

Article

High-Performance Electric/Hybrid Vehicle—Environmental, Economic and Technical Assessments of Electrical Accumulators for Sustainable Mobility

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Abstract: The present work aims to provide a technical, economic, and environmental analysis on the electric accumulators used for electric mobility (pure electric, hybrid, full hybrid and/or mild hybrid) to reduce the environmental, social and economic impacts generated by private vehicles. Initially, the scenarios for the development of electric mobility and the regulatory context were assessed. Attention has been focused on the batteries used in electric vehicles and the technological aspects related to their charging operations. With regard to the economic aspects, the evolution of battery costs in relation to capacity and size has been highlighted in recent years. The advantages related to the containment of environmental impacts are highlighted considering the aspects related to the end of life of the batteries themselves. As retrofitting ICE vehicles by electric motor currently represents a potential transition solution to improve the shift towards the widespread adoption of electric vehicles, the retrofit methodology of some of the current B-segment vehicles was evaluated. In the present work, the authors wanted to demonstrate how the solution proposed here, the retrofitting of class B vehicles, can represent a medium-term way to implement the transition from MCI-based traction to electric.

Keywords: electric vehicles; batteries package; economic analysis; electric mobility



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1. Introduction

The increase in the world population and, in particular, that residing in urban centers will lead to an increase in the use of private mobility. To date, the solution to urban mobility that is also sustainable is electric mobility, a rapidly growing sector in which all car manufacturers are now investing. An electric vehicle is a vehicle in fact similar to those with an internal combustion engine, the power plant of which consists of an electric motor. The characteristic power source from battery packs is in the tank of the classic fossil fuel tank. Currently, one of the problems of electric cars is linked to autonomy, that is, to the number of km traveled with a single recharge, not comparable to the autonomy obtainable with a conventional vehicle. The other problem is related to vehicle recharging, in particular, the charging time, the electrical power used by the column and the scarce diffusion in the territory of the charging stations themselves.

An important parameter for electric vehicles is range. Many consumers would welcome electric vehicles that have a comparable or even the same range as a conventional vehicle [1,2]. Currently, the range of electric vehicles is more than 100–120 km for entry-level vehicles, much lower than that of a conventional motor vehicle. One of the main challenges for the electric vehicle industry is therefore to increase this value. It is therefore necessary to improve and develop new types of accumulators, consequently increasing the availability of charging stations [3]. All this, however, will weigh on the electricity distribution network, since it will have to be able to meet the high demand for electric vehicles during the charging phase.

There are currently about 11 million electric cars in the world which, according to the Stated Policies Scenario (STEPS), will become about 145 million by 2030, with an annual growth rate of about 30%. These forecasts consider the current energy policies and the disbursements of the manufacturers in the sector. The forecasts for electric cars in terms of the total number of vehicles registered in the world should be around 7% by 2030. In particular, it is expected to sell about 15 million electric vehicles in 2025 and over 25 million in 2030 [3]. In 2030, global EV sales will reach 23 million and the stock will exceed 130 million vehicles in the New Policies Scenario. Figures 1 and 2 report these scenarios [4].

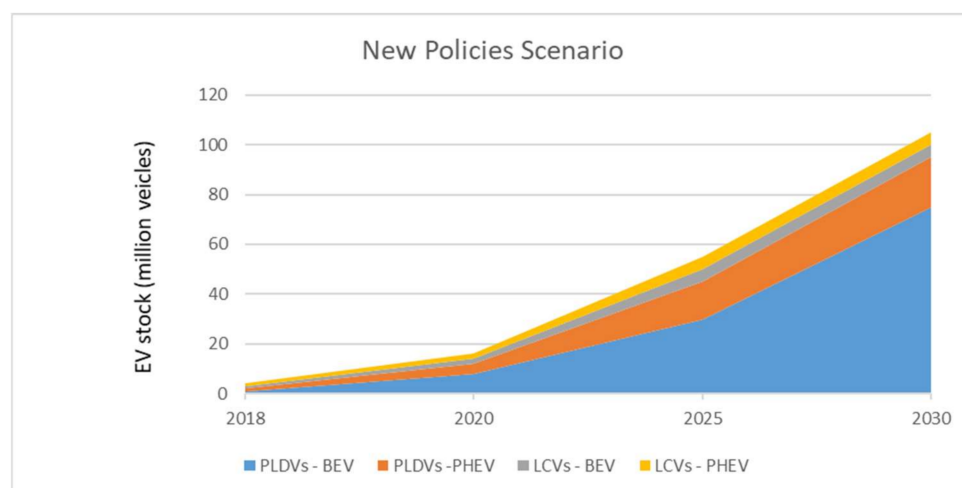


Figure 1. Future global EV stock (STEPS) [4].

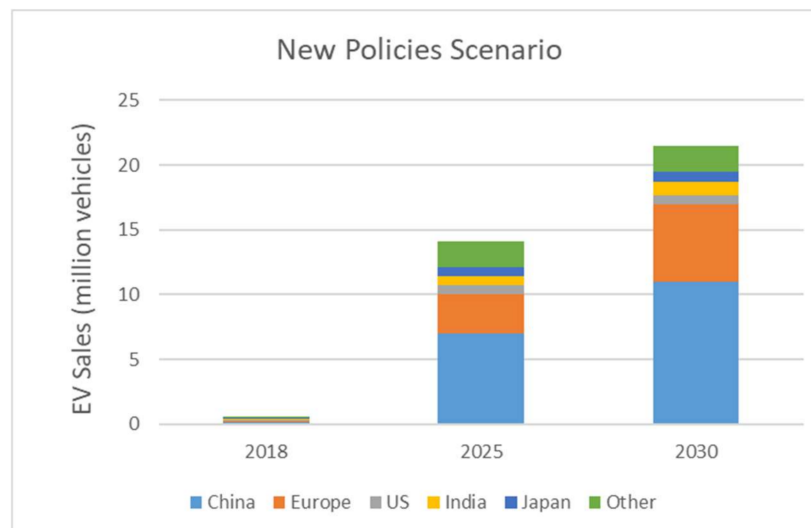


Figure 2. Future global EV sales (STEPS) [4].

In summary, the use of electric cars can lead to a reduction in harmful emissions to the environment. In fact, in the city's contributions, a cancellation of local emissions and a reduction in cumulative emissions of CO₂ was equal to 40–45% compared with similar petrol versions and between 22–40% compared with diesel versions. In addition, the reduction in noise pollution will lead electric cars to be characterized by a lower noise level than traditional cars. The new-generation cars are often arranged with acoustic devices that signal their presence when circulating within pedestrian areas and allow circulation in some limited traffic areas (ZTL). For example, taking as a referral some European cities, electric car owners can not only enter limited traffic areas at any time of the day, but are not required to pay the ticket.

As for the disadvantages, this technology still needs to improve in terms of some critical issues, which are the limited and lower range compared with diesel and petrol and hybrid cars. This makes them difficult on long journeys, due to the lack of electric charging stations on the highway. From a safety point of view, these batteries are characterized by a high possibility of catching fire in the case of road accidents. They are also characterized by long charging times not comparable to the times of classic fossil fuel refueling. Finally, the environmental impact of the process of disposing of car batteries—that if not carried out in the most appropriate ways—could be an anti-ecological operation.

2. Legislative Context

As electric mobility is an emerging topic, with a vast array of differences in its implementation and development [5], a worldwide applicable legislative context has not been reached yet. Initiatives such as the UN Environment’s Electric Mobility Program provide useful information regarding electric vehicle policies around the world, which can be found in their Global Electric Vehicle Policy Database [6].

These policies can be classified into the following categories:

- Improve: incentive policies to improve the performance of current urban mobility systems;
- European Union: use of incentive tools for the use of electric public transport;
- China: policies that may contain investments in the conventional mobility sector and the use of incentives that reward the best performing electric cars;
- Japan: policies to reduce by 80% the greenhouse gas emissions produced by endothermic propulsion vehicles produced in its territory by 2050, using hybrid electric and fuel cell vehicles;
- Canada: British Columbia aims to sell only electric vehicles by 2040;
- India: the “Faster Adoption and Manufacturing of Electric Vehicles in India” program is underway, which consists of encouraging the purchase of both private and public hybrid and electric vehicles;
- Korea: purchase incentives, and reductions in toll and parking costs for low-pollution vehicles.

3. The Technical and Economic Analysis

While there are many energy storage technologies and battery chemistries, currently the most used batteries for electric traction are lithium-ion batteries [7–9]; therefore, the following analysis covers Li-ion batteries. The lithium-ion cell rated voltage is about 3.2–3.6 V. EVs use these cells stacked in a series connection so that the required voltage is achieved [10]. Comparing lithium batteries with other batteries such as lead–acid cells or NiMH, lithium cells provide high power, energy density, long life and low self-discharge rate. High energy density makes lithium-ion battery technology attractive for a wide range of applications and on-board systems.

Table 1 reports some details of the latest lithium batteries under development and their technical specifications [7–9].

Table 1. Parameters of batteries in development [7,9].

Type of Battery	Cell Voltage (V)	Energy Density (Wh/kg)
Li-ion (next generation)	3.8	387
Zinc-air	1.65	1086
Li-sulfur	2.2	2567
Li-air	3	3505

3.1. Accumulators for Electric Mobility

The batteries used in electric traction can have different specifications depending on the application; for example, for long distances, very fast charging times are preferred [8,9]. Lithium-ion batteries are characterized by positive and negative electrodes coupled through

a separator; their thickness varies from 10 to 20 μm . The thickness of the user for the electrodes is closely linked to the energy and power that can be supplied by the battery. The transfer of ions between the electrodes is possible only in the presence of an electrolyte, generally a liquid organic type. The movement of electrons through the external circuit supplies the electrical energy, in the discharge phase. During the charging phase, the process is reversed. The useful life of the lithium-ion battery is represented by the number of charge and discharge cycles that it can perform [10–12]; this value is about 1300 cycles. The capacity of a battery is represented by the electric charge, which is how many amperes can be delivered. This parameter together with the voltage characterizes the battery's capability to store energy [12].

In Li-ion batteries (see Figure 3), unlike lithium batteries, the metal lithium anode, which presents safety and reactivity problems, is replaced with an inserted anode capable of accumulating and exchanging a large amount of lithium ions. In this way, the ions can access the electrode more easily; since there is a lower internal resistance, consequently the battery is able to absorb more power. A lithium-ion battery can consist of different types of electrodes and electrolytes, with voltage, energy density, and power density being very different from each other, in order to adapt to the specific application. The LiFePO_4 , Li-Titanate [12] electrodes are those able to guarantee greater safety, which, however, cannot be considered absolute; hence, the need to use a control system capable of managing the charge and discharge of the battery itself.

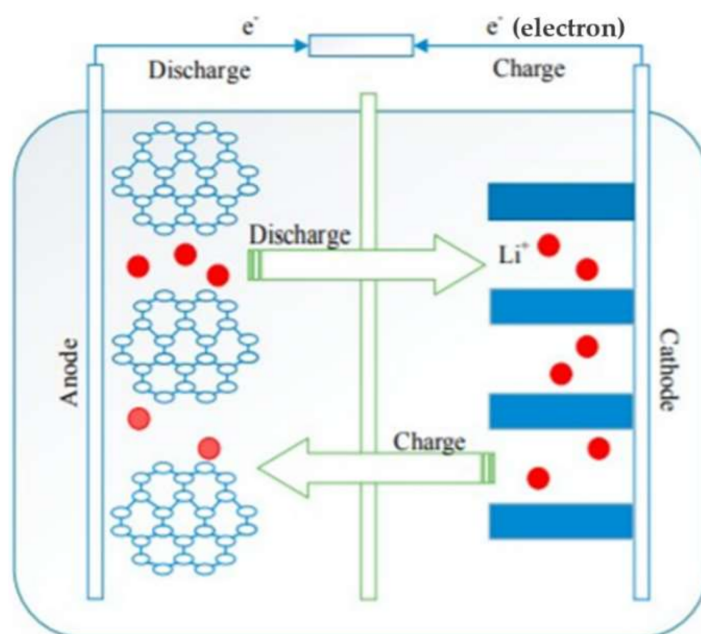


Figure 3. Structure of Li-ion battery [12].

3.2. Charging Technological Aspects for Electric Vehicles

Public battery chargers in 2018 amounted to approximately 540,000, 24% more than in 2017; however, the figure in terms of absolute value is down compared with previous years, at 30% in 2017 and 80% in 2016. About half of the total installations in 2018 were made in China [6]; these installations are mainly represented by fast charging stations as opposed to those installed in Europe and the United States (see Figure 4 [6]).

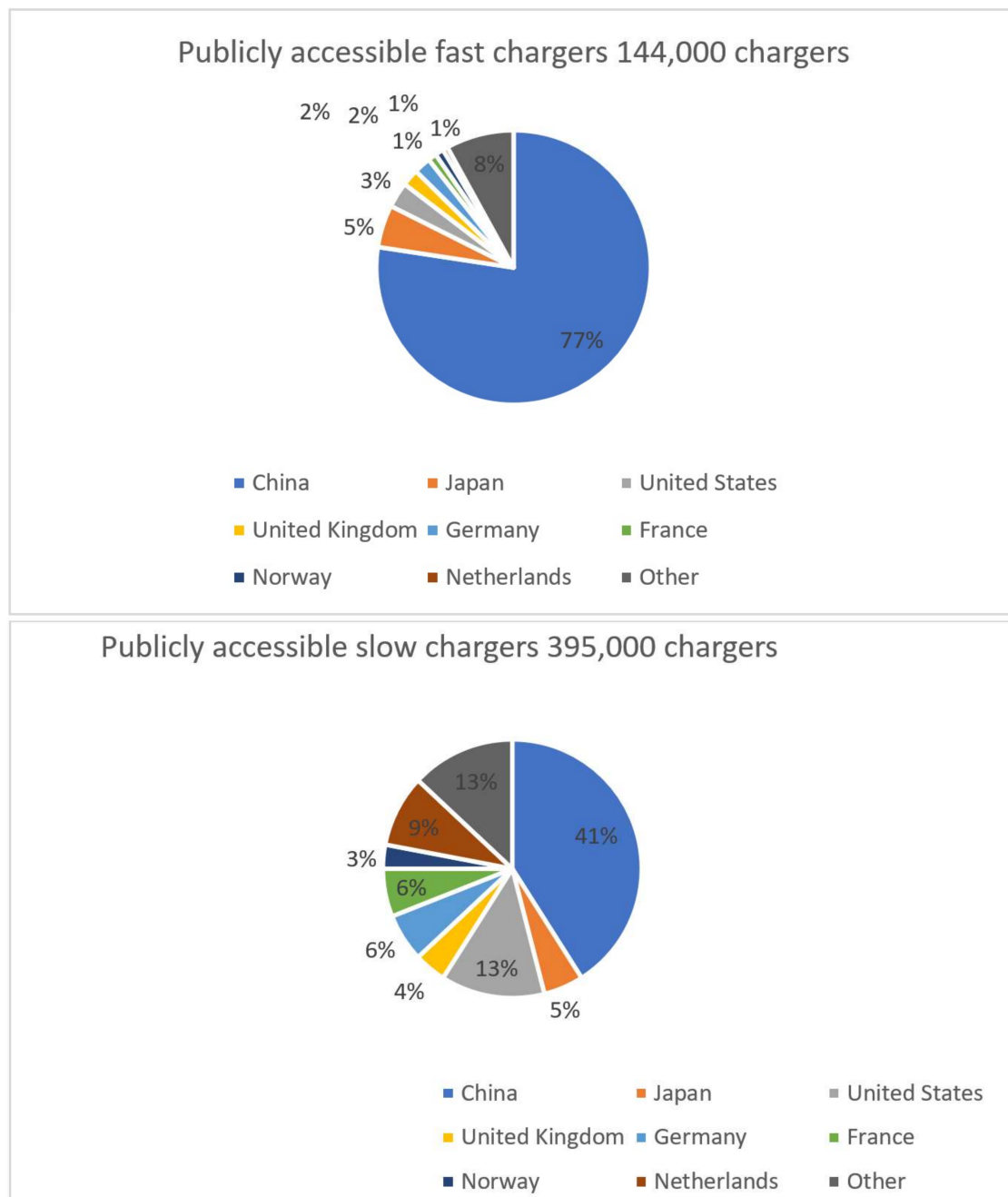


Figure 4. Publicly accessible chargers by country [6].

3.3. Economic Evaluation

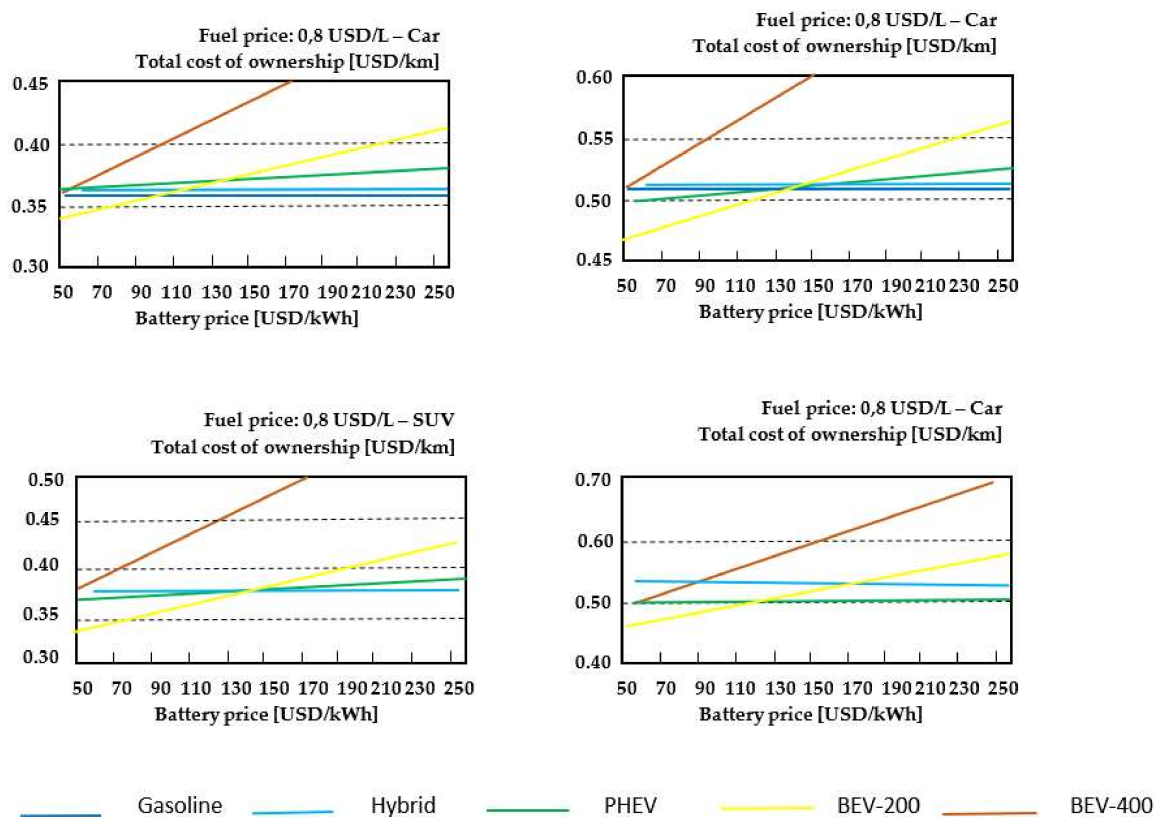
The main cost of an electric vehicle is related to the batteries, about EUR 117 per 1 kWh. The variation in the cost of Li-Ion, NiMH and lead–acid batteries is shown in Table 2. All of this results in a significantly higher purchase price for an electric car than a combustion engine (ICE) car, of approximately 40% more.

Table 2. Comparison of battery prices [8,13].

Battery Type	Year	Price (USD/kWh)	Number of Lifetime Cycles (n°)
Lead-acid		100–200	500
Li-ion	2010	700–900	1300
Li-ion	2012	350–700	-
Li-ion	2014	280–350	-
Li-ion	2016	175–280	-
Li-ion	2018	125–175	-
Ni-MH	2004	680	700
Ni-MH	2013	450–500	-
Ni-MH	2018	265	-

The battery package installed on a “segment B” car guarantees an average mileage of 20 km (36 kWh batteries). The costs of running an electric car compared with a conventional engine, assuming the cost of fuel is equal to 1.5 USD/lt and a mileage of 12,000 km/year, are lower only if the prices of the batteries fall below USD 150/kWh.

In the case of an autonomy of 400 km, the electric car is advantageous compared with the petrol car only if the cost of the batteries is equal to 70 USD/kWh [9], as shown in Figure 5. Table 2 reports this comparison [8,13].

**Figure 5.** Total cost of ownership as a function of battery and fuel prices for a passenger sedan and SUV [6].

The cost of the battery pack is mainly determined by the overall dimensions, type and production capacity of the production plants. The analysis of these parameters allows us to affirm that, over the course of 2018, the cost of batteries decreased and this should represent the future trend, as shown in Figure 6 [6].

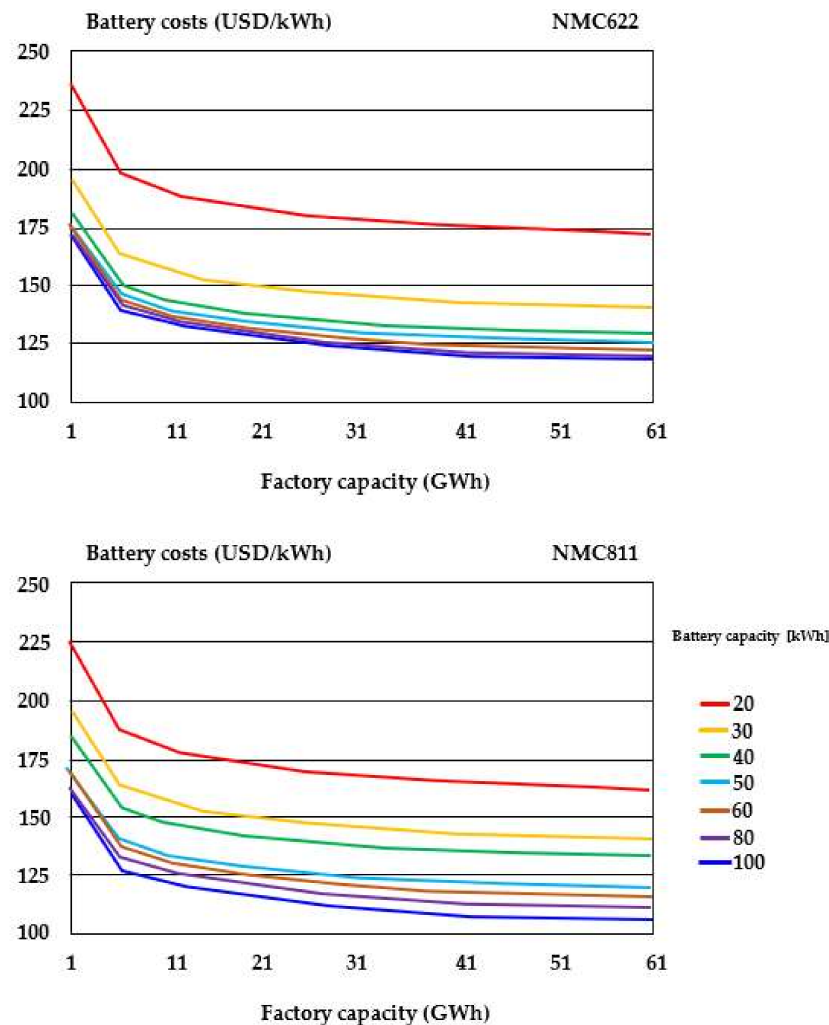


Figure 6. Lithium-ion battery cost relative to capacity and factory size.

As final remarks, lithium-ion batteries are a fragile technology that requires a protection circuit; lithium-ion is used where a very high energy density is needed and the cost is secondary. The advantages of their use are:

- They are able to release current at high intensity;
- High energy density. A lithium battery is capable of accumulating three or four times the energy of a nickel–cadmium (NiCd) battery of the same size;
- Reduced self-discharge. Unlike traditional lead–acid batteries, the self-discharge of lithium-ion batteries is very low and corresponds to only 1–2% per month;
- The memory effect is very small, which is an effect that causes the pre-stations of the old generation batteries to worsen as a result of frequent partial charging. In lithium-ion batteries the capacity remains constant despite sustained use;
- Possibility to perform intermediate recharges of the batteries even if not yet completely discharged. This recharge, total or partial, does not damage the battery;
- A longer service life than batteries that adopt other technologies.

In contrast, today's lithium-ion batteries have the following disadvantages:

- Susceptible to damage from overload and excessive discharge;
- Due to the very high energy density, great care in handling is required;
- High thermosensitivity of batteries.

4. Environmental Impacts for the Development of Electric Mobility

Electric mobility is considered as a key element for decarbonising transportation, an area that represented around 24% of the total CO₂ emissions from fuel combustion in 2020 [14], and that has not yet made a significant change in order to meet the emission reduction goals many countries have set. When combined with renewable electricity sources, electric mobility is deemed to have considerably less environmental impacts than our current transport methods, involving internal combustion engines and the use of various fuels, providing the following environmental benefits [15]: a drastic reduction in air pollutants, which benefits cities with severe air-quality problems, and a reduction in CO₂ emissions, depending on the fuel mix of electricity generation.

However, as with every other human intervention in nature, the development of electric mobility has a certain degree of environmental impact. The main “externality” is linked, inevitably, to the processes of extraction of raw materials, such as lithium for batteries or rare earth metals for magnets in electric motors or to power electronic components. Consequently, the production process of the component (batteries, motors, etc.) also requires energy that must be generated and at the end of the production process there will be waste that must be disposed of. Finally, the management of the end of life of the components themselves will generate waste, with some being highly polluting.

Decommissioning of Electric Car Batteries

In order to mitigate the environmental impact of electric car batteries once they have reached the end of their useful lives, a circular economy model for recycling and reusing waste as inputs again is required [16]. Figure 7 shows different sustainable end-of-life options for batteries. The common end-of-life procedure includes the following steps:

- Decommissioning: the dismantling and removal of the energy storage system.
- Transport of batteries: transportation of old batteries to a refurbishment, recycling or disposal facility.
- Refurbishment and reuse: if feasible, batteries can be reused in “second life” applications, or refurbished—if it is a cost-effective solution.
- Recycling: via pyrometallurgical or hydrometallurgical processes.

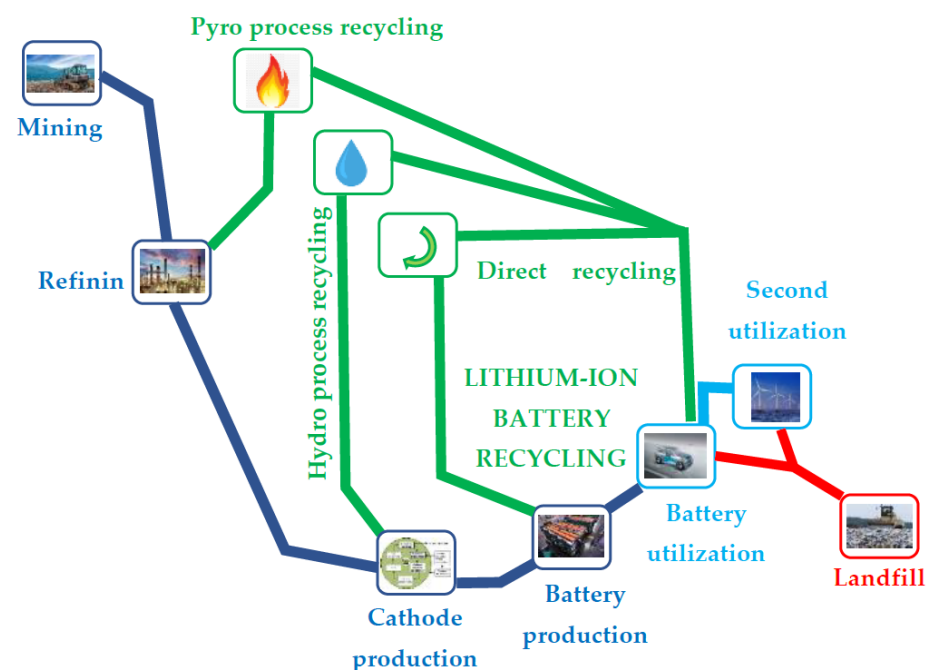


Figure 7. End-of-life management of Li-ion batteries.

5. Engine to Electric Vehicle Retrofitting

The transition towards electric mobility can be implemented through the electric retrofit of vehicles with internal combustion engines. This would make it possible to ensure the greater social acceptability of electric traction and, at the same time, allow the development of the infrastructure for the management of electric vehicles. The advantage for the user would be characterized by a significantly reduced retrofit cost compared with the purchase of a new electric vehicle. In almost all retrofits, a plate is used to couple the electric motor to the conventional gearbox, and in doing so it is not necessary to eliminate the original transmission. To date, few workshops are able to carry out a retrofit operation even if their number is growing; retrofitting prices vary according to the segment of the car to be converted and range from EUR 8000 to 15,000 [17].

5.1. Vehicle Design and Simulation

Below is a summary of the simulation values and procedures. The simulation was carried out by ADVISOR, an Advanced Vehicle Simulator developed by the US Department of Energy and the National Renewable Energy Laboratory, to obtain the technical specifications of different type of vehicles (hybrid and conventional). ADVISOR allows, based on the characteristics of the vehicle and the road routes, the modeling of the behavior of the vehicle for different driving cycles. This presents a library with some parameters to carry out the simulations. If they are missing, they can be added. In the present work ADVISOR was used to verify the fuel consumption, discharge and recharge of the battery pack (SOC), the size of the various components and the satisfaction of the energy demand in the various driving cycles.

The parameters chosen in the ADVISOR program are:

1. The choice of the type of hybridization;
2. Vehicle model;
3. Endothermic engine model;
4. Electric motor model;
5. Battery model;
6. Generator model;
7. Model for transmission;
8. Wheel/axle;
9. Powertrain control;
10. Drive cycle.

The main characteristics of the hybrid vehicle are reported in Table 3 [8,18], while the drive cycles used were the ECE cycle (also known as UDC = Urban Driving Cycle), an EUDC cycle (extra Urban Driving Cycle), the ETC cycle (European Transient Cycle = 1 ECE + 1 EUDC + motorway driving), the actual standardization NEDC cycle (New European Driving Cycle = 4 ETC + 1 EUDC) and a customer WVU (West Virginia Urban) cycle. For any mission type (as well as ETC, EUDC, and WVU), the engine energy balance is computed by calculating the instantaneous power request at the wheels, adding the transmission losses and considering the charging efficiency of the battery package. The effect of the KERS has not been included in the simulations presented here.

Table 3. Vehicle designs.

Vehicle Type	Weight (kg)	Electric Motor (kW)
Compact	1388	95
Mid-size	1617	110
Full-size	1890	140
Small-SUV	1700	120
Mid-size SUV	2100	125
Delivery truck	7430	200

The segment of electric B-SUVs will potentially be one of the most popular in the coming years, so it is particularly interesting to see how the models that make up this market niche are currently performing commercially. In the same manner, the market that makes up the SUVs of segment ‘B’ will most likely evolve the most in the coming years, which is reflected by the number of sales these type of vehicles have obtained during this year.

The reasons behind this exponential growth lie mainly in two different factors. Leaving aside the general increase in sales of electric cars, the main reason is the rising popularity of the electric B-SUV segment and its favorable position in the market. Below (Table 4) are reported the values of engine power, weight and dimensions of the battery of the best-selling B-Segment electric vehicles until April 2021, in Europe. The following information (Table 4) was obtained from the technical data sheet of each vehicle and manufacturer [19,20].

Table 4. Bestselling B Segment electric cars’ characteristics, up to April 2021.

SUV Model	Weight (kg)	Electric Motor (kW)	Battery Type and Capacity (kWh)
Hyundai Kona	1685	150	Lithium-ion Polymer 64.0 kWh
Peugeot 2008	1548	136	50
Opel Mokka	1550	100	50
Mazda MX-30	1720	105	35.5
MG ZS	1620	115	72.6
DS 3 Crossback	1598	100	50

5.2. Segment B Vehicle Retrofitting Analysis

5.2.1. Engine Design

Segment B is the second category of European segments for passenger cars, commonly known as “small cars” [21]. It is also known as “Supermini” in the United Kingdom and “Subcompact” in the United States. In general, a B-Segment vehicle is expected to have the following features:

- A small hatchback design.
- Length under 4 m.
- A decently sized engine, ranging from a 1.2 L petrol engine upwards.
- Diesel option available, depending on manufacturer.
- Manual or automatic drivetrain.
- Premium car features.

Table 5 shows the top five B-Segment ICE vehicles sold in Europe in 2020, with some technical specifications regarding engine power.

Table 5. Best selling ICE B-Segment vehicles in Europe, 2020.

Brand	Model	N° of Vehicles Sold	Power (HP)
Renault	Clio	248,602	65–130
Peugeot	208	199,316	74–129
Opel/Vauxhall	Corsa	198,887	69–150
Toyota	Yaris	179,867	69–90
Volkswagen	Polo	169,467	80–207

As can be seen, there is not a single definition for a B-segment vehicle, since it covers a wide array of vehicles and technical specifications that fit into this category. In order to determine the engine and battery dimension for a B-segment vehicle retrofit, an electric motor of rated power of 100 kW (equivalent to 134.1 HP) will be selected, as it is within the range of the previously mentioned vehicles.

Regarding the technology of the chosen electric motor, it can be either induction or direct current (DC), both typically used in electric vehicles and each having their pros and cons. These motors come in different sizes and can provide a wide array of horsepower and torque combinations needed for any particular electric vehicle retrofit. For the current analysis, an AC induction motor was selected.

5.2.2. Battery Design

In contrast to ICEs, EVs should be the lightest possible to optimize range and performance. An EV must also be sufficiently “Strong” to carry the weight of the required battery. Many vehicles can be converted to EV, but some are better candidates than others. Lightweight ones are favorites to be converted because they are optimal for mounting the batteries, and have a more homogeneously distributed weight.

This means that they can carry the weight of batteries and still have the ability to use it for charging. To establish the dimension of the batteries, the weight of the car to be equipped, the autonomy, and the space available for the battery equipment of each vehicle must be considered. For example, if we refer to Table 4, a vehicle with a battery capacity of 35.5 kWh has an autonomy of 170 km, and a vehicle with a battery capacity of 64 kWh has an autonomy of 395 km. In that sense, under the aforementioned considerations, for a vehicle with significant and average autonomy, a 50-kWh battery is recommended. This represents an autonomy of 200 to 230 km.

5.2.3. Remarks on Charge Controller Selection

In the case of 100% electric vehicles (BEV), there is another critical factor to consider: the time spent on charging. Although the process of filling the tank of a car with an internal combustion engine (ICE) is a matter of a few minutes, the time required to recharge the battery, especially in the case of BEVs, is significantly longer. It is in this scenario, recharging through a linked point of opportunity, that governing the on-board charger becomes fundamental.

The Society of Automobile Engineers (SAE) defined the main types of charge available for electric vehicles through the standard connector SAE J1772 (used in the United States). The agency offers estimated recharging times based on the recharging point to which the vehicle is connected.

However, these estimates can only be taken as a rough guide, as there are many influencing factors, including the state of charge (SOC) of the battery and the efficiency of the charger. Similar to the selection of the electric motor to use for a retrofit, the proper charge controller will be directly dependent on the selected technology, rated current, nominal power and other key technical specifications of the motor; in most cases, manufacturers will sell both motor and charge controllers in the same bundle. For the current case study, a charge controller solution that matches the chosen electric motor was chosen.

5.2.4. Summary of Technical Specifications

The following specifications of an electric motor, battery and charge controller are proposed for the retrofit of an average, generic B-Segment vehicle. It is important to note that the selection can be further improved if a particular model of vehicle is analyzed.

- Electric motor rated power: 100 kW;
- Electric motor type: AC induction;
- Battery capacity: 50 kWh;
- Charge controller: bundled with electric motor.

An example of an electric motor [22] and charge controller [23] that fit the selection criteria is shown in Table 6, while an example of a battery array that fits the selection criteria is reported in Table 7.

Table 6. Technical specifications of selected electric motor and charge controller [22,23].

Electric Motor	Charge Controller
Curtis 1238e-7621 HPEVS Dual AC-34 Brushless Motor Kit—96 Volt	HPEVS Curtis 1238e-7621 96 V 650 AMP Controller
<p>Motor Face: B-Face Motor Diameter: 2260 mm Motor Case Length: 5029 mm Motor Shaft Length End to End: 610 mm Motor Type: AC Induction Brushes: No Interpoles: No Weight: 68 kg Max Voltage Input: 129 V Terminal Stud Size: 9.25 mm Integrated Sensors: Encoder Rated Torque: 289 Nm Rated Power: 95 kW Continuos RPM: 5000 Max RPM: 10,000 RPM Sensor: No</p> <p>Drive End Shaft: 3.175 mm with 6.35 mm Keyway Acc/Commutator End Shaft: Optional 22.25 mm with 4.76 Keyway Timing: N/A Max Efficiency: 88% Thermal Cooling: Internal Fan Max Temperature: 180 °C Matching Dual Controllers included in Price: Curtis Controller (quantity two) Warranty Period: 1 Year</p>	<p>Max Current 650 Amps with Liquid Cooling (2 Min. Max) Rated Power: 50 kW Input Voltage 72–130 Volts Length: 275 mm Width: 232 mm Height: 80 mm Weight: 5.45 kg Adjustable Max Output Voltage: 96 Switching Frequency: N/A Brake Input Overrides: Yes Error Output Warning Indicator: Yes Precharge Circuit: Built In Computer Interface: Ethernet Port Data Logging Capabilities: Yes Tach Output: Yes 1, 2, 4, 6, 8 Pulses Limp home Mode: Yes, Controller WillDerate To Keep Pack Above Minimal Battery Voltage Firmware Upgradable: Yes Internal Contactor: No Thermal Derating: Yes, Derates After Temperature Gets Above 80 °C Reverse Capability: Yes Adjustable Acceleration (Slew Rate): Yes Idle Function: Yes, 500–1500 RPM (Modern Vehicles Idle from 600–800 RPM) Programmable Inputs: Yes Programmable Outputs: Yes Terminal Stud Size: 9.25 mm RPM Sensor: Internal Max Efficiency: 88% Thermal Cooling: Yes, Chill Plate Sold Separately Warranty Period: 1 Year</p>

Table 7. Technical specifications of selected battery [22–24].

CALB 180 Ah SE Series Lithium Iron Phosphate Battery
Array: 3 × 30 cell array, total of 90 units, rated power of 51.84 kWh at 96 V
Capacity: 180 Ah
Height: 275 mm
Width: 71 mm
Length: 182 mm
Weight: 5.6 kg
Bolt Size: M8
Voltage nominal: 3.2 V
Charge voltage cut-off: 3.6 V
Discharging cut-off: 2.5 V
Life Cycle (0.3c Charging–Discharging, 80%DOD): 2000
Maximum Discharging Current (10 sec.): 1000 Amps
Internal Impedance (1 khz Ac, m-Ω): Less Than 0.8
Chemistry: LiFePO₄
Warranty Period: One-year factory warranty on manufacturing defects

6. Final Remarks and Conclusions

Electric cars represent a great opportunity for mobility but, considering the current state of the art, it would be better to aim only for their use in urban areas, avoiding aiming at the complete replacement of the current international car fleet. It would also be appropriate to try to make cars with a number of places limited to two; in city travel users often move alone, so in many cases four places in the car are not necessary. This would allow sustainable electric mobility within cities in the immediate future. Aiming for a total replacement of the car fleet with electric vehicles must be a long-term goal when the capacity of the batteries will be such as to guarantee long distances. In the urban oil retrofit field, today it represents a good compromise with respect to the purchase of a new electric car.

Electric mobility is firstly highly dependent on the batteries used for the storage of electricity, since the latter determine the range of the vehicle, which, for entry-level models, does not exceed 100–120 km. Secondly, it depends on the accessibility of charging points. The worldwide total number of accessible charging points reached 539,000 in 2018, up 24% from 2017. At the regulatory level, it must be considered that electric mobility is a relatively new technology; there is no legislative framework applicable worldwide. Although there are many types of electric accumulators, currently, lithium-ion ones are the most used. The spread and adoption of electric vehicles is strongly influenced, in addition to performance, by the cost of accumulators.

The estimated prices for the next generation of batteries are around 117 EUR per 1 kWh. In addition, the purchase of a standard medium-sized electric vehicle is about 40% more expensive than a conventional ICE vehicle of similar size. However, the use of electric cars and the environmental advantage linked to their use is conditional on containing the environmental impact of the “batteries decommissioning”, so a circular economy model is needed for recycling and reusing “the waste” as input.

Retrofit is a potential transitional solution to improve the shift towards the widespread adoption of electric vehicles and can help facilitate the adoption of electric vehicles. Particularly interesting, as discussed in this article, is the B-segment vehicle market and SUVs of the same segment, since they are currently the most marketed vehicle segment. Thus, summarizing:

- o Electric mobility has a wide legislative context, based mostly on the country or region and on the current rate of electric mobility implementation;
- o The main advantages of Li-ion cells are the higher power, long life cycle and low self-discharge rate. The Li-ion batteries have higher energy density than lead–acid and NiMH, which makes them suitable for a wide range of applications in different industrial sectors;
- o Given the assumptions made by lithium-ion battery manufacturers, the cost of these batteries after 2020 should be around 100 EUR/kWh;

- o Electric mobility is key for decarbonizing transportation and reducing its environmental impact;
- o EV retrofitting can potentially increase the adoption pace of EVs, enhance public acceptance of EVs, lift the resource utilization of ICE vehicles and boost the speed of EV infrastructure development;
- o Regarding engine and battery dimensions for a B-Segment vehicle retrofit, an average engine power of 100 kW is recommended. Additionally, a 50 kWh battery is recommended, representing an autonomy of 200 to 230 km. Examples of the selected equipment are shown in the document;
- o Retrofitting prices range from about EUR 8000 for smaller cars to about EUR 13,000 to 15,000 for passenger sedans.

The present study has analyzed the many aspects related to electric mobility, with particular reference to lithium batteries. Unlike the other studies cited in this paper, in addition to environmental, economic and technological assessments regarding electric accumulators for sustainable mobility, this study focused on the methodology to be used for the transition from the current thermal propulsion system to an electric one through the retrofit mechanism. In practice, the retrofit of part of the current car fleet can help to make the use of electric vehicles with lower costs more easily accessible than the purchase of new electric cars, allowing a gradual transition to new-generation hybrid vehicles, the costs of which in the coming years should decrease significantly and therefore become accessible to many. In fact, electric mobility has been analyzed, marking the path to follow to arrive at a totally electric mobility.

Finally, this research can be considered the “starting point” for the future, and an important application will be to evaluate the technical and economic feasibility of the retrofit in the scenario of different city-dine municipalities, such as London, Paris, Berlin and Rome.

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Nomenclature

ADVISOR	Advanced Vehicle Simulator
BEV	Battery Electric Vehicle
ECE	Urban Driving Cycle
ETC	European Transient Cycle
EU	European Union
EUDC	Extra Urban Driving Cycle
EV	Electric Vehicle
HEV	Hybrid Electric Vehicle
ICE	Internal Combustion Engine
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
NEDC	New European Driving Cycle
SAE	Society of Automobile Engineers
STEPS	Stated Policies Scenario
SUV	Sport Utility Vehicle
WVU	West Virginia Urban Cycle

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