Environmental Aspects of the Electric Vehicle

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Abstract The purpose of this chapter is to understand the complete environmental impact of Electric Vehicles (EVs) compared with traditional combustion engines (ICE). In addition, a review of how European rules have been adapting to cover these impacts is presented. Although the typical approach to the problem is based on the evaluation of the emissions during the use of vehicles, the approach presented here covers the whole life of the Vehicle (manufacturing, use of the vehicle and end of life and recycling) and estimates the amount of material and energy used, the emissions or the toxicity. Results show that EVs have an environmental impact, which is concentrated in the manufacturing phase. Compared with traditional ICEs, EVs have clearly lower emissions when driving, which is certainly critical when defining air quality policies in urban regions. The importance of coordination in environmental policies regional and worldwide is therefore required to guarantee a sustainable and fair transition to a decarbonized transportation.

Currently there is a debate on the environmental impact of Electric Vehicles (EV), based on contradicting information. While the new industry uses the message that EVs are 'Zero Emissions', critics argue that EVs are even more polluting than ICE cars since the Li-Ion battery is not recyclable. To clarify this discussion, and above all give the reader tools for a complete and grounded analysis, this chapter presents different methodologies to assess the environmental impact of EVs, reviews results of the ecological footprint of the EVs during its life and presents the different existing regulations in Europe. By the way, we anticipate that the EV is less contaminated than the traditional combustion engine (ICE).

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1 Evaluation of the Environmental Impact of Electric Vehicles

The recent history of transportation has relied on using fossil fuels (ICE), with different derivatives such as gasoline, diesel and natural gas (liquified or gasified). The combustion of these fossil fuels releases thermal energy, which is converted into mechanical power, and additionally produces exhaust gases released to the atmosphere (carbon dioxide CO_2 and monoxides CO, and nitrogen oxides $NO_{x,}$ among others). The impressive evolution of road transportation in the last century due to the increasing numbers of trips per person and travelled distances, and the concentration of people in big cities, resulted in high concentration levels of these gases, and generated a real problem of polluted air in major cities in the World [1].

Alternative vehicle technologies based on electricity (battery electric vehicles BEV, hybrid vehicles HEV, or fuel cell vehicles FCEV) are a real solution to the pollution challenge. However, the process of developing these new technologies is not exempt from having an environmental impact throughout its life cycle, from the construction of the different components, its use as a means of transport, to the final phase of destruction and recycling. During its useful life, different resources are used (e.g. lithium or cobalt in the manufacturing of batteries or natural gas to produce the energy stored in them), and environmental impacts occur (e.g. derived from the emissions when vehicle transits).

There are two traditional approaches to understand and quantify the environmental impact of any kind of vehicle technology: Life Cycle Assessment (LCA) and Well-to-wheel model (WTW). LCA is a tool to assess in a quantified way the environmental impact of manufacturing and using products [2]. In this way, the amount of material used, the energy consumed, the emissions and waste from all the entire life of a vehicle can be analysed in detail [3]. In addition, this tool has the potential to identify the critical processes from an environmental point of view, e.g. in the case of EVs the battery both manufacturing and end of life [4].

Well-to-Wheel (WTW) model zooms on a specific part of the LCA approach, which are the 'energy consumption' and 'Greenhouse Gas emissions' during the life of a vehicle, as shown in Fig. 1. Therefore, this second analyse does not include the energy or emissions during the manufacturing and end of life of the vehicles, nor the impact of vehicles in health or resources use. This analyse is structured into two stages: well-to-tank (WTT) and tank-to-wheel (TTW). The first stage, WTT, quantifies the energy required and the GHG emissions resulting from the production, transport and distribution of road transportation fuels, from the source to the fuel pump or plug. The second stage is TTW, and focuses on the vehicle, quantifying the emissions and energy use during driving, and therefore considering the efficiency of different powertrains. The resulting emissions and energy used for any technology can be obtained as the addition of both values $WTW = WTT + TTW$.

Both LCA and WTW analyses require first a detailed inventory of the use of material/resources and understanding of processes, and also a detailed calculation of indicators. LCA analysis focus on the use of material resources such as energy,

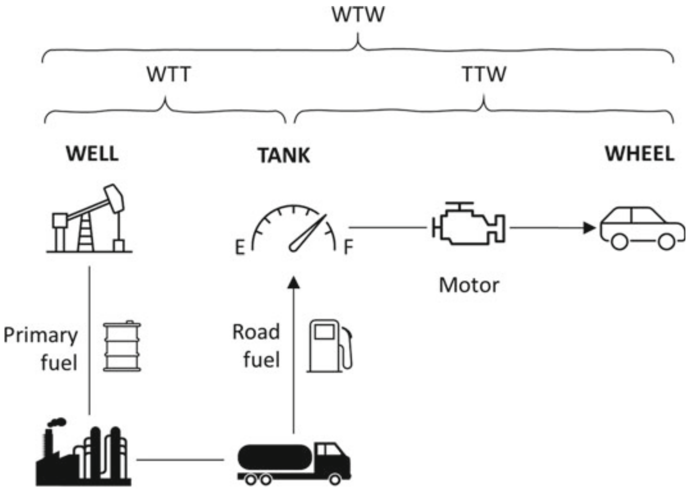

Fig. 1 Well-to-wheel analyses

emissions and waste, and the calculation of emissions and extraction of resources, to obtain the so-called environmental characterization factors [5]. This calculation in LCA process is also known as ReCiPe, which is based on the calculation of 18 midpoint indicators and 3 endpoint indicators. Figure 2 shows aggregated categories where it is necessary to analyse the impact, where the intermediate indicators analyse specific environmental problems, such as water use or acidification of the land, while the final indicators show the impact in three areas: effect on human health, biodiversity and lack of resources.

From a legal standpoint, the idea of life cycle should also be taken into consideration when governing environmental impacts and protection. For instance, at the international level it should be considered when regulating the international trade of pieces or other components (fuel included) related to the manufacture, use and disposal of vehicles.

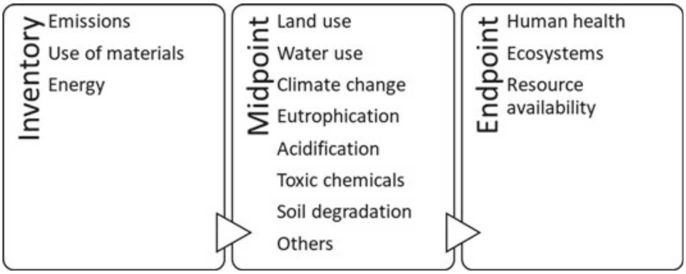

Fig. 2 ReCiPe [6] impact categories and endpoints

Focusing at the European level, Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008, on waste, includes the concept of life cycle in several articles:

- As a justification for Member States to depart from the waste hierarchy to deliver the best overall environmental outcome in relation to specific waste streams, taking into consideration the general environmental protection principles of precaution and sustainability, technical feasibility and economic viability, protection of resources as well as the overall environmental, human health, economic and social impacts (article 4.2).
- As part of the obligations that may be imposed on producers of certain products, when applying the 'extended producer responsibility scheme' (articles 8.2 and 8a.4.b).

The Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions 'Closing the loop—An EU action plan for the Circular Economy' (Brussels, 2 December 2015, COM [7] 614 final), must also be mentioned. This Communication refers to the transition to a more circular economy, where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimized.

Before this Communication, the Commission Recommendation 2013/179/EU of 9 April 2013, on the use of common methods to measure and communicate the life cycle environmental performance of products and organizations, had been published in the Official Journal of the European Union of 4 May 2013, L 124. This Recommendation promotes the use of the environmental footprint methods in relevant policies and schemes related to the measurement or communication of the life cycle environmental performance of products or organizations.

The rest of this chapter details the environmental impact of EVs based on the LCA and WTW models, covering the three main stages (manufacturing, use and end of life). A discussion on how regulation in Europe is covering these topics will be presented. It must be advanced that the environmental legislation in Europe is complete and covers all aspects that may refer to these three stages. However, it must adapt, as deemed appropriate at all times by the legislator, to the specific cases of the ICEs and the EVs according to the technologies and the requirements of environmental protection are evolving. The key issue is to apply the life cycle approach that has been pointed out, so a comprehensive and coherent environmental protection is ensured, beyond partial or poorly informed opinions.

2 Environmental Effects in the Manufacturing Process of EVs

The quantification of the environmental impact of manufacturing vehicles requires a comprehensive list of elements and processes, including three levels of disaggregation: (1) components, which are integrated into (2) subsystems and in turn are added into (3) units.

The main elements associated with the manufacture of the EV are summarized in Fig. 3, where the production of the different components and their assembly require the use of raw materials (steel, aliminium, copper, etc.), energy for manufacturing (electricity and heat), other materials (water, chemicals, etc.) and transportation of elements among assembly factories [5]. When analysing vehicles, regardless of technology, two large units can be differentiated: the structure of the car and the power train. Nowadays, it can be assumed that the structure and interior of the car—iron and plastics—is independent of the propulsion technology used, therefore there will be no difference between the conventional ICE and EVs regarding the main body [8]. Anyway, this is expected to change in near future, as the distribution of the weight in EVs is different: an important weight in conventional ICE vehicles is the power train, located in the front of the vehicle, while the main weight in EVs is in the battery pack, which is distributed on the floor of the vehicle. In addition, EVs will become autonomous in near future, and these vehicles will even change how passengers are seated, usually face to face [9]. To guarantee the safety of people in the car, under the event of a car crash, both the new distribution of weights and passenger positions will require new designs in car structures, and therefore differentiate from the structure of traditional ICE vehicles.

The power train in an EV consists of the battery pack and the electric motor. The battery of an EV is the critical unit from an environmental point of view, in comparison with traditional ICE vehicles, and therefore a detailed analysis is required. The battery back can be structured in 4 subsystems: cooling system, cells, structure and the

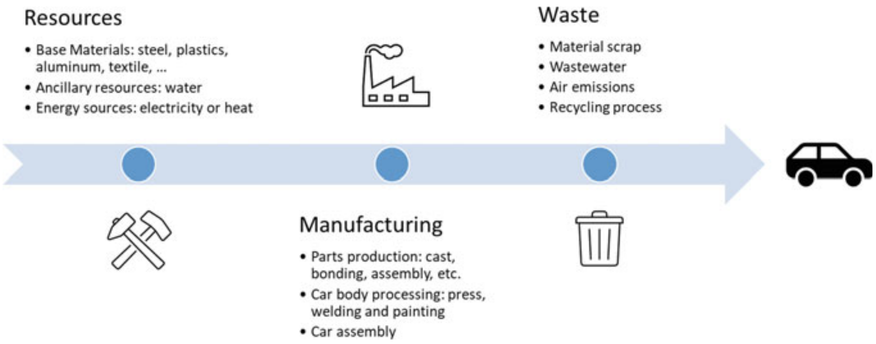

Fig. 3 Main elements in the production phase of a VE

Battery Management System. A typical distribution of weights among these subsystems is 4.1%, 60.1%, 32.1% and 3.7%, respectively [10], which also corresponds to their environmental impact importance.

The smallest elements in a battery are the cells, which are packed in modules, connected in series and parallel to build the battery pack (e.g. the Nissan Leaf has 192 cells packed in 48 modules). The basic components are the anode and cathode; the anode is the element where the oxidation reaction (loss of electrons) occurs, and the cathode is the element where the reduction reaction occurs (acquisition of electrons). Lithium-Ion batteries are currently a standard for most EVs. The cathode composition of these batteries can be very diverse: with Manganese $LiMn_2O_4$ (LMO), Iron Phosphate $LiFePO_4$ (LFP), Cobalt Li (NiCoAl) O_2 or mixture of several Li (NixCoyMnz) or O_2 (NCM), among others [11]. On the other hand, anodes are usually built with carbon or lithium titanate, to guarantee stability and safety. Lithium and Cobalt are the most relevant materials, from the environmental availability points of view, which directly impact its price. In 2018, the largest producer of Lithium was Australia (27.2 tonnes), followed by Chile (16 tonnes) and China (8 tonnes). On the other hand, Congo was the leading cobalt producing country (90 million tonnes) followed by Russia and Cuba (5 million tonnes), although Cobalt refineries are located in other regions such as China and Europe.

The second element of the power train is the electric motor. There are two technologies of electric motors used for the traction of EVs: Permanent Magnet and induction motors, used in 83% and 11% of EVs, respectively, leaving 6% of sales for EVs with both technologies [12]. Permanent Magnet motors are typically used because of their higher power density and efficiency compared to induction motors (for an average 50 kW permanent magnet motor is 30% lighter than a conventional induction motor). These improved characteristics can cost up to 4 times the conventional induction motor [13]. From the constructive point of view both motors consist of a cast iron or aluminium structure and copper or aluminium windings; the main difference between the two technologies is that synchronous motors additionally need permanent magnets. These magnets are constructed using so-called ‘rare earths’, such as neodymium. The world’s leading copper producer was Chile (5.5 Mton in 2017), followed by Peru and China . Regarding rare earths, the extraction of these minerals is concentrated in certain geographical areas such as China and in limited quantities [14], which makes there price volatile, and whose availability in the medium term is not guaranteed.

From a regulatory point of view, there is a huge number of international, European, national and even regional and local rules aimed at protecting the environment that will apply to each specific production process. Just to show some of the most important at the European level, the following may be mentioned:

(i) Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010, on industrial emissions (integrated pollution prevention and control). This Directive lays down rules on integrated prevention and control of pollution arising from industrial activities, as well as rules designed to prevent or, where that is not practicable, to reduce emissions into air, water and land and to prevent the generation of waste, in order to achieve a high level of protection of the environment taken as a whole (article 1). This Directive applies to the activities set out in Annex I (article 10) and to other specific activities referred to in Chaps. III to VI of the Directive (article 2.1), but not to research activities, development activities or the testing of new products and processes (article 2.2).

Among the activities subject to the Directive the following within Annex 1 may be cited: combustion of fuels in installations with a total rated thermal input of 50 MW or more (Section 1.1), certain installations for the processing of ferrous metals (Section 2.3), installations for the manufacture of glass including glass fibre with a melting capacity exceeding 20 tonnes per day (Section 3.3), installation for the production of organic chemicals and of inorganic chemicals (Sections 4.1 y 4.2), installations for the disposal or recovery of hazardous waste with a capacity exceeding 10 tonnes per day involving one or more of the following activities (Section 5.1) and installations for the surface treatment of substances, objects or products using organic solvents, in particular for dressing, printing, coating, degreasing, waterproofing, sizing, painting, cleaning or impregnating, with an organic solvent consumption capacity of more than 150 kg per hour or more than 200 tonnes per year (Section 6.7).

(ii) Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011, on the assessment of the effects of certain public and private projects on the environment. This Directive applies to the assessment of the environmental effects of public and private projects which are likely to have significant effects on the environment (article 1.1).

Among others, certain projects referred to the energy industry (Section 2 of Annex I), integrated works for the initial smelting of cast iron and steel (Section 4.a) and the mining industry (Section 19), are subject to this Directive.

(iii) Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008, on ambient air quality and cleaner air for Europe.

This Directive lays down measures aimed at, inter alia, defining and establishing objectives for ambient air quality designed to avoid, prevent or reduce harmful effects on human health and the environment as a whole; assessing the ambient air quality in Member States on the basis of common methods and criteria; and obtaining information on ambient air quality to help combat air pollution and nuisance (article 1).

The Directive refers to pollutants such as sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter, carbon monoxide and ozone.

(iv) Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000, establishing a framework for Community action in the field of water policy. The purpose of this Directive is to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater which, among others, prevents further deterioration and protects and enhances the status of aquatic ecosystems; promotes sustainable water use based on a long-term protection of available water resources and aims at enhanced protection and improvement of the aquatic environment.

Among others, the Directive contains rules on environmental objectives, protected areas, recovery of costs for water services and strategies against pollution of water.

(V) Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003, establishing a system for greenhouse gas emission allowance trading within the Union. This Directive establishes, among others, a system for greenhouse gas emission allowance trading within the Union in order to promote reductions of greenhouse gas emissions in a cost-effective and economically efficient manner (article 1).

This Directive applies to emissions from the activities listed in Annex I (for instance, combustion of fuels in installations with a total rated thermal input exceeding 20 MW—except in installations for the incineration of hazardous or municipal waste; metal ore—including sulphide ore—roasting or sintering, including pelletization; and production of primary aluminium) and greenhouse gases listed in Annex II (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride).

In addition to these rules, and for the purposes of this article, it is worth mentioning Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000, on end of life vehicles, that lays down measures which aim, as a first priority, at the prevention of waste from vehicles and, in addition, at the reuse, recycling and other forms of recovery of end of life vehicles and their components so as to reduce the disposal of waste, as well as at the improvement in the environmental performance of all of the economic operators involved in the life cycle of vehicles (article 1).

Among other things, and in order to promote the prevention of waste, this Directive imposes on Member States the obligation to encourage (article 4.1):

- vehicle manufacturers, in liaison with material and equipment manufacturers, to limit the use of hazardous substances in vehicles and to reduce them as far as possible from the conception of the vehicle onwards, so as in particular to prevent their release into the environment, make recycling easier, and avoid the need to dispose of hazardous waste;
- the design and production of new vehicles which take into full account and facilitate the dismantling, reuse and recovery, in particular the recycling, of end of life vehicles, their components and materials.

Member States must also ensure that materials and components of vehicles put on the market after 1 July 2003 do not contain lead, mercury, cadmium or hexavalent chromium (other than in cases listed in Annex II of the Directive, under the conditions specified therein—article 4.2).

3 Environmental Effects in the Use of EVs

The environmental impact of EVs during their useful life can be classified in direct emissions due to wheel-to-road friction (also called non-exhaust emissions such as small particles) and maintenance, and an indirect impact on the use and transport of resources to provide electric charging of the battery, as indicated in Fig. 4.

For direct emmisions in the process of combustion, ICE vehicles produce a set of gases that have an impact on the air quality, while EVs do not produce these gases. Additionally, the movement of the vehicle in a road increases the generated PM_{10} and $PM_{2.5}$ due to factors such as brake wear, road wear, tyre wear and road dust resuspension. These emissions are called non-exhaust emissions and are almost proportional to the mass of the vehicle. Currently, due to the weight of the battery pack EVs are around 20% heavier than the corresponding diesel or gasoline vehicles, resulting in the fact that EVs emit similar particulates compared to modern ICE vehicles; assuming that EVs have no particle emissions due to exhaust or brake wear, being heavier will result in slightly higher values for road wear and resuspension of particles. Some authors quantified a reduction of 1–3% in $PM_{2.5}$ for EVs and no reduction in PM_{10} [15].

A second direct environmental impact occurs during the maintenance of the vehicle that can be predictive and corrective, although it has a much lower impact than the previous circulation effect. As EVs have almost 50% less mechanical components compared to traditional vehicles, this will directly imply a higher reliability and lower maintenance. The predictive maintenance process for any vehicle will require a periodic review of elements such as brake and cooling fluids, as well as the cabin air filter; however, for EVs it is not necessary to include oil changes (engine or gearbox), as well as fuel filters, belts and other ancillary elements. According to some studies, the maintenance of the EV is almost 40% cheaper than their diesel or gasoline counterpart [16]. On the other hand, corrective maintenance, associated with possible breakdowns, is expected to be significantly lower in EVs, since they are simpler and more robust than ICE vehicles, avoiding traditional problems associated

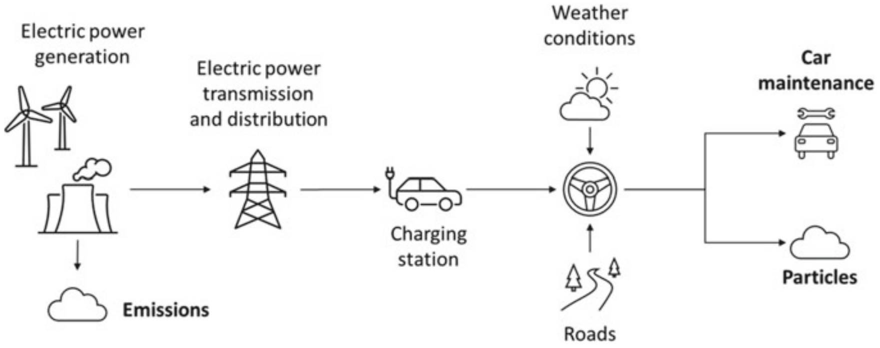

Fig. 4 Emissions associated with the use of the VE

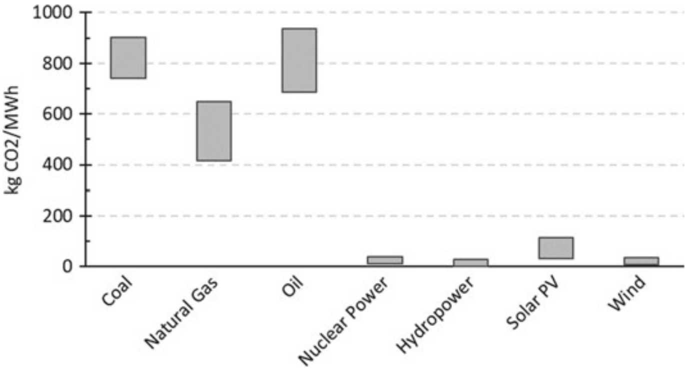

Fig. 5 Life cycle emission factors for electricity generation from selected technologies. *Source* Own elaboration

with the timing belt breaks or problems in the injectors. However, embedded systems and software designs are becoming the main elements for EV reliability [17].

Although EVs do not have direct exhaust emissions, they could have relevant indirect emissions associated with the generation of electricity required to charge batteries. The process of electric generation requires energy and have emissions. This process includes the extraction and transportation of raw material—such as gas or coal—to the generation power plants, the conversion to electricity, and the transmission and distribution of the electricity through the networks down to the charging poles. From the energy point of view, the production of electrical energy has a typical efficiency in the range of 30%, while the transport and distribution of electrical energy represents losses of around 15%. Electricity generation emission factors include the greenhouse gas carbon dioxide (CO_2) and additional gases which are not greenhouse but are considered as critical pollutants sulphur dioxide (SO_2), and nitrogen oxides (NO_x). Figure 5 compares the emissions of different electric generation technologies, using a Life Cycle Analysis, that includes not only the use of resources but also the manufacturing of the power plant components. From this figure it is clear that renewable generation can provide up to 100 times less exhausting gases (both GHG and other pollutants) compared with traditional fossil fuels [18]. Then, the emissions associated with the transition to electro-mobility in each country will mostly depend on its power generation mix, as shown in Fig. 6 [13].

WTW analysis also helps to characterize for different traction technologies global energy use and compare local emissions (TTW). Table 1 compares the efficiency and CO_2 emissions for different technologies of a medium size utility car with an average consumption of 15 kWh/100 km, supplied by a partially green energy mix [21, 22]. Results in TTW show that BEV together with Fuel Cell Vehicles are clearly the ones that provide the lowest impact in air quality locally compared with fossil fuels. From a country or regional perspectives, it is quite relevant the energy required for the transportation sector (WTT), as it affects regional imports; in this section, EVs are still the best option with close to overall 50% efficiency, followed by Hybrid EVs.

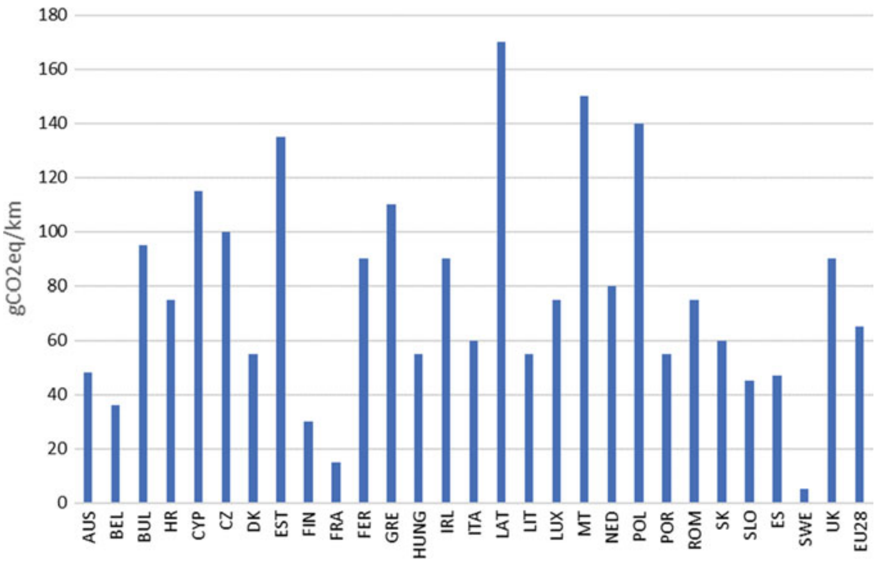

Fig. 6 WTW CO_2 emissions for electric vehicles in different EU Member States for 2013 generation mix [19, 20]

Table 1 WTW comparison of emissions and efficiency of different traction technologies

	WTT		TTW		WTW	
	Efficiency (%)	gCO_2/km	Efficiency (%)	gCO_2/km	Efficiency (%)	gCO_2/km
Gasoline EURO 6C	81	54.04	18	192	15	246
Diesel EURO 6C	86	42.96	21	170	18	213
GLP	88	47.77	15	181	13	228
GNC	89	25.82	18	162	16	188
FCEV	58	95	42	0	25	95
HEV	81	54.04	44	109	35	163
BEV	61	51.62	77	0	47	52

In relation to the rules on emissions from vehicles, Regulation (EU) 2019/631 of the European Parliament and of the Council of 17 April 2019, setting CO_2 emission performance standards for new passenger cars and for new light commercial vehicles, must be cited. This Regulation establishes CO_2 emissions performance requirements for new passenger cars and for new light commercial vehicles in order to contribute to achieving the Union's target of reducing its greenhouse gas emissions, as laid down in Regulation (EU) 2018/842, and the objectives of the Paris Agreement and to ensure the proper functioning of the internal market (article 1). It also establishes that the Commission shall no later than 2023 evaluate the possibility of developing a common Union methodology for the assessment and the consistent data reporting of the full life-cycle CO_2 emissions of passenger cars and light commercial vehicles that are placed on the Union market, and transmit to the European Parliament and to the Council that evaluation, including, where appropriate, proposals for follow-up measures, such as legislative proposals (article 7.10).

Other rules mentioned above may also be taken into consideration when dealing with the use of EV, such as those on the production of waste derived from such use. Some others are mentioned in the following section.

4 Environmental Effect Associated with the End of Life of EVs

When the vehicle ends its useful life, a process of disassembly and recycling of its different components begins, as shown in Fig. 7. In the process of recycling of EVs the valuable components are those that have metal parts that can be found in the body of the vehicle (mainly steel), battery pack (such as nickel, cobalt, manganese) and power train (aluminium and copper) [5]. The processes for recycling each metal are usually very energy intensive.

Regarding the battery, when its capacity reduces below 80% of the original value it is not appropriate for traction applications, and therefore needs to be retired. However, the battery can still be used for other applications such as stationary electrical storage devices. This application will be integrated into the power system, typically in low and medium voltages, to store energy integrated into a photovoltaic or wind power plants [23], to provide different services, such as reducing or eliminating congestions in the network, support voltages. Lifespan estimation for this second life of the battery can go from 6 to 30 years depending on the services they procured [24].

Finally, in case the capacity of the battery is exhausted with less than 20% of the original capacity value, the process starts from a pyrometallurgical furnace in

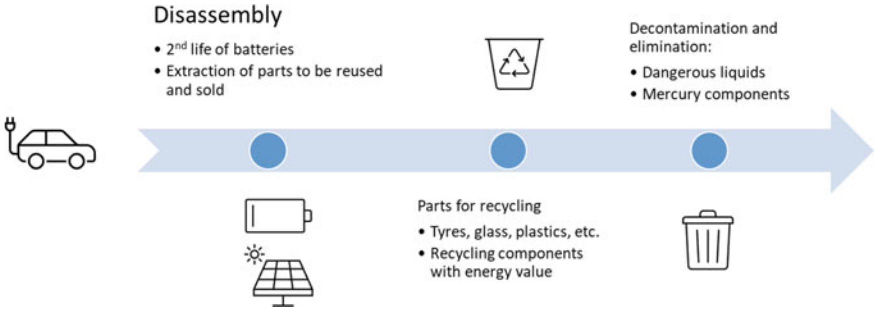

Fig. 7 Main processes at the end of the life cycle of the VE

order to recover cobalt and nickel. The slag is mainly composed of compounds of Aluminium, Silicon, Calcium, Iron and also Lithium Oxide. This slag can be used as an additive in construction or cement [25].

According to the Directive 2000/53/EC mentioned above, and among other rules, Member States shall take the necessary measures to ensure:

- that economic operators set up systems for the collection of all end of life vehicles and, as far as technically feasible, of waste used parts removed when passenger cars are repaired (article 5.1);
- the adequate availability of collection facilities within their territory (article 5.1);
- that all end of life vehicles are transferred to authorized treatment facilities (article 5.2);
- that all end of life vehicles are stored (even temporarily) and treated in accordance with the waste hierarchy and the general requirements laid down in article 4 of Directive 2008/98 cited above, and in compliance with certain minimum technical requirements set out in Annex I to the Directive 2000/53/EC (article 6.1);
- that any establishment or undertaking carrying out treatment operations fulfils at least the certain obligations as set out in the Directive, such as the following (article 6.3): (a) end of life vehicles shall be stripped before further treatment in order to reduce any adverse impact on the environment; (b) hazardous materials and components shall be removed and segregated in a selective way so as not to contaminate subsequent shredder waste from end of life vehicles; and (c) stripping operations and storage shall be so as to ensure the suitability of vehicle components for reuse and recovery, and in particular for recycling.
- that producers provide dismantling information for each type of new vehicle put on the market within six months after the vehicle is put on the market (article 8.3).
- (without prejudice to commercial and industrial confidentiality) that manufacturers of components used in vehicles make available to authorized treatment facilities, as far as it is requested by these facilities, appropriate information concerning dismantling, storage and testing of components which can be reused (article 8.4).

Member States shall set up a system according to which the presentation of a certificate of destruction is a condition for deregistration of the end of life vehicle (article 5.3). The Directive also sets certain reuse and recovery targets (article 7).

5 Overall Environmental-Global Impact of EVs

Once the impacts in the whole life cycle of EVs have been detailed in the previous sections, Fig. 8 summarizes these standarized impacts, with a focus in 3 relevant midpoints from the 18 defined in the ReCiPe Model: Global warming and depletion of mineral and fossil resources) [26]. Results compare different traction technologies in the utility segment (ICE and EVs) and two Lithium battery technologies for EVs (Li-NCM and Li-$FePO_4$). According to these results, the environmental impact of

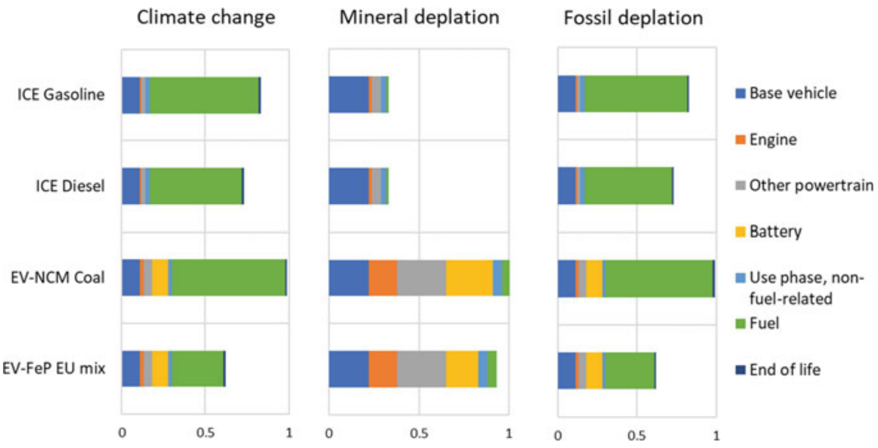

Fig. 8 Standardized vehicle impact (based on [26])

EVs is concentrated in the manufacturing phase of the batteries and the motor, while the impact of ICE-based vehicles is more relevant in their use phase. In case of EVs supplied with an average European generation mix, we would able to reduce the impact on global warming by up to 24% compared to ICE vehicles, and also Li-$FePO_4$ batteries have lower impact compared to Li-NCM [27].

The transition from conventional vehicles into electric mobility will have an impact on the use of natural resources and raw materials, and hence will certainly have international geopolitical effects. In the manufacturing phase, EVs (including hybrid and battery) need new raw materials, such as cobalt, lithium, rare earths and copper are required in high amounts. This will allow new players to enter into supply chain, such as Chile, Congo and China.

But it is even more important the use phase, where EVs will typically run with autochthonous energy sources such as renewables or coal in Germany or the UK. This represents a change with respect to current status based on the oil supply chain (diesel or gasoline and lubricants), where traditional oil production is concentrated in North America, Russia and the Middle East.

Therefore, as it is shown in Fig. 9, it is expected a change in the role of countries and regions as mayor suppliers of raw material for road transportation. This transition requires to adequality measure the possible negative environmental effects in the different areas to regulate in such a way that these effects could be eliminated or at least compensated. Although the estimations of EV sales in the coming years are relevant, the change of the vehicle fleet will be progressive, as it is expected that the upgrading rate of cars per year remains the same, typically 4%, leaving up to 25 years for a complete vehicle technological change.

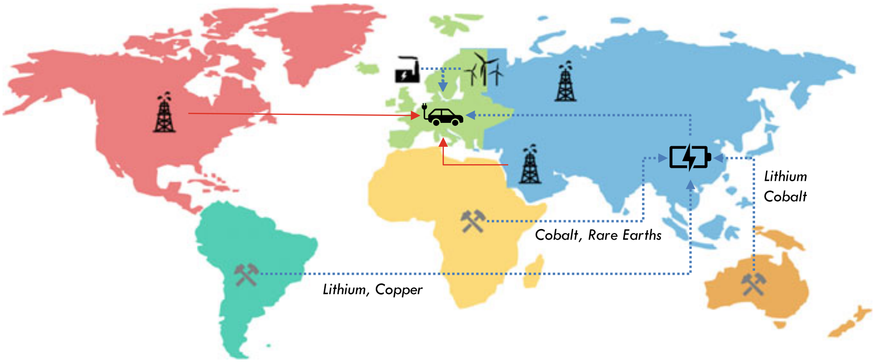

Fig. 9 Geopolitical effect of technology change in transportation (red: traditional supply chain, blue: EVs supply chain)

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