Chapter

Evolution towards a Sustainable Public Transport in the City of Madrid

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Abstract

This chapter is a vision of the path followed by EMT of Madrid, during 25 years, towards the sustainability, efficiency, and contribution to the air quality in the city, starting from a diesel fleet, until getting a fleet 100% of clean vehicles, mostly GNC, which is already a reality. It shows the evolution and the use, from the practical perspective of an operator, of all the technologies available at each moment (bio-diesel, bioethanol, hydrogen, electricity, natural gas, hybridization, dualisation, start-stop, catalysis, etc.) in Madrid, in a fleet of more than 2000 buses, more than 200 lines, and more than 400 million passengers per year, which makes this case an international benchmark. In addition, EMT is currently at the end of the transition to gas vehicles (CNG) and the implementation of urban electric mobility from the double perspective of the mobile material and the associated infrastructure needed, an essential case study towards sustainable public transport.

Keywords: sustainable transport, bus public transport, air quality, bus fleet, new bus technologies

1. Introduction

Worldwide, cities, with an extraordinary growth of their population, face a challenge in relation to air quality where traffic is a key element. Air pollution is the origin of a large number of deaths per year, greater than, for example, traffic accidents [1]. There are three paths towards a more sustainable transport: the rationalisation of the systems, the substitution of fossil fuels through renewable energies, and energy saving [2].

The energy dedicated to transport exceeds 33% of all used energy and 40% of the emissions. In the Community of Madrid, this amount is even greater due to the high population density and the importance of the service sector [2]. This makes transport one of the main causes to expose the urban population to air pollutants. Therefore, contributing to sustainable and efficient mobility in urban environments is essential for a better air quality and to reduce fuel consumption, loss of time, and waiting times, as well as polluting emissions.

In Europe, significant progress has been made in reducing the main pollutants in urban areas. However, a total of 23 countries exceeded the authorised daily maximum of PM10 particles in 2010 in at least one or more measuring stations [3].

In large urban centres, 66% of NO_x contamination, the most severe for people's health, is produced by road traffic. Buses on regular urban lines generate only 7.5% of this percentage, whereas private cars are responsible for 64.8% of said pollution [4].

Public transport is therefore essential to achieve the objectives of air quality, traffic decongestion, accessibility, and health in cities in terms of mobility [5]. Thus, authors such as Silvia Cruz and Kazt-Gerro [6] analyse the focus on public transport companies as the essential entities for the development of sustainability in the production chain and how public policies, management of economic resources, and the oil market restrict the possible strategies towards an improvement of the environment. In this chapter, we will dive deep into and analyse the strategies and implementation towards the sustainability of the urban bus service in the city of Madrid through the real experiences of the "Empresa Municipal de Transportes de Madrid" (EMT de Madrid).

2. Urban public transport on surface: EMT Madrid

EMT Madrid is a public limited company owned by the Madrid City Council that deals with urban bus transport in the capital. It is also entrusted with the management of other tasks related to mobility in the city, such as the city's tow truck, a part of the public car parks, the cable car, and the public city bike system, as well as an international consulting area.

The company was founded in 1947 to meet the demand for transport in Madrid. Currently, it is one of the most important urban transport companies in Europe in terms of fleet size, number of transported passengers, or technological innovation. More than 420 million passengers are transported annually and 95 million kilometres are covered in its 213 regular lines, of which 26 provide a night bus service. It employs more than 9300 workers and manages the city's 88 tow trucks, its 6 impound sites, and 24 of the city's car parks with almost 11,000 parking spaces [7]. Likewise, it has 5 operation centres from which the fleet is supplied and

Figure 1.
Madrid and the distribution of its five operation centres.

maintained (**Figure 1**). More than half of this fleet is powered by compressed natural gas (CNG), and there are more than 80% of low emission buses. The average age of the bus fleet is 7.13 years (2018) and this figure is expected to continue decreasing in the coming years.

EMT has made a firm commitment in recent decades to be a sustainable company that takes care of the environment. The activity of the EMT makes it a key tool for sustainability and improvement of the Madrid environment.

3. Practical experience

According to UITP (International Association of Public Transport), approximately 80% of all public passengers worldwide are transported by bus [8]. Beyond the different developments in the bus system, there is no consensus on the most effective strategies [9]. In spite of everything, studies have been carried out relating to urban planning, mobility, air quality, and pollution by emissions and the connection of these elements with variables such as the average speed, the frequency of the bus service, and the bus system network to reduce these emissions [10]. Some of the studies that take into account fuel efficiency, traffic congestion, taxes on coal, and improvements in public transport conclude that a mix of strategic measures for public transport is the best option towards a sustainable environment [11]. Thus, the performance in infrastructure (either through BRT or exclusive bus lanes), electric vehicles or those running with new sources of energy such as natural gas and its positive impact on the drastic reduction of NO_x [12], the application of technology for service improvement [13] and user information or route optimization, international research, and development or service improvement are some of the most important strategies, which are developed in the bibliography [13].

It is clear that depending on the size of the city and the conditions of the environment, the strategy to be implemented will differ from one case to another. In the following, the real experience of EMT Madrid in the last decades is shown, acting in a transversal way simultaneously and synergic in all of EMT's activities. Thus, separate experiences are shown in operation and road infrastructure, mobile material (buses), the personnel and the facilities, and infrastructures, which are necessary for the operation (operation centres: refuelling, workshops, etc.) according to **Table 1**.

3.1 Operations and infrastructures in the street

3.1.1 Redesigning bus lines and sustainable mobility in the city

EMT within the scope of its competencies as an operator continuously performs a study of the bus lines in service. In 2018, more than 68,123,000 kilometres were studied, analysing the quality offered, the evolution of regularity, and the occupancy levels at peak hours; monitoring the basic service variables, the evolution of the urban fabric, and the demands of lines (individual and aggregate); and checking the programmed speed with the actual operating speed on a three- or four-month basis.

In this sense, the technology based on GIS (geographic information system) is being improved to improve the planning and exploitation of transport as well as the construction of the infrastructure for analytical models based on big data with new calculation of multimodal routes (bicycles–bus–on foot–parking lots). But it also strives to optimise the bus models of each line according to the environmental

Strategies for a sustainable transport-EMT case study	About operations and road infrastructure	• Redesign of bus lines and sustainable mobility in the city
		• Implementation of bus lanes and their control
	About the mobile material	• Establishment of vehicle acquisition criteria
		• Exhaust gas treatment
		• Start-stop system
		• Compressed natural gas (GNC) buses
		• Electric transmission
		• Fuel cell (hydrogen)
		• Hybrid buses
		• Electric minibuses
		• Recharging opportunity
		• Electric buses
	About EMT staff	• Training with driving simulators
		• Efficient driving
		• EMT staff transport
	About infrastructure design	• Energy saving and environmental certification
		• Adaptation of operation centres
		• New operation centre 100% electric
		• Public access charging points for electric vehicles

Table 1.
Strategies for sustainability in transport-EMT case study.

conditions of the area through which they pass or redesigning them ensuring the same service (speed, stops, and safety) producing the least possible contamination.

The ECCENTRIC project (CIVITAS H2020 funded by the European Union) aims to implement sustainable mobility solutions in peripheral areas of the city including public transport. EMT participates as a partner being responsible for the administrative coordination that directly impacts on the rethinking of the sustainable model. In this sense, EMT is also developing the MaaS (Mobility as a Service) project as an application that integrates and visualises the different mobility options to go from one point to another in the city at any time. International projects such as IMOVE are there to support the deployment and improvement of MaaS in Europe with innovative solutions.

The Dynamic Mobility Management project tries to implement this improvement for the planning and management of the urban bus service operations by assigning traffic and public transport that allows modelling scenarios and situations by analysing the impact different measures may have on mobility, on the transport network, and on the air quality of the city of Madrid, with the combination of own and external data such as telephone data or mobility apps. The functionality in the forecast of pollution episodes, the simulation of new scenarios, and the adaptation of supply to demand in a more agile way will allow greater flexibility and adaptability of the entire public transport system in Madrid.

3.1.2 Implementation of bus lanes and their control

BRT and exclusive bus lanes are a very common measure to prioritise and improve the speed of urban bus transportation. In this sense, EMT currently has 34,735 kilometres of road axes with bus lane separators, growing progressively and allowing the improvement in the quality of the service provided and the optimization of operation reducing fuel consumption and emissions that are linked to it. In 2018, in Madrid, a total length of more than 1.5 kilometres per direction was implemented with more than 395 separators and 260 beacons.

These lanes are at the same time controlled by EMT staff with contamination-free electric vehicles (SACE).

3.2 Bus fleet

The EMT fleet has undergone a continuous change in the last decades as shown by the example in **Table 2** that represents the evolution in the last 15 years, but that will be better understood when analysing each of the experiences and tests made in these years.

3.2.1 Establishing vehicle acquisition criteria

In the middle of the nineties, the division of "Definition of Bus Fleet" was created allowing the development of a list of conditions for the acquisition of buses with all the characteristics and conditions that must be fulfilled in order to minimise the energy consumption of vehicles and emission levels. In addition, the acquisition criteria are aimed at using clean energy and contemplating the quantification and assessment of emissions during the life cycle of the vehicle. This inclusion in the EMT documents was done long before the European legislation indicated it, not only taking into account the cost of acquisition. In this sense, EMT is integrated in the working groups related to bus fleet and the purchase of buses with the UITP with the idea of integrating and creating synergies sharing good practices at an international level.

3.2.2 Exhaust gas treatment

The bus fleet has been mainly diesel until 2016, so the emission reduction focused on finding alternative fuels and on changing the existing buses of the EMT

Año (31-12)	Gasoleo	Dual Fuel	GNC	Etanol	Transm. eléctrica	Electricos	Hidrógeno	Hibridos	Flota	Flota alternativa
2004	1789		155		20		4		1968	179 9,10%
2005	1802		165		20		3		1990	188 9,45%
2006	1793		201	5	20		3		2022	229 11,33%
2007	1647		351	5	20	10			2033	386 18,99%
2008	1634		381	5	20	20			2060	426 20,68%
2009	1670		393	5	12	20			2100	430 20,48%
2010	1603		465	5	3	20		4	2100	497 23,67%
2011	1415		651	5		20		4	2095	680 32,46%
2012	1234	1	723			20		22	2000	766 38,30%
2013	1088	1	767			20		27	1903	815 42,83%
2014	1090	3	767			20		27	1907	817 42,84%
2015	1091	3	767			20		27	1908	817 42,82%
2016	1068	3	799			18		27	1915	847 44,23%
2017	928	3	1019			23		52	2025	1097 54,17%
2018	629	3	1334			36		48	2050	1421 69,32%

Table 2.
EMT fleet evolution 2004–2018.

fleet. Thus, in order to reduce the contribution of urban transport to NO_x pollution, in addition to using fuels that produce it in smaller amounts, it became necessary to implement exhaust gas treatment systems in buses that were already in service, using oxidation and reduction catalysts to eliminate both the particles and the NO_x.

Between 2012 and 2014, 510 catalysts were installed in diesel buses to improve their emissions. These elements make buses that were originally approved according to the Euro III emission regulations to emit exhaust gas at levels lower than those seen in the Euro V Standard, with which the Low Emissions Zone of Madrid was fully served by low-polluting buses.

3.2.3 Start-stop system

The start-stop systems achieve a saving in fuel consumption and a reduction of polluting emissions, stopping the combustion engine when it is idling due to a stop of the vehicle. The system is activated at traffic lights and at passenger stops, as well as in other traffic conditions that involve stopping the vehicle for a certain time. They allow, therefore, having the heat engine turned on only when the bus is in motion.

A bus, running in Madrid, travels an average of 200 km per day and performs about 50 stops (more than 5 seconds) per hour, standing in each of them about 28 seconds during 15 hours a day, which accounts for almost 40% of the total work time. Since the fuel consumption at idle is 0.5 g/s, a fuel saving of 10.5 kg of diesel per day is achieved, that is, an 8% decrease, similar to the reduction in pollutant emissions [14, 15].

3.2.4 Compressed natural gas (CNG) buses

EMT has been one of the first companies in Europe to use CNG as a fuel for urban buses, receiving the National Environmental Award for this strategy in 1998, although other companies such as New York, Melbourne, or Paris are also starting on this way.

In 1994, EMT began its experience in the use of CNG as fuel by participating in the ECOBUS Project of the European Union, under the umbrella of its THERMIE programme. After the success of this project and the results obtained by being one of the cleanest fuels that exist, being compatible with diesel technology, being assured of its regular supply, having a stable price, and being an alternative to oil, EMT of Madrid decided, as of 1995, to introduce the use of CNG as a new fuel into its fleet. In that year, the first compressed natural gas station with a capacity for 20 buses was implemented, charging them in about 3 hours. Since then, the number of buses in the fleet powered by CNG has gradually increased and, consequently, the size of the charging facilities, which have grown in power, efficiency, and speed of charging. Today, the refuelling is carried out by charging stations using powerful compressors that supply fast filling stations in 3 minutes (**Figure 2**).

As it is currently the best alternative to diesel from the environmental and economic point of view, EMT, from 2010, took the decision to adopt CNG as the basic fuel of its fleet, so that all buses that were acquired should use alternative energy to diesel and be CNG, hybrid, or electric.

At the end of 2018, more than 80% of the fleet was considered green (this is those that comply with the Euro V standard or higher, CNG, electric, or hybrid vehicles). It is planned that by 2020 the entire EMT fleet will be CNG, as well as a small number of electric and hybrid vehicles. In all the operation centres, CNG refuelling stations are already available, with a centre entirely designed for CNG buses (Sanchinarro) (**Figure 3**).

Figure 2.
First GNC bus in 1994 and first charging station of 20 GNC buses.

Figure 3.
New bus fleet.

EMT's use of this type of buses has meant a reduction of 75% in NO_x emissions and 95% in particles, while the advance of diesel technology has allowed an average reduction of 55% NO_x emissions and 80% of particle emissions in the same period.

3.2.5 Dual-fuel project

Compressed natural gas (CNG) has economic and environmental advantages over diesel. For this reason, EMT has been interested in a dual-fuel technology, which allows natural gas to be used simultaneously with diesel fuel, in diesel buses [14, 15].

The dual-fuel (or shared combustion) technology can be defined as the simultaneous combustion of two fuels; in this case, natural gas is used in combination with diesel to operate the diesel engine. In urban transport, percentages of 50% diesel and 50% natural gas can be reached. Once the modification has been made, the engine can operate in dual-fuel mode or exclusively with diesel, but in no case with natural gas exclusively.

The use of the mixture of natural gas and diesel significantly reduces the emissions of polluting gases, which depend on the engine's operating conditions and the substitution levels of diesel that are reached. Assuming typical substitution levels of 50%, CO_2 reductions are between 10% and 15%, particle reductions can reach 50%, and NO_x levels are between 35 and 65% [16].

In addition, by replacing a part of diesel with CNG, which is cheaper, there is an economic benefit that allows the return of the investment and makes the project economically viable.

3.2.6 Electrical transmission

In the year 2000, a fleet of 20 electric transmission vehicles was put into service to run in the city centre. These were vehicles of medium length (9 m) that had an electrical transmission consisting of a generator, power electronics, and an electric motor, in addition to the auxiliary elements that this entails, instead of the traditional mechanical kinematic chain (clutch and gearbox). However, the energy is still supplied by a diesel thermal engine, does not carry energy, and does not recover braking energy.

The performance of the electric kinematic chain was superior to that of the mechanical chain, which results in savings of fuel and emissions of 10% compared to a conventional vehicle of the same size that performs the same type of service. Likewise, the comfort of the passengers improves when increasing the smooth running of the electric motor (**Figure 4**).

3.2.7 Fuel cell (hydrogen)

EMT participated during the 2003–2005 period in the CUTE/ECTOS and CITYCELL projects, consisting of the start-up of electric buses equipped with a fuel cell. This type of buses uses hydrogen as the primary energy vector, generating the electric energy necessary for traction and producing water vapour as the only by-product [14, 15].

When participating in the two projects, EMT Madrid was the only company that had, simultaneously, 4 fuel cell buses in service.

Project Cute: It consisted of 3 Mercedes Benz buses with a 205 kW fuel cell working in the full power mode, that is, producing electricity at the time it was needed, without accumulation and working on a transitory basis (**Figure 5**).

Project Citycell: It consisted of 1 IVECO bus, with a 62 kW fuel cell, functioning as a hybrid vehicle, with storage batteries and working in stationary mode (**Figure 6**).

It was shown that the fuel cell technology is viable in urban transport, with zero emissions of exhaust gases and very low noise pollution, but also showing that it is necessary to increase the autonomy and reliability of vehicles and charging stations, as well as how to create a hydrogen distribution network.

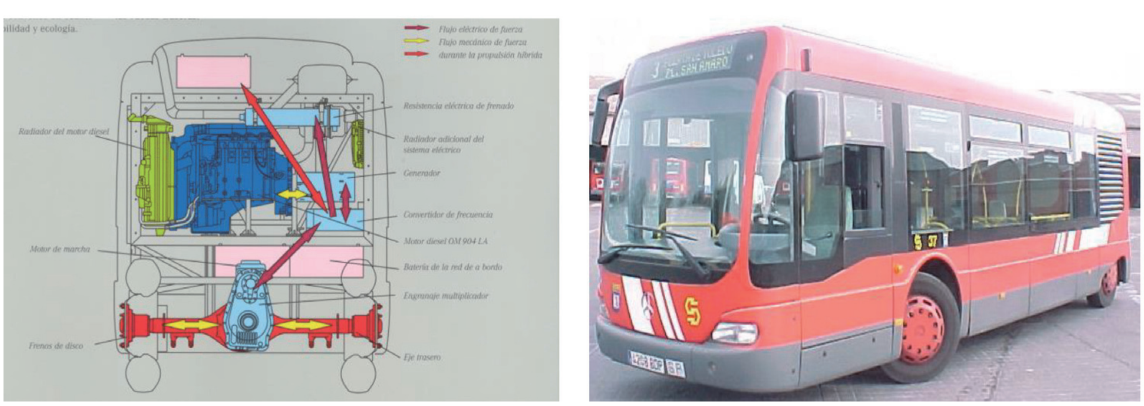

Figure 4.
Electrical transmission bus.

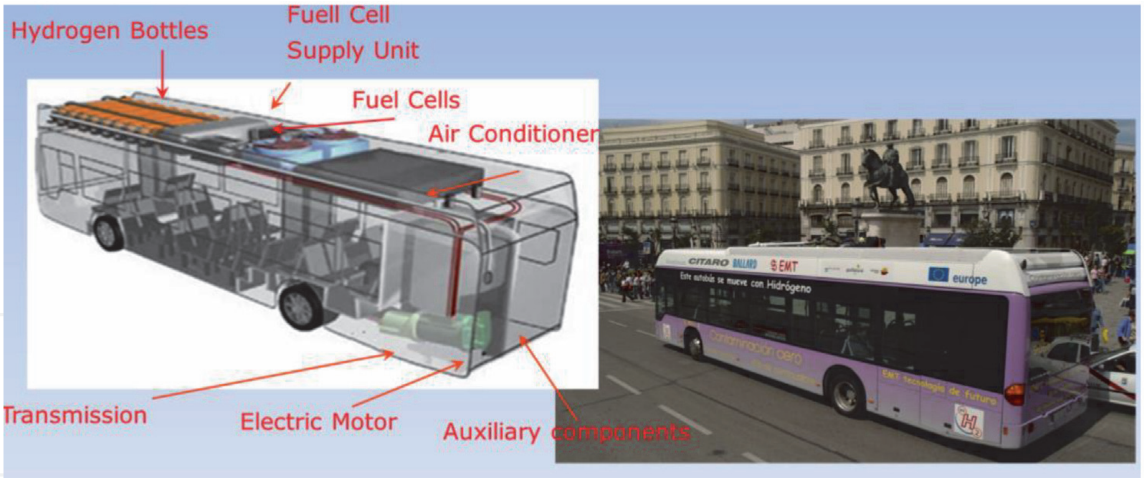

Figure 5.
Hydrogen bus.

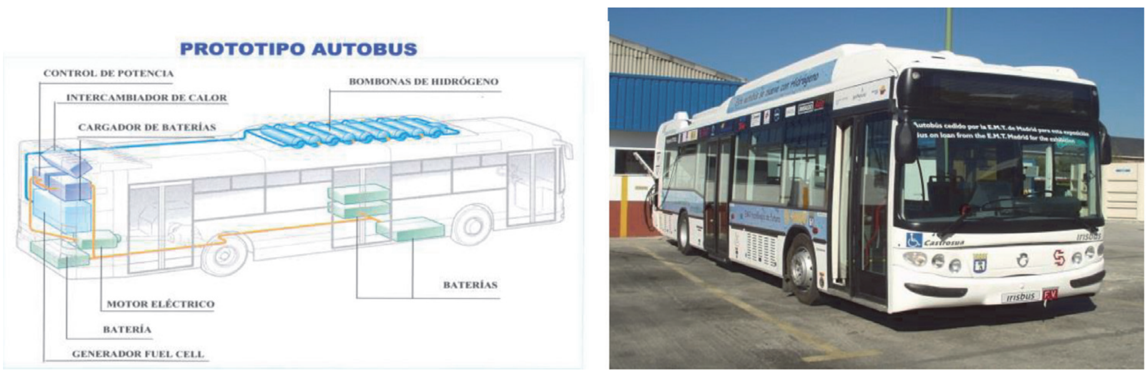

Figure 6.
Hydrogen bus, Citycell.

3.2.8 Hybrid buses

The need for sustainable transport in today's society is beyond doubt, as well as that electricity will be the driving power of the future. But, with the current state of energy accumulation technique, buses have problems of autonomy to perform the usual daily service if pure electric propulsion is used, having to resort to intermediate recharges in their working day.

Due to this, the use of buses with hybrid propulsion, by means of the use of thermal and electric motors, and with energy accumulation systems, has become general and will be essential during the transition period from buses with current thermal engines to the purely electric buses of the future.

With hybrid propulsion, it is possible to run with electric traction, energy sourcing from the accumulated energy for a certain time, recharging these accumulators when necessary through the thermal engine, thus achieving the required autonomy, fuel savings, and a reduction of polluting emissions.

In urban transport, depending on the employed control strategy, hybridisation can be used as a tool to improve air quality in the city, allowing the operator to decide when the bus is running in pure electric mode (for example, in the ZBE), thus contributing to the local reduction of emissions (**Figure 7**).

3.2.9 Diesel hybrid

In 2016, EMT acquired 30 hybrid diesel buses, 17 from MAN, equipped with ultra-capacitors, and 13 from IVECO, both with non-pluggable batteries. These

Figure 7.
Hybrid buses.

vehicles are used to run in specific lines in the east of the capital and are included in the European project ECCENTRIC, which aims to implement sustainable mobility systems integrated with urban planning. The savings in fuel and, consequently, emissions and CO_2 are between 30% and 35% compared to a conventional propulsion vehicle.

3.2.10 GNC hybrid

EMT asked the bus manufacturers Castrosua and Tata Hispano to develop a hybrid bus powered by natural gas and thus emerged two models of CNG hybrid buses of which EMT has acquired 23 units, 10 from Tata Hispano and 13 from Castrosua, being the first CNG hybrid buses to be marketed in Europe.

The consumption and the CO_2 emissions have been reduced between 28% and 35%, in comparison with the values of a CNG bus and up to 70% emissions of NO_x and PM with respect to a diesel vehicle.

3.2.11 Converted buses

EMT Madrid participated, together with TMB Barcelona and EMT Valencia, in the Electrobus Project, with financing from the Institute for Diversification and Energy Saving (IDAE), consisting of the conversion of diesel buses into hybrid diesel-electric buses. In 2011, a conversion of 4 Iveco CityClass Euro III diesel buses was carried out on electric diesel hybrid buses, which have reduced their diesel consumption and their emissions by 18% compared to conventional propulsion vehicles.

The transformation consisted in the elimination of the gearbox, the installation of a 180 kW electric generator driven by the original thermal engine, the incorporation of two tandem electric traction motors, each with 67.5 kW of power, and the incorporation of control and auxiliary elements such as inverters, radiators, or a steering pump.

As energy storage elements are installed, 6 units of supercapacitors, with a total voltage of 750 volts and a capacity of 10 farads, are put on the roof area.

3.2.12 Biofuels

In addition to all the above, EMT has carried out different projects and pilot tests with biofuels (reduced percentages of biofuels with diesel) from the Bio-Bus prototype (1997–1999), and the following projects and trials were carried out:

The BD5 biodiesel trial was developed from November 2003 to March 2005 with four buses equipped with a Euro III engine running over 260,000 kilometres. The biodiesel used was a BD5 with 5% methyl ester derived from sunflower oil. There were no problems in the bus injection system, having correct values of the analysis of filters and oils used. There is no significant increase in consumption of buses that use diesel as fuel (**Figure 8**).

Figure 8.
Biodiesel bus: Bio-bus.

Project Biodiesel EHN 100%: the specifications of Euronorm 14,214 and RD 1700/2003 were followed. It was used pure without mixing with diesel oil, from vegetable oils of first use and a mixture of different types mainly soy, sunflower, rapeseed, and palm. The tests were made between June 2005 and October 2006 on 6 vehicles: 4 Euro II (two Mercedes O/405 and two Iveco CityClass Cursor all from 1998) and 2 Euro III (Iveco CityClass Cursor 2002). They made more than 300,000 kilometres, not seeing an increase in breakdowns in the injection and power systems compared to the rest of the buses of the same model and year. There was a slight increase in fuel leakage failures in the Mercedes model (7 years old).

Project Biodiesel CLM: 20% supplied by Biodiesel Castilla La Mancha obtained by mixing 20% of methyl esters of vegetable oils from the recycling of used oils with 80% conventional diesel. The test was carried out from August 2005 to September 2006 in 6 buses: 3 MAN NL-263F of 2003 and 3 IVECO CityClass Cursor of 2004. These buses made more than 300,000 kilometres, and there were no breakdowns in the systems, injection, or supply.

Biodiesel test invariable proportion: a third test was carried out on a MAN Nl-263F of 2003 from sunflower oils of first use, testing the benefits and the consumption with biodiesel varying the proportion between 20 and 100%. This bus covered more than 40,000 km between January and December 2005 without specific problems, or breakdowns in the power system, although there was an increase in consumption and power decrease that increased with the proportion of non-linearly used biofuel (**Table 3**).

Biofuel in the entire fleet: in October 2006, the use of large-scale biofuels was started in all diesel cars in a depot of EMT (Fuencarral A) with 20% biodiesel and mixing directly in the EMT storage tanks. The fleet's study objects were 150 IVECO CityClass Euro II, 30 IVECO CityClass Cursor Euro III, and 30 Mercedes O/405 N (Euro II).

3.2.13 Electric minibuses

Since 2007, EMT has had 20 Tecnobus electric minibuses, model Gulliver, that provide service in two lines that run through the narrow streets of the historic centre of Madrid, within the ZBE. During its journey, the environmental conditions are not altered by emitting any polluting gas and it only produces the dull rolling noise of the tyres on the asphalt. These small vehicles, 5.5 m long, work with the energy stored in two Ni/NaCl accumulator modules, 72 kWh at 85 V. The weight of each module is almost 300 kg and they are located in the rear of the vehicle.

Types of biodiesel		Increase of average consumption
BD5		1.54%
CLM 20%		4.50%
EHN 100%		7.50%
Variable	100% bio	9.90%
	50% bio 50% diesel	6.50%
	30% bio 70% diesel	6.30%
	20% bio 80% diesel	4.40%
B20 (entire fleet)		3.54%

Table 3.
Types of tested biodiesel and increase in average consumption (adapted from Terrón [17]).

The electric motor that moves the bus, front-wheel drive, has a maximum power of 27.2 kW, reaching a maximum speed of 32 km/h. This achieves a commercial speed of 6 km/h, a satisfactory figure given the characteristics of the streets through which it runs. This has saved about 6000 litres of diesel fuel per minibus per year, which would have been consumed in the case of this transport with conventional vehicles, with the consequent reduction pollutants and greenhouse gases.

There is also another electric minibus, Breda model ZEUS, for internal and institutional transport.

The electric minibuses have been replaced in full between 2018 and 2019 by 18 electric minibuses of the Wolta model of the manufacturer Microbuses de Lujo SL (**Figure 9**).

3.2.14 Recharging opportunity systems

Since the electric buses, which currently exist in the market, do not have the required autonomy, it is necessary to replace them in the middle of their working day with others, that are already charged, or to use intermediate charging systems during their service called recharging opportunity systems. These recharge the vehicle partially, on the line itself, usually in its terminals. In this way, by means of

Figure 9.
Electric minibus.

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successive recharging during their working day, their autonomy increases indefinitely.

The recharging opportunity can be carried out by conductive charging, by contact, generally with a pantograph that is installed in a more or less visible structure; or with the newest and least visible system of recharging-by electromagnetic induction, without physical contact between the vehicle and the charging terminal, carried out by means of a primary coil on the underside of the bus and a secondary coil under the pavement of the road. During the time the vehicle remains at the final destination of each trip, the batteries are charged without any other human intervention than placing the vehicle on the loading area. This allows the use of a safe and fast charging system, eliminating visual pollution in the city and extending the autonomy of the bus indefinitely. It is a very interesting system for specific lines that enter certain sensitive areas of the city, since it enables the electric mobility of the bus without any autonomy problems.

EMT has recently (in October 2017) implemented a line of electric buses with recharging opportunities by induction. Previous experiences allow ensuring a system efficiency of 95%, leading to savings higher than 15%, since there will be no empty trips due to the lack of autonomy of the vehicles. In addition, due to the recharging opportunities, the number of batteries installed on board of each bus can be lower, having a lower consumption per unit. Thus, there is already one line (line 76 of Madrid) that consists of high-power recharging opportunities on a route that connects an outer neighbourhood of Madrid with the city centre, where the existing buses are replaced by zero-emission vehicles whose retrofit stems from an investment in R&D converting a hybrid bus with CNG to 100% electric vehicle with induction charging, little on-board energy, and little autonomy, which is charged in each terminal (**Figure 10**).

3.2.15 Electric buses

EMT believes that the future of urban transport, in the long term, passes through electric mobility, which will be the only one capable of making cities environmentally sustainable. In order to achieve the electrification and decarbonisation of urban transport in one decade, it is necessary to start implementing that mobility from today on.

The advantages of using the electric vehicle can be easily grouped into three areas: energy efficiency, through a more rational use of the consumed energy; environment, with a substantial improvement in the global pollution emitted "from the well to the wheel" and a total elimination of local pollution; and demand management, through greater efficiency of the electric system, reducing the energy dependence on fossil fuels and using the off-peak hours for charging. However, the current state of the art regarding the autonomy of the buses, the charging of the batteries, and the state of the electrical distribution networks, as well as the cost of vehicles and facilities, are barriers that make the road to the future neither easy nor fast.

EMT is starting on this road to the electro mobility of its fleet with the aforementioned recharging opportunity project, beginning with the implementation of 12 metre long electric buses, with a strategy of growth of the electric fleet in Madrid that includes actions in a term of about 6 years, so that by 2020 there are going to be about 80 electric buses, a figure that will increase to 250 by the end of that period.

As for standard electric buses of 12 metre length, EMT has carried out tests with the main bus models of these characteristics that are being marketed in Europe. The brands are IRIZAR, BYD, FOTON, EURABUS, EVOPRO, SOLARIS, and IVECO, all of them with a low floor. With the exception of IRIZAR, whose batteries are made

Figure 10.
Bus charging by induction and necessary installations.

of molten salts, the rest are equipped with lithium-ion batteries. Although each one has a different storage capacity, they all exceed 200 kWh of stored energy; only the IRIZAR model reaches 376 kWh.

From the tests carried out, it can be deduced that current electric buses have an energy consumption of between 1.5 and 1.7 kWh/km, so with the current state of the art, they cannot yet compete with the autonomy of other types of energy, but they are increasingly approaching that at a high speed.

EMT has acquired 15 electric IRIZAR buses that will serve as initial pilot fleet to gradually increase the number of "zero emission" buses running in Madrid. Thus, in February 2018, the first electric charging station was commissioned in the Fuencarral Operation Centre with 80 kW chargers and its own transformation centre. It is foreseen that in 2019 up to 35 standard electric buses will be integrated, currently finishing the necessary electrical installation by means of an electrical split achieving the necessary power, thereby taking advantage to test all the available technologies (charging by pantograph, chargers, and intelligent charging) and anticipating the execution of the new project that is already designed and planned to be built in 2020 from a 100% electric operation centre with a capacity for 330 buses (**Figure 11**).

3.3 Human resources

3.3.1 Training with driving simulators

EMT owns four driving simulators that reproduce EMT's existing bus models as well as simulate the operation and traffic (private, bicycle, etc.) that can occur in the city. These hours of practice in simulators contribute significantly to energy

Figure 11.
Electric standard bus.

savings and reduce the emission of gases and noise in the process of training driving staff. Training for all EMT employees in the year 2018 amounted to a total of 200,697 hours, taking into account that most were focused on driving staff.

3.3.2 Efficient driving

As it not only affects the operation and exploitation of the urban bus service or the rolling stock and infrastructures, but also the human component, EMT is currently working on improving the driving efficiency of its more than 2000 buses with the dual objective of reduction of polluting emissions and fuel consumption, as well as a certain improvement in the maintenance and conservation of the vehicle.

The EFIBUS project (first project in Madrid with the Innovative Public Procurement method) therefore seeks to reduce emissions, improve safety and travel experience, and offer detailed information to know the vehicle's condition. Thus, the technological solution focuses on an on-board module that stores and processes the relevant information (acceleration/abrupt braking and speed) informing the driver, in real time, of its degree of efficiency in driving and sending the control centre data for further analysis. The objective is to try to compare the same conditions to the driver with himself in the same conditions and a continuous improvement plan focused on each individual.

In addition, the module allows controlling the switching on and off of the bus's own systems such as lighting, air conditioning, ticketing systems, etc., which also allows a reduction in the energy consumption on the whole. The incorporation of these systems, together with a policy of training and continuous assessment of drivers in efficient driving, allows to achieve estimated reductions of up to 11% in the short term (3% in a sustained manner over time).

3.3.3 Transport of EMT staff

Since 2018 EMT also has a Transportation to Work Plan as a commitment between the management of the centres and the company's staff, which is characterised by the rationality in the journeys generated by the work activity. Thus, there are staff buses and auxiliary electric, hybrid, and CNG vehicles. But additionally, the recurrent trips that are made every day because of work are sought to redirect them towards socially and environmentally sustainable modes of transport. The Air Quality and Climate Change Plan of the City of Madrid includes the Sustainable Labour Mobility Plans and specifies actions to be carried out: "development of sustainable mobility plans in companies and public bodies, as well as in business areas of the capital". Currently, this Transportation to Work Plan is implemented at the headquarters, beginning its implementation in the operation centres and other EMT units. For this, a survey asking the staff has been carried out with a total of 646 responses (about 9530 workers at that time). The modal distribution, the geographical distribution of the origin of the trips, and the time used to arrive in the case of headquarters offices (with 1357 workers) are shown below. As a support, an advisory group and a car sharing platform have been created, as well as a new distribution of parking spaces giving priority to ecological vehicles, providing transport and travel cards for the use of other ways of sustainable public transport (for example, Madrid's public bicycle), as well as considering the family situation.

On the other hand, for the internal service of the company, there is a fleet of auxiliary vehicles for tourism within which, since 2015, there are 5 Renault ZOE electric cars equipped with 22 kWh lithium-ion batteries and a 65 kW electric motor, with autonomy close to 150 km and a maximum speed of 135 km/h (**Figure 12**).

Figure 12.
EMT auxiliary vehicles to support the service.

3.4 Installations and infrastructures

In fixed installations and buildings, from the design stage of the construction project, whenever possible, it must be taken into account that they are energy efficient, use renewable energy, and use efficient recycling.

With this concept arose the operation centres of Carabanchel, for diesel vehicles, in 2007, and Sanchinarro, built for vehicles of compressed natural gas, following the decision of EMT in 2010 that the new buses had to be predominantly of this fuel. The Sanchinarro Center was designed and built to employ construction techniques that are not aggressive for the environment, generating little waste and maximising recycling (**Figure 13**).

3.4.1 Energy saving and environmental certification

The energy saving of the centres has a direct impact on the consumption of gas and electricity, as well as on the level of polluting emissions. For this reason, an exhaustive control of the correct operation of the facilities is carried out to try to achieve continuous energy efficiency.

The roofing floors of Carabanchel and Sanchinarro are equipped with solar, thermal, and photovoltaic panels, to reduce the consumption of fossil energy and, consequently, the pollutants emitted into the atmosphere, thus contributing to improve the air quality of the city.

Respect for the environment has been of great interest in the design of buildings, as evidenced by the fact that natural gas is used as fuel for all the Centre's machinery, to filter the ventilation air, which is returned to the exterior after recovering part of the used energy to collect the washing water from the buses for their subsequent recycling and reuse, and to increase the green areas, having a landscaped part of the roof and vertical gardens.

EMT has the management systems ISO 9001, 14,001, and EMAS that contribute to the sustainable development of the company as a reference in the process of awareness, respect, and conservation of the environment that surrounds us, having as objectives the minimization of environmental impacts and the generation of an image committed to preserving the environment as an example to follow. Thus, controls are carried out on the impacts on the soil, water, and atmosphere, acting preventively and correctively according to the implemented management systems.

Figure 13.
View on the Sanchinarro operation Centre built in 2010.

In this sense, clauses of social content related to responsible management in the supply chain are also included in the specifications and contracts.

3.4.2 Adaptation of operation centres

All the actions on the exploitation and training and, mainly, on the bus fleet would not be possible without the suitable adaptation of the different operation centres.

To achieve greater efficiency in the management of the centres, the operation and maintenance of a more sustainable fleet as well as the improvement in the working conditions of the employees of the EMT have carried out a series of actions as those listed that highlights the installation and improvement of CNG stations (except for Sanchinarro, which was already 100% CNG, all the centres have been adapted for the operation of a 100% CNG fleet) during the years 2017, 2018, and 2019, as of electric recharging points for buses (in Carabanchel and Fuencarral) in those same years. In addition, actions have been taken in training (improvement of simulators) in 2018 and in the recirculation of water in the washing stations as well as in the pre-treatment of water.

3.4.3 New 100% electric operation centre

The recently completed project (ended 2018) of the new operation centre La Elipa, which will be executed according to the quality, finishing, design, and installation standards of Carabanchel and Sanchinarro, will begin its execution by 2020 with an execution deadline of 18 months. The operation centre is conceived with sustainable criteria, with plant facades for its landscape integration within the environment located in a consolidated residential neighbourhood. This centre shows that in the future 100% of the fleet will be constituted by electric buses. This project has been carried out with BIM technology to facilitate work monitoring, management, and subsequent operation of the centre. It has 313 places for buses of 12 metres and 20 places for articulated buses, 32,200 square metres bus parking

Figure 14.
New 100% electric operation Centre La Elipa (project finished).

platform, and a workshop building with a floor area of 6200 square metres. The underground parking of a basement can accommodate 347 spaces.

The building has been designed with almost zero energy balance criteria (ZEB building), through the use of recycled materials for construction, increased energy efficiency, the obtaining of renewable sources, and the provision of elements that favour the reduction of emissions of greenhouse effect. It has a photocatalytic cover (34,000 m^2) with a decontaminating effect that will reduce the pollution of the environment (elimination of NO_x polluting oxides) and that will generate an important energy saving, and a vertical garden of 1100 m^2 of vegetated air purifying modules, with vegetal facade translucent of 800 ml of climbing species and 400 m^2 of landscaped roof. Additionally, it has a photovoltaic installation with more than 7200 panels installed on the roof that will generate up to 2 MW of energy (**Figure 14**).

3.4.4 Public access points for charging electric vehicles

Likewise, compatible with this strategy of global electric mobility in Madrid, EMT is innovating the existing recharging systems in the facilities it manages in the city (car parks, operations centres, etc.), installing fast charging points for public use, such as the case with those implemented during 2017 and 2018 in several car parks, with the participation of the Madrid City Council, which has a dock for simultaneous rapid loading of four vehicles. At this moment, there are already 75 slow charge points and another 12 fast charge points. In the car parks of residents managed by EMT, it is sought to provide the opportunity to have electric vehicles supporting electric charge in them. Additionally, an electric station for public use is being proposed for the new operations centre of La Elipa.

4. Conclusions

All the aforementioned actions have contributed to the drastic reduction of NO_x and PM emissions of the EMT fleet in the last decade. The challenge of EMT and the city is to continue with the achieved downward trend. But while the electro mobility plans are being carried out, EMT has already completed its transition strategy from diesel to CNG as a real alternative to traditional fossil fuels, for economic and environmental reasons. Thus, by 2020, all urban buses in the capital will be powered by CNG, with the exception of those previously mentioned, leaving diesel as a fuel of the past (**Figure 15**).

By taking all these measures, our users can enjoy EMT's mobility offer and move around Madrid using the least amount of energy necessary for transport, using the least polluting techniques and technologies and having a company that is a European reference in the urban transport sector.

According to the results of EMT, in the following figures, the NO_x and CO_2 emissions per kilometres of some of the mentioned technologies can be seen, their cost per kilometre with a focus on the cost of the fuel in each case. There is still a way to go, but what has been achieved so far is, of course, a successful transition towards CNG and an initiated transition towards the future of electro mobility (**Figure 16**).

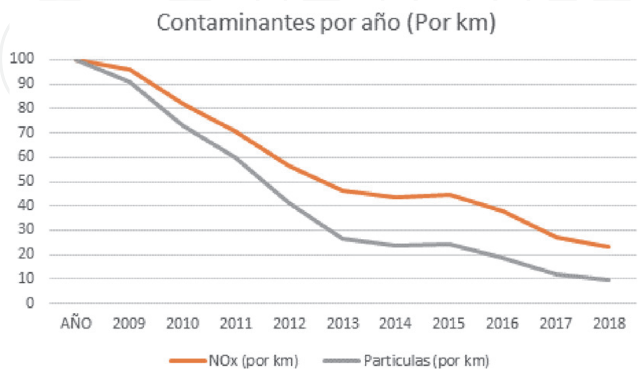
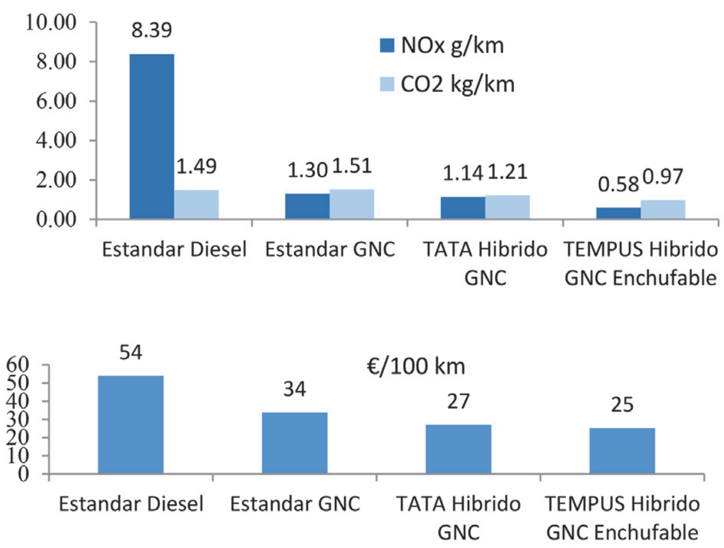
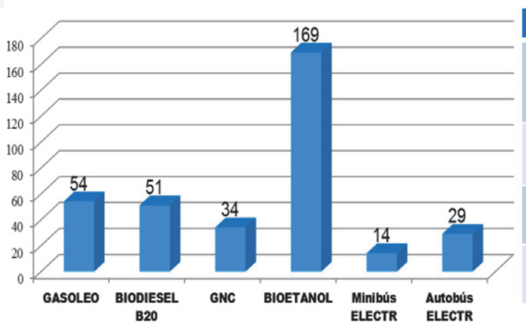


Figure 15.
Evolution of NO_x and PM emissions according to the EMT fleet.





€/100 km	GNC	Gasóleo	%
Coste combustible y compresión	34	54	-37 %
Coste de mantenimiento	53	51	4 %
Coste adquisición	38	33	15 %
Total	125	138	-9 %

Figure 16.
Own results of different technologies and impact on costs and emissions.

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