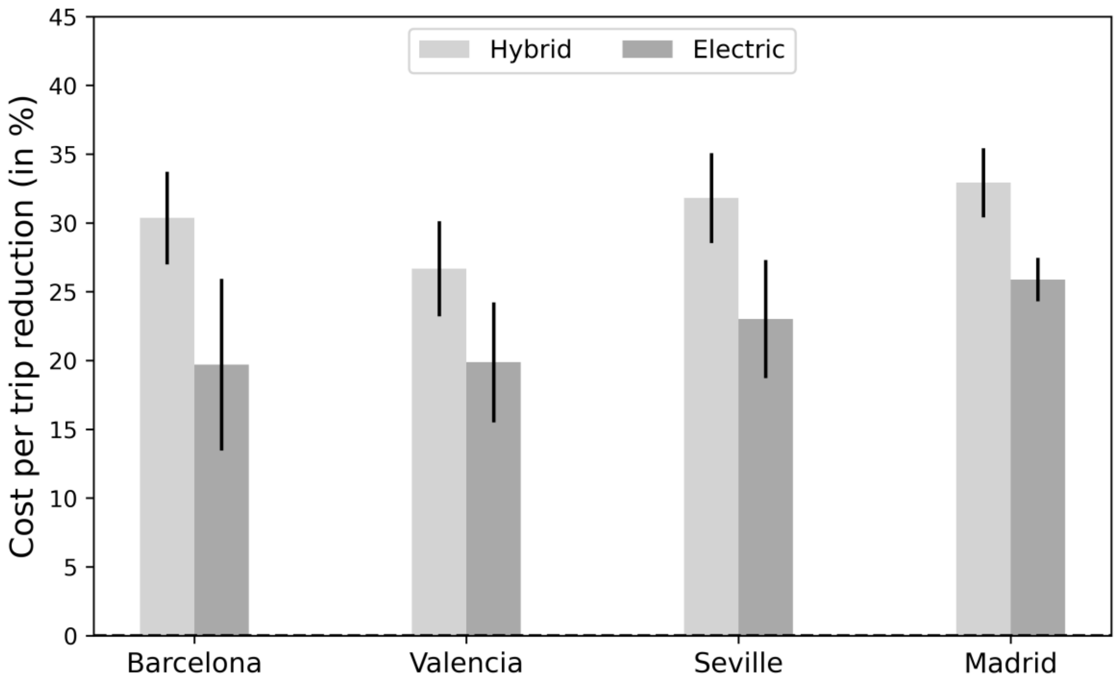
Despite its high capacity and large battery packs installed in the electric buses, they are not able to match the driving range (around 180 km) of a conventional diesel bus (around 400 km). This is due to the high energy density in the liquid petroleum fuels (gasoline, diesel, etc.) due to which they can carry more energy in their fuel tanks as compared to the electric buses. Hence, it can be said that the energy carrying capacity of the electric vehicles must be enhanced a lot to make it capable to achieve autonomy as achieved by a hybrid or even by a conventional diesel bus. Also, to compensate with this fact more charging stations should be installed as the buses will be out of fuel (electricity) more quickly than a diesel bus. But in fact, the number of gas stations are surely more than the number of charging stations. Moreover, the charging time taken by an electric vehicle is much more than the time needed to fill the tank of a diesel-powered bus. This can be also seen in related works published by other researchers across the world [66][67].

3.5. Cost Benefit Analysis

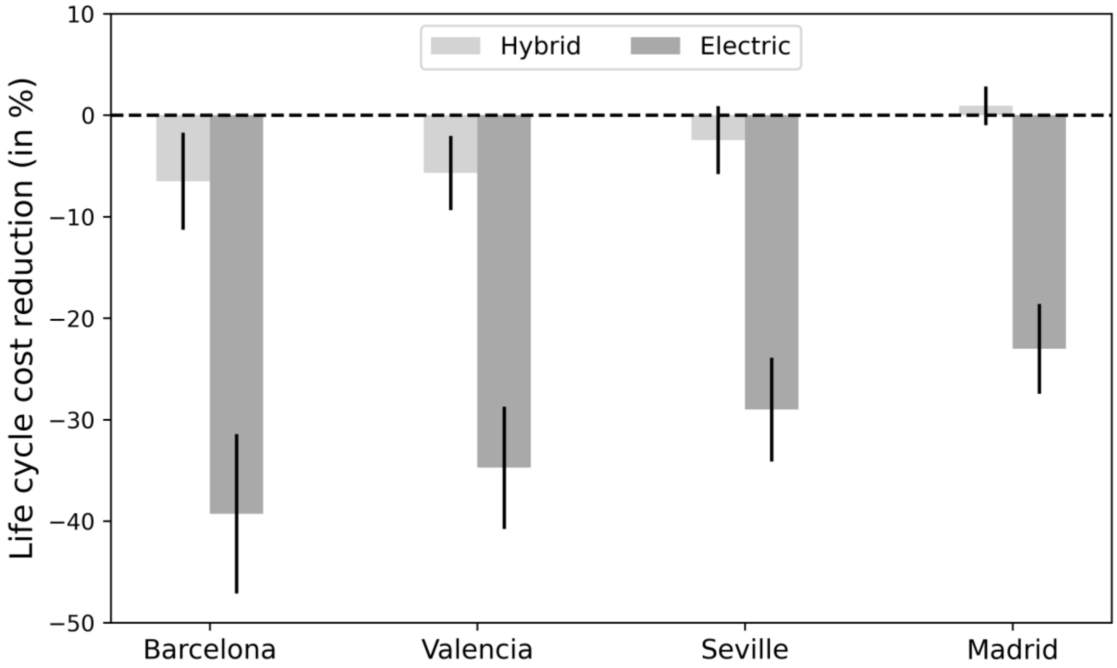
Finally, a cost benefit analysis of the different bus types is done for all the four cities (represented in Figure 10). The energy cost per trip is calculated using the equation (11) and for the calculation of the life cycle cost is calculated using the equation (12)[68]. The equation (11) refers to the price of the energy carrier (fuel or electricity) and the fuel energy consumed respective to that specific bus route for covering every 100 km. On the other hand, in the equation (12) the cost is evaluated considering the cost of each bus model [69][70], cost of the fuel/energy consumed in each of the bus route by each of the bus model and the cost of maintenance involved in the life cycle of each bus type (tyres, coolant, engine oil, etc.).

$$C_T\left(\frac{Euros}{100km}\right) = C_E * EC_F\left(\frac{L}{100km}\right) \tag{11}$$

$$C_{LCA}\left(\frac{Euros}{km}\right) = \frac{C_{Vehicle} + C_F + C_{Main}}{LCD} \tag{12}$$



(a)



(b)

Figure 10: Cost Benefit Analysis; (a) Energy cost per trip (b) Life Cycle Cost, by Hybrid and Electric buses in the 4 cities.

In terms of the cost per trip, shown in Figure 10(a), the average reduction from EBs is around 20% while HBs reduce it almost by 30%. On an average, there is a saving of about 15 euros/100km with HBs and of about 10 euros/100km for EBs. However, for the life cycle cost, shown in Figure 10(b), HBs have merely an average addition of about 2.5% but with the EBs the cost increases by more than 30-35%. These results are heavily dependent on three things: Purchase cost of the three different bus models, the energy consumption of the three different types and the cost of the fuel (diesel/electricity). Hence, as the purchase cost of hybrid and electric buses are significantly higher than the diesel buses, their cost benefit analysis is very much dependent on the energy consumption and the cost of the fuel used in each of them respectively. As the diesel fuel consumption is reduced by the hybrid powertrain it is having almost the same life cycle cost as the diesel, overcoming the high purchase cost of the hybrid buses, compared to the diesel bus. In case of the electric bus the energy consumption is surely reduced heavily, but still due to the high cost involved with electricity (in Europe specifically) the fuel or energy cost reduction is not sufficient to balance the high purchase cost of the bus model, despite lower maintenance costs. This reflects requirement of high investment for choosing the path of electric propulsion for CO_2 footprint reduction. Thus, it can be said that the path of hybridisation will be a much more economical way for the decarbonisation of the BRT networks as it has CO_2 emission savings as well as cost savings advantages. On the other hand, due to the immaturity of the electric technology it is currently very much expensive and faces heavy competition by hybrid vehicles for its cost advantages.

3.6. WTT CO_2 Emissions predictions for 2030 and 2050

WTT emissions are an important parameter that is responsible for the WTW emissions. Figure 11 shows the difference in the WTT emissions for a hybrid bus (dark grey) and electric bus (black) with reference to the conventional diesel bus. It is evident that hybrid buses have an average decrease of about 40% WTT emissions than the diesel buses, while electric buses, on the other hand, have about 30% higher average WTT emissions than the diesel buses, due to the fuel saving obtained from the hybrid buses. While for the electric bus it is significantly higher, as despite having very low energy consumption and being more energy efficient than hybrid or a conventional ICE vehicle, due to the high energy emission intensity in electricity production the Well-to-Tank emissions for Electric buses is exceptionally high. A detailed presentation of these features can be seen in the figure below. The result trends observed in this section is in accordance with that published by other researchers as well [64][33].

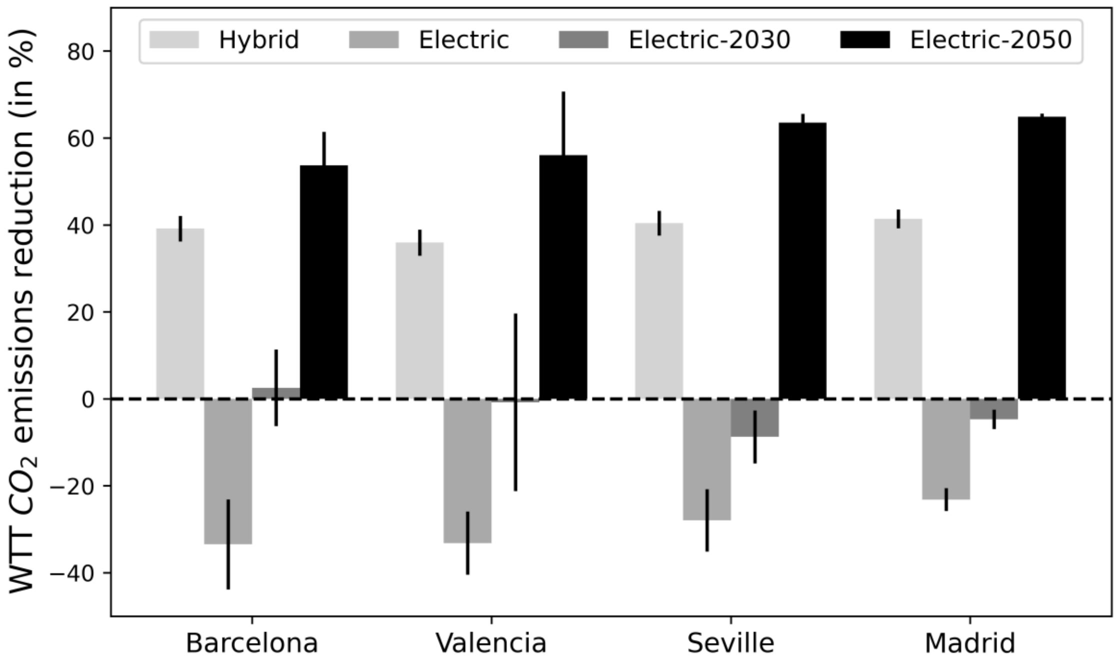


Figure 11: WTT CO_2 footprint reduction (current and predicted in 2030 and 2050) in the 4 cities by Hybrid and Electric buses.

Thus, WTT emissions is an important parameter which must be reduced for the electric buses to make it a strong possibility for future sustainable mobility. The analysis also considers the data for the 2030 and 2050 electricity mix's effect on the WTT emissions for the electric buses' performance in the future scenarios. Figure 11 shows that for saving the WTT emissions EBs will cross the current hybrids only by the year 2050 (dark grey). In the year 2030 too (grey), the emissions value will be quite like that of the diesel scenario. This trend in the result is evident due to the high carbon emission intensity involved in the electricity production for the average European Electricity mix. It is very important to understand that the electricity production source is very important for the evaluation of the WTT emissions, if the source of electricity generation is changed, the whole emission scenario from the EVs will change. For example, if the EV charging of the EVs is done by only renewable sources, it will result in heavy decrease in the WTT emissions, even when compared to a hybrid vehicle as the CO_2 emission upstream for generation of electricity is almost eradicated. Also, with an electricity generation mix of a different region (for ex. USA) the emission values will be changing significantly. Thus, based on the projections for the reduction of the carbon intensity of the European electricity generation for the year 2030 and 2050, this study has been carried out to have a larger and futuristic picture of the well-to-tank emissions, currently as well as in the coming future years.

3.7. Life Cycle CO_2 Footprint Prediction for 2030 and 2050

Like the WTT CO_2 emission evaluation, the CO_2 LCA emissions were also predicted for the year 2030 and 2050 using the approach described in the methodology section 2.4 and 2.5. For the LCA estimation in the years 2030 and 2050, the TTW is still going to be zero due to no involvement of any carbon-based fuel during operation and only electricity consumption. Figure 12 shows that in comparison to the conventional diesel bus, an average reduction of about 40% is obtained with HBs (in dark grey) and a reduction of about 60% obtained with electric buses (in black). This is because the electric buses have higher emissions from the production phase, due to the high share of emissions coming from the battery production of the bus. Further, there is also a significant reduction in the maintenance of the electric vehicles (due to lesser parts involved) yet due to the high carbon emitting process involved in the other phases of the electric vehicles during its life cycle, the emissions are comparatively higher than the values obtained for the well-to-wheel emission values. These results are in accordance with the research data published by other researchers as well [71][13].

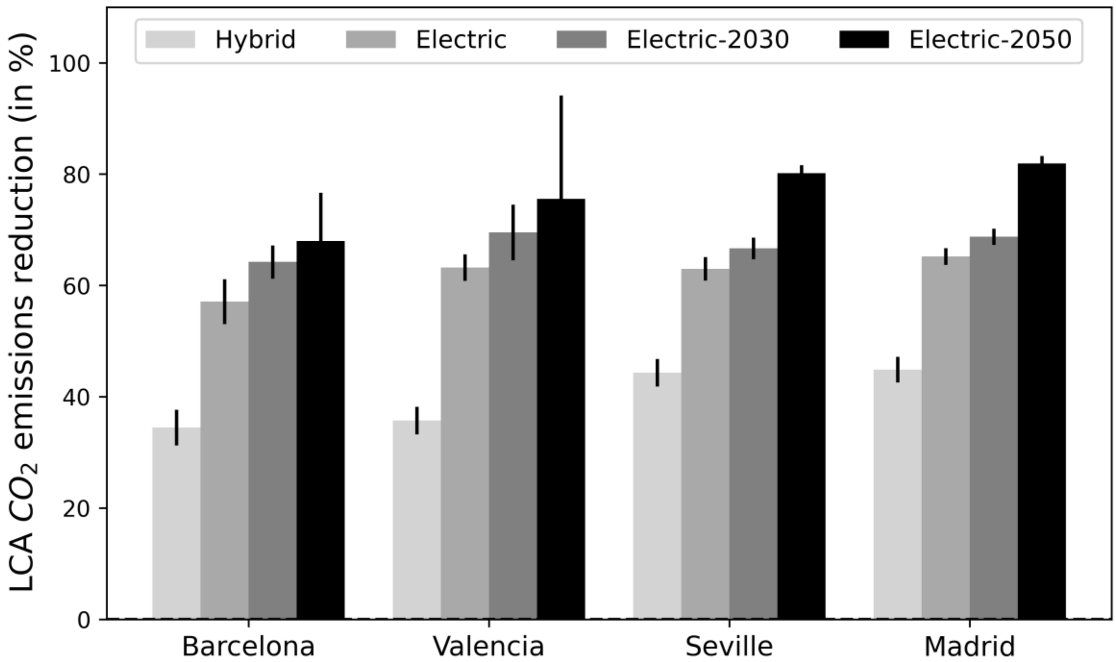


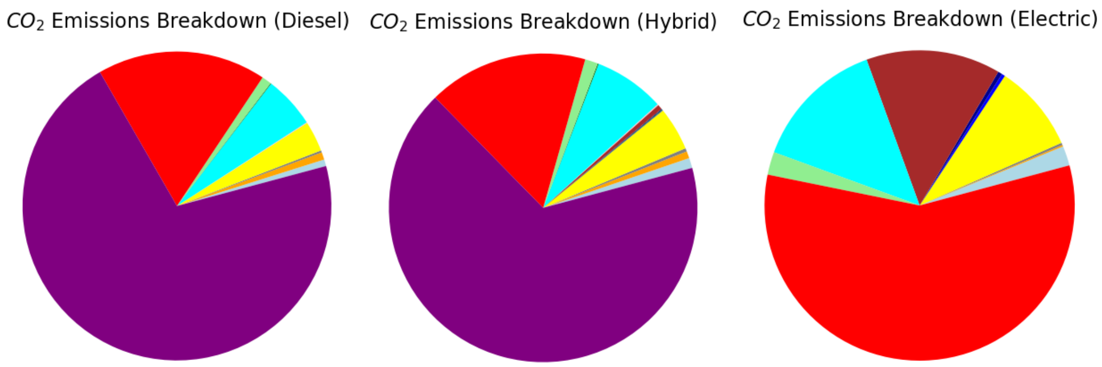
Figure 12: Life cycle CO_2 footprint reduction (current and predicted in 2030 and 2050) in the 4 cities by Hybrid and Electric buses.

In the figure above, the projections for the years 2030 and 2050 are shown in dark grey blue and black, respectively. From the figure, it is evident that by 2030 there will not be much difference in the LCA CO_2 as compared to the current scenario, as light and dark grey bars are around the same range. Only in the year 2050 (in grey), there is likely to be about 80% reduction in the CO_2 life cycle footprint by the electric buses. The main reason behind this trend observed in the Figure 12 is the emissions obtained from the production of the electric vehicles and electricity. The Hybrid buses despite having diesel fuel to power them, are not much behind the electric vehicles for their potential to reduce life cycle emissions, this is mainly because electric buses will result in more emissions during its production and its well-to-tank emissions are significantly high even than the conventional diesel bus. This WTT emissions are mainly due to the current high carbon emission intensity of the EU electricity generation mix, which is expected to be cleaned in the future years. Thus, this study is enhanced to extend to have an estimation of the life cycle emission for the future years of 2030 and 2050.

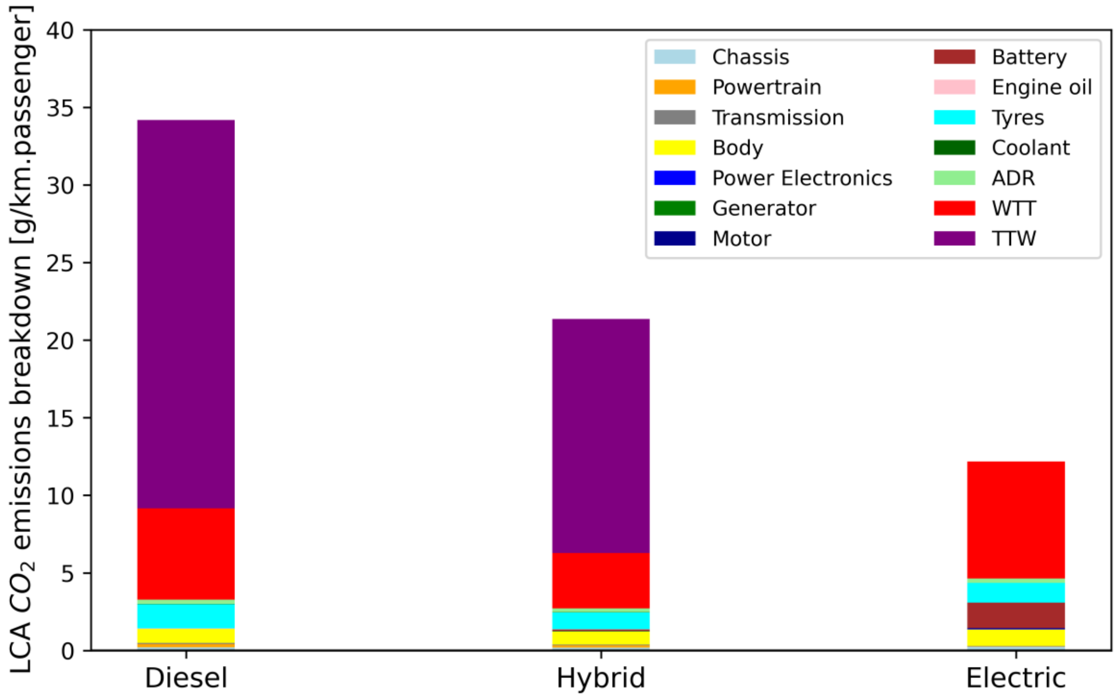
3.8. Life Cycle CO_2 Emissions

Based on the explanation in section 2.4, the LCA CO_2 emissions are calculated using the equation (13)[49] which basically involves the emissions from all the four main phases included in this evaluation for the life cycle estimation. This is done to account all the emissions that will be related to a bus during its entire life cycle from cradle to grave. Thus, the results of the life cycle assessment bring out the overall picture of the emissions coming out from the different powertrains for a more holistic evaluation of CO_2 emission potentials of the different technologies. The well-to-wheel emissions only accounts the emissions from the use phase of the vehicle. But if the climate change or global warming is the concern for the different countries worldwide, then the LCA emissions needs to be accounted for the evaluation of the different powertrain concepts. This is because the global climate is sensitive to all the CO_2 emissions being emitted to the environment in the entire life cycle of the vehicles. and not just while it is in operation. The equation (13) is the representative formula used to have the LCA emissions which is further presented in the Figure 13 .

$$CO_{2\,\mathrm{WTW}} = CO_{2\,\mathrm{P}} + CO_{2\,\mathrm{WTW}} + CO_{2\,\mathrm{Main}} + CO_{2\,\mathrm{ADR}} \quad (13)$$



(a)



(b)

Figure 13: Averaged CO_2 Life Cycle Emissions (a) % distribution by component/phase in the three bus models and in (b) Average emissions (in gCO_2 eq/km*passenger) by each component.

The individual share of each component and phase considered during the life cycle of the three types of buses (as presented in Figure 13) for the LCA CO_2 emissions for each of the four cities are shown below. **¡Error! No se encuentra el origen de la referencia.**(a) shows that other than the WTW emissions, the CO_2 emissions from the electric are much higher than the diesel and hybrid buses. However, in absolute basis the life cycle emissions are around 34 g/km.passenger for DBs, around 21 g/km.passenger for hybrid buses and 12.5 g/km.passenger for electric buses. Thus, Figure 13(b) is the overall summary of emissions calculated from each part and phase involved in the bus life cycle for an average estimation of the CO_2 emission footprint for each of the powertrains: diesel, hybrid and electric. As more than 50% out of the total emissions from the electric bus is due to the WTT emissions, this highlights the need for the reduction of WTT emissions from the electric bus powertrains. Further, it can be also said that to make the electric buses more competitive with the hybrid buses, it should be focussed to reduce the WTT emissions only, as that is the major contributor of the emissions observed from the electric buses. Thus, it can be said that the emission from the Electric powertrains is heavily dependent on the source of electricity production that is used to fuel the bus powertrains. In case the electricity generation is having a significantly lower carbon emission intensity, the WTT emissions, which is the major contributor in the life cycle emissions of an electric vehicle, is reduced there will be a significant decrease in the overall emissions from the electric bus (like in the year 2050, when major source of electricity will be from renewables).

4. Conclusion

A comparative analysis of the hybrid and electric propulsion was carried out to assess their true potential in reducing CO_2 footprint as well as on other parameters such as fuel energy consumption, driving range, and cost benefits in the BRT System of Spain. The analysis included forecasting the performance of the two propulsion technologies in the years 2030 and 2050 to have a better assessment for their implementation in the coming years to decarbonize Spanish BRT networks. The main inferences of the study are given below:

- EBs are significantly more energy efficient mode of transportation as they consume almost half the energy consumed by HBs, and about 1/4th compared to the standard DB.

- Despite being twice energy efficient and installing large heavy battery packs, EBs travels almost 60% less distance than a DB in one full single charge. HBs, however, can extend the distance by about 30%. This makes HBs a better candidate for longer journeys as well as for the heavy-duty goods transportation sector.

- In view of the cost-benefit analysis in comparison to DB, the HBs reduce life cycle costs, but EBs incur additional costs. Also, a comparison of the cost per trip showed that HB is more economical than EB.

- From the point of view of LCA, HBs provides a reduction of 40% and EBs provides a reduction of 60% in CO_2 emissions when calculated in terms of passenger and kilometre travelled.

- Predictions of the LCA CO_2 emissions for 2030 and 2050 revealed that it is only by the year 2050 that the EBs will be capable of decarbonising the BRT systems significantly by 75%. And by 2030, it will remain almost the same as it is emitted currently. Moreover, based on the predictions for WTT CO_2 emissions, EBs currently emits about 25% more CO_2 and only in 2050 it will go ahead of the emission savings that HBs have now.

5. Outlook

From the above points it can be suggested that the BRT networks, particularly in Spain, should currently go for Hybrid Buses to decarbonise its network, and keep the option of electric fleets after 2050. By using the more economical Hybrid buses, the saved resources may later be used as an investment to develop the Electric infrastructure. It is quite likely that by 2050 there may be major advancements in the technologies which can increase the range of the EBs with ultra-high-capacity batteries for dense energy storage, or even very little life cycle CO_2 emissions by the decarbonisation of the overall processes and phases involved in the life cycle of the buses. Hence, the current focus should be to use Hybrid Propulsion to bridge the gap between the current transportation needs and the E-Mobilised world of the future.

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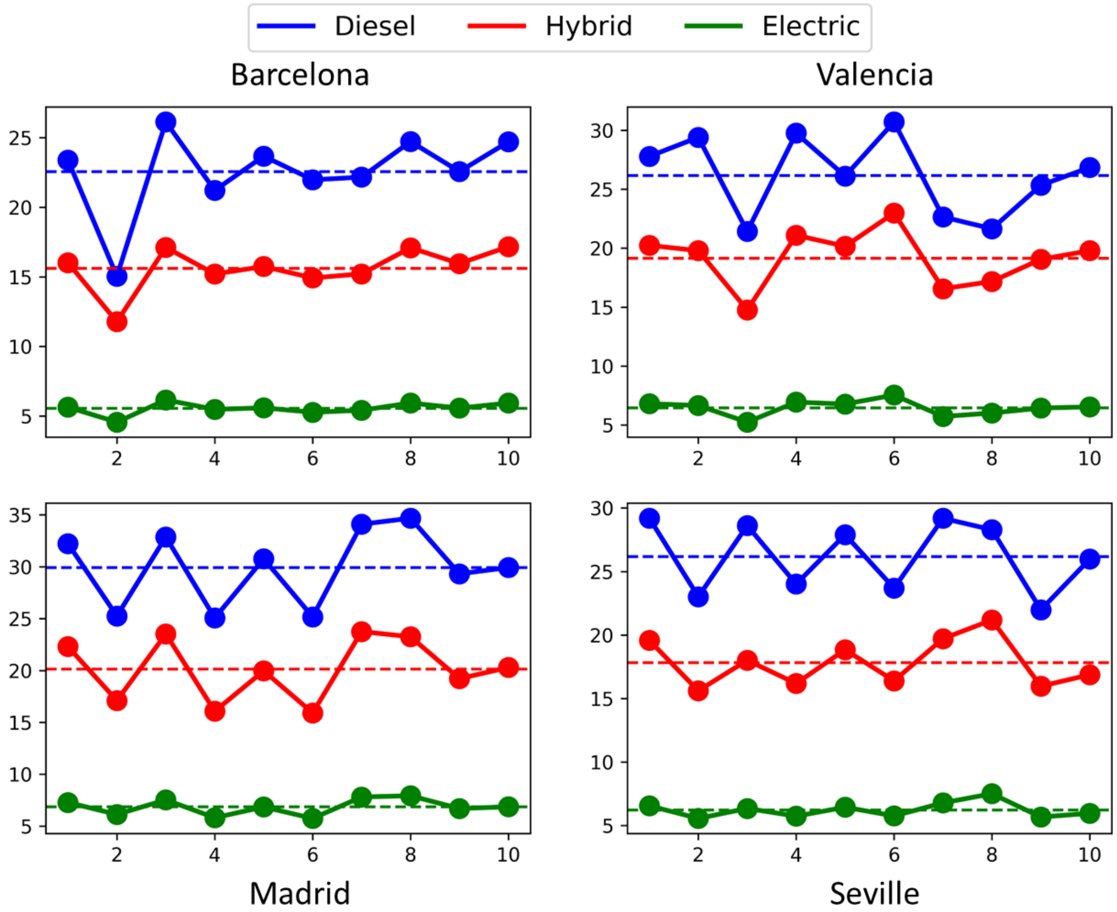
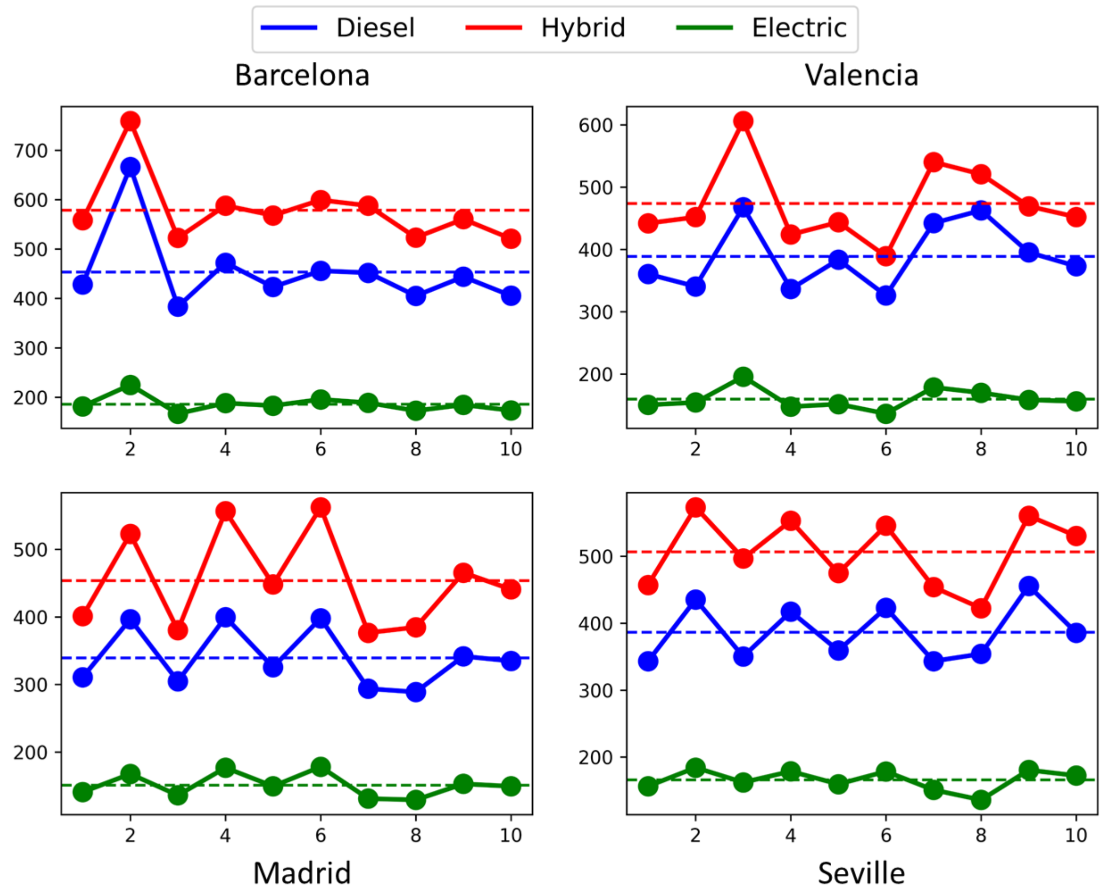
6. APPENDIX

The Cycle-to-Cycle variability in each city is presented below to understand why there is change in the behaviour of the powertrains in the different routes of the different cities:

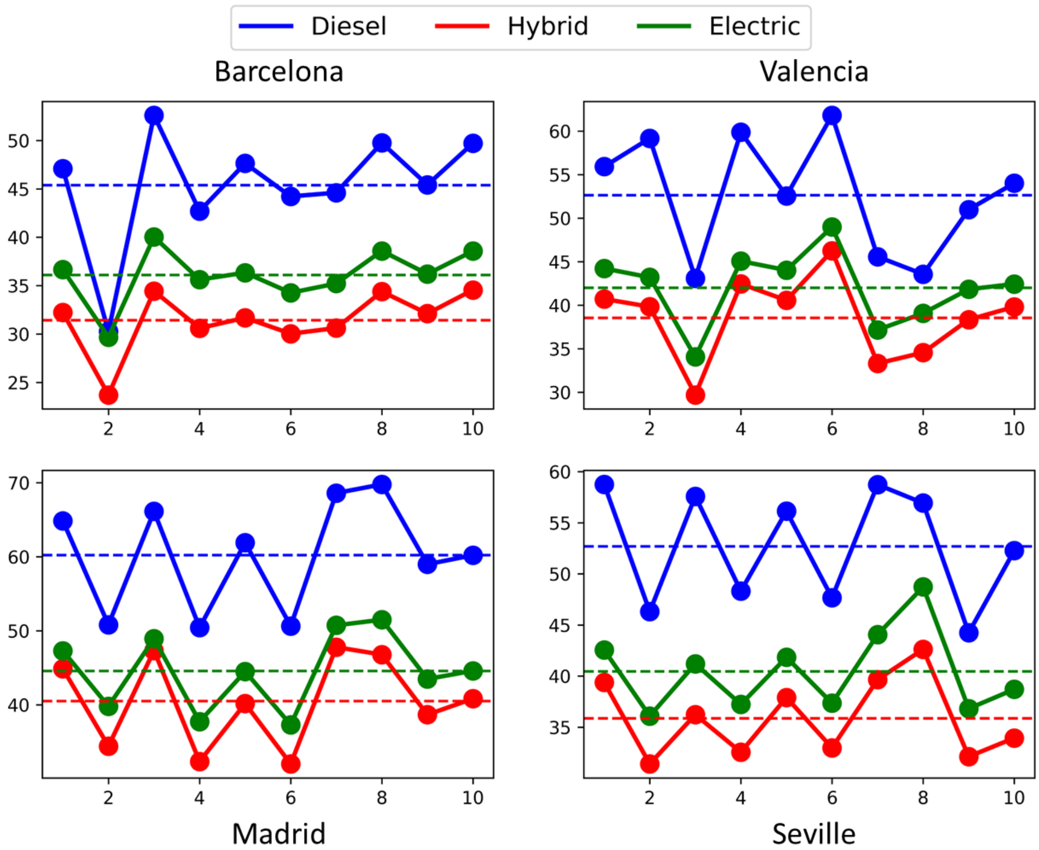
(a) Reduction in the Fuel Energy Consumption (MJ/km) from the different BRT Lines by Hybrids and Electrics can be seen;



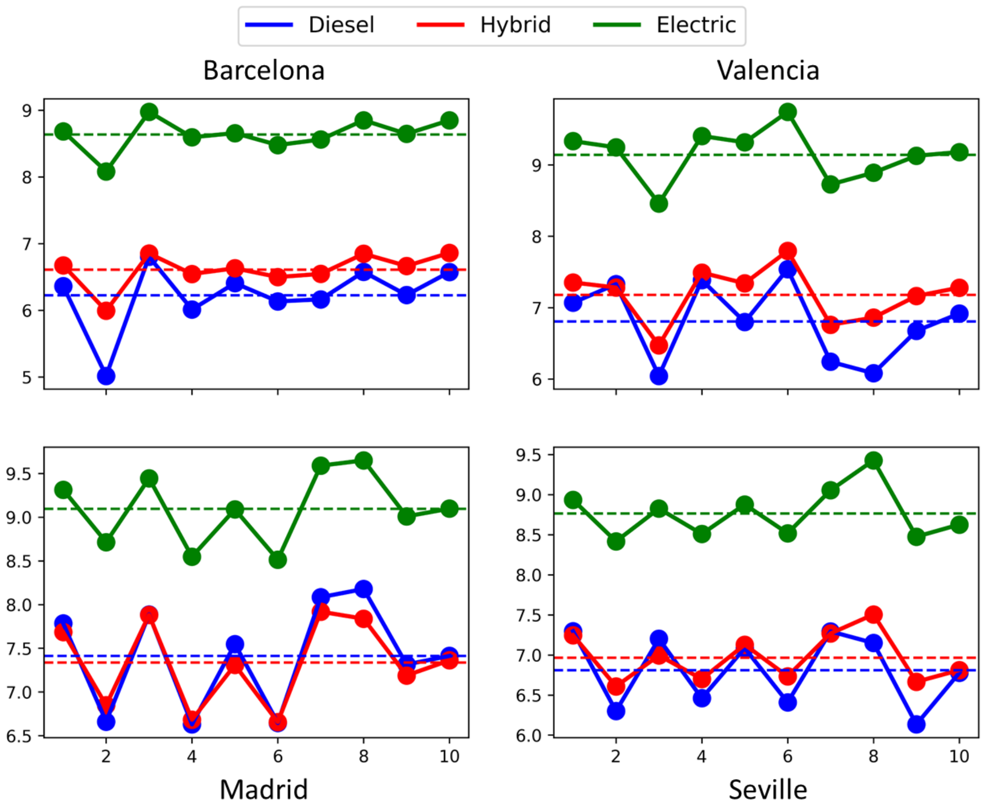
(b) Change in the Autonomy (km) of the BRT buses by Hybrids and Electric powertrains can be observed.



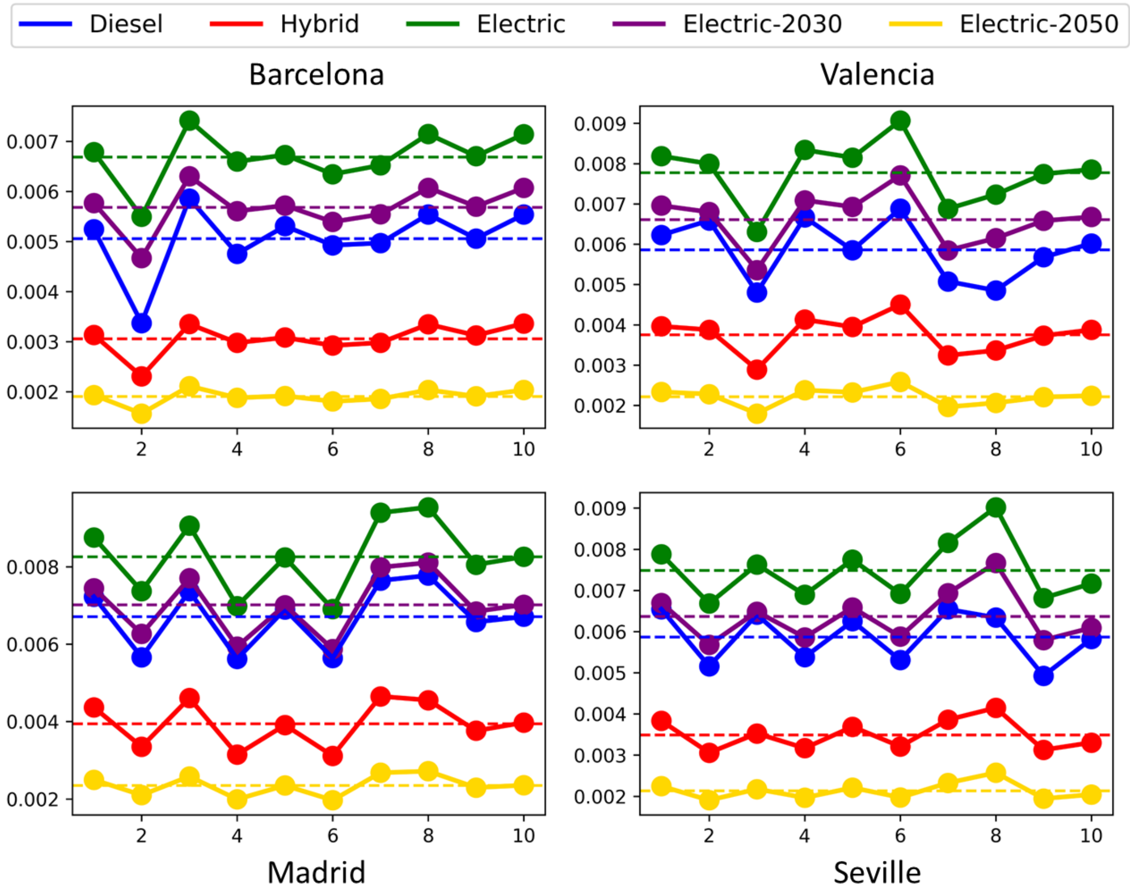
(c) Reduction in the Cost per trip (euros/trip) of the BRT bus lines by Hybrids and Electric powertrains is shown;



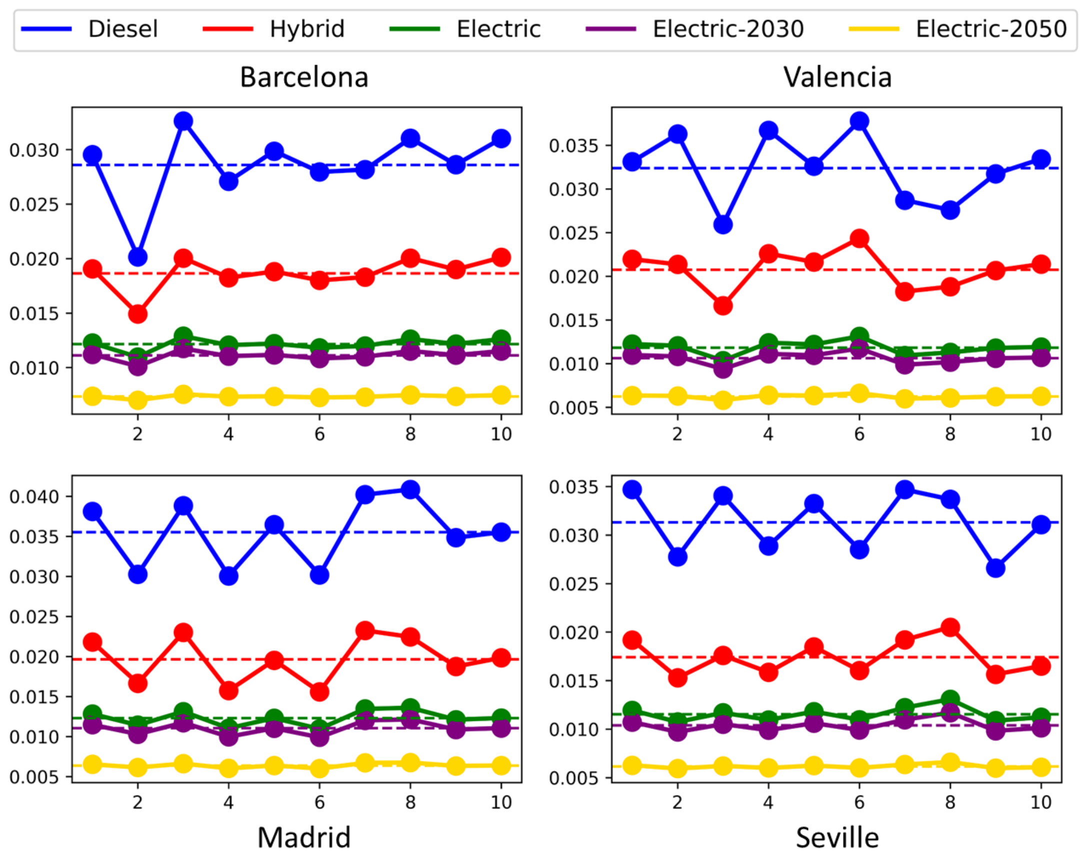
(d) Change in the Life Cycle Cost (euros/km) of the different BRT lines with the use of Hybrid and Electric Buses is presented;



(e) Change in the WTT CO_2 emissions (kg/km.passenger) from the different BRT lines with the use of Hybrid and Electric Buses;



(f) Change in the LCA CO_2 emissions (kg/km.passenger) from the different BRT lines with the use of Hybrid and Electric Buses;



Below we have the characteristic features of the different lines in the different cities. Mainly including; Bus Route, Number of stops, Distance covered and the average speed.

BRT Network		No. of Stops	Distance covered (in kms)	Average Speed (km/h)
Barcelona	B4	39	11.5	9.97
	B12	8	8.4	18.2
	B14	32	8.5	8.85
	B18	13	5.83	12.8
	B20	46	13.74	9.4
	B21	17	6.2	10.3
	B25	40	13.5	11
	B34	32	10.33	10.4
	M6	18	6.93	10.85
	N5	25	7.46	10.7
Valencia	9	25	8.92	10.55
	10	26	7.5	8.02
	19	28	8.33	11.43
	70	32	9.16	9.02
	89	22	5.76	15
	90	19	5.36	9.78
	92	39	11.42	12.8
	93	28	10.3	17

	95	39	12.77	12.06
	99	43	15.4	10.75
Seville	2	27	10.57	7.62
	27	27	10.21	9.25
	32	22	7.13	8.4
	C2	21	10.53	8
	C1	19	8.32	10.32
	13	22	7.05	7.13
	LE	9	9.94	12.34
	LN	11	8.46	8.5
	EA	11	14.76	10.34
	5	28	11.32	10.31
Madrid	34	41	12.74	6.93
	27	27	7.86	9.7
	70	29	10.16	6.4
	C1	32	11.7	7.36
	C2	30	8.97	6.7
	21	35	10.05	6.85
	31	27	8.25	8.69
	28	30	9.36	6.76
	35	39	13.42	8.2
	38	34	11.03	6.55