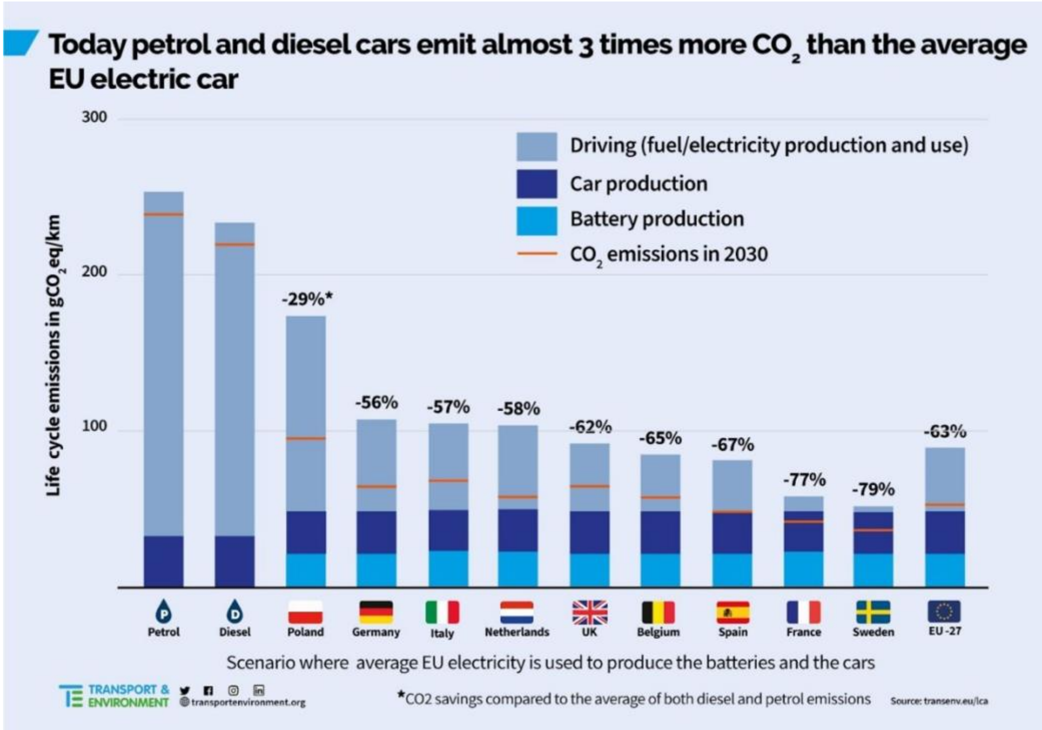
Electric Vehicle Batteries Frequently Asked Questions (FAQ)

June 2020

1. **Are Electric vehicles (EVs) better for the environment than Internal Combustion Engine (ICE) vehicles?**

Electric cars will reduce CO2 emissions four-fold by 2030 thanks to an EU grid relying more and more on renewables[1][2].

Electric cars in Europe emit, on average, almost three times less CO2 than equivalent petrol or diesel cars. Even in the worst-case scenario, an electric car with a battery produced in China and driven in Poland still emits 22% less CO2 than diesel and 28% less than petrol, as shown by the new calculation tool developed by Transport and Environment. In the best-case scenario, an electric car with a battery produced in Sweden and driven in Sweden can emit 80% less CO2 than diesel and 81% less than petrol.



The tool, along with numerous other studies, also firmly establishes the overall emissions advantage of EVs[3]: if carbon is also emitted when manufacturing EVs - as for ICEs - the environmental benefits of the vehicles over their total lifecycle clearly go in favour of EVs over ICEs, by up to 70% in countries with decarbonised power generation. Though figures can vary, some experts have anticipated a 50% reduction in the life-cycle emissions of an average EV by 2030[4].

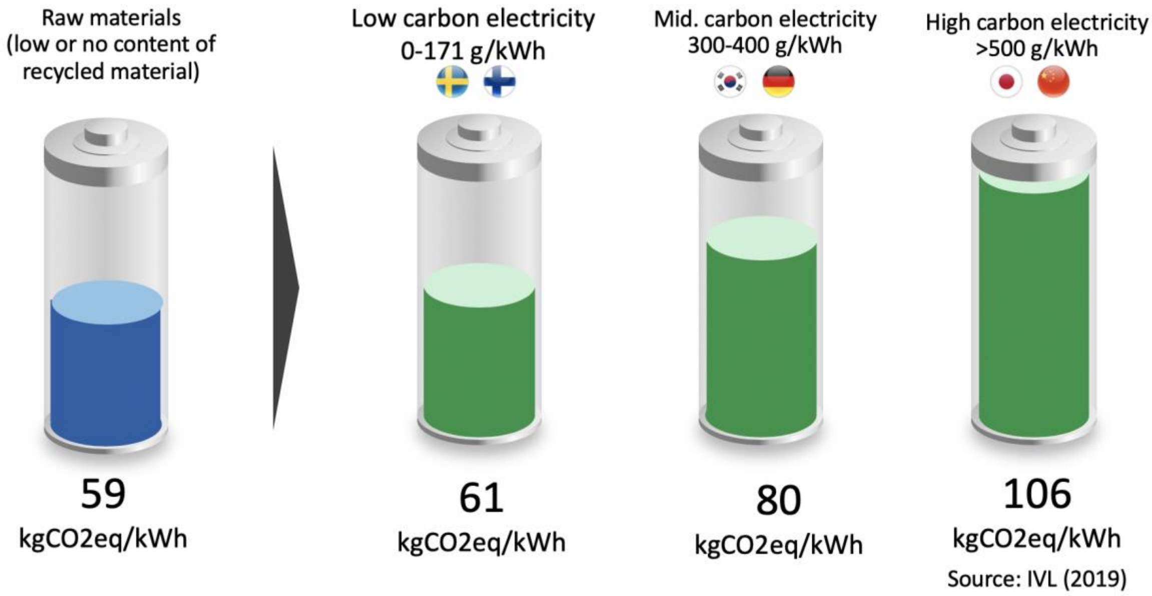
[1] Retrieved from: https://www.transportenvironment.org/news/does-electric-vehicle-emit-less-petrol-or-diesel, April 2020
[2] Retrieved from: https://www.transportenvironment.org/what-we-do/electric-cars/how-clean-are-electric-cars, April 2020
[3] Retrieved from https://www.law.berkeley.edu/wp-content/uploads/2020/04/Building-A-Sustainable-Electric-Vehicle-Battery-Supply-Chain.pdf, April 2020
[4] Retrieved from https://www.law.berkeley.edu/wp-content/uploads/2020/04/Building-A-Sustainable-Electric-Vehicle-Battery-Supply-Chain.pdf, April 2020

2. What is the impact of battery manufacturing and production on the environment?

The production of batteries is already 2-3 times better than 2 years ago and is getting cleaner every year [5]. This trend is expected to continue for the foreseeable future.

Batteries are energy intensive products. Together with the upstream emissions from mining, refining and transportation of the materials, the carbon emissions from the production of batteries accounts for about 20% to 40% of the total lifecycle greenhouse gas (GHG) emissions of an electric car[6]. In fact, 50-70% of the total carbon footprint of a traditional battery is related to the energy consumption in the production process[7].

The manufacturing step of the production process also accounts for a large share of the total carbon footprint. For instance, producing 1 kWh battery capacity requires about 60-80 kWh energy consumption. To decrease batteries' total carbon footprint, the use of natural gas and electricity from carbon intensive grids can be replaced by renewable electricity of less carbon intensive electricity mix (*see figure below)*.



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[5] Retrieved from: https://www.transportenvironment.org/news/ev-batteries-are-getting-cleaner-and-cleaner-2-3-times-better-2-years-ago, May 2020.
[6] Estimates can vary depending on the electricity that is used during the production phase and use phase of the vehicle. Retrieved from https://www.transportenvironment.org/news/does-electric-vehicle-emit-less-petrol-or-diesel, May 2020
[7] Retrieved from Erik Emilsson, Lisbeth Dahllöf (2019) Status 2019 on Energy Use, CO2 Emissions, Use of Metals, Products Environmental Footprint, and Recycling, IVL, May 2020
[8] Retrieved from Northvolt. May 2020

There are several improvements that contribute to the decreasing environmental impact of battery manufacturing. These range from:

- The use of carbon neutral electricity generated on site as well as the decarbonisation of the electricity grid across all EU countries;
- Efficiency gains in the manufacturing processes, among others thanks to economies of scale;
- Battery chemistry and density improvements that allow us to produce batteries with less raw material and reduce or eliminate the use of the most impactful materials such as cobalt;
- Recycling of battery materials through dedicated recycling facilities striving towards more efficient and environmentally optimal processes;
- Continued efforts to incorporate increasing rates of recycled materials in new batteries;
- Vertical integration and relocalization of the production process to reduce the impact of transportation.

Finally, in Autumn 2020, the European Commission will propose new measures and policies to ensure that materials for batteries are sourced responsibly. This will provide a huge boost to the sector and help clean up the environmental footprint of battery manufacturing in the EU in particular. At the same time, it will create the conditions for a competitive battery recycling industry in Europe and ensure that EV battery production is in line with the EU's circular economy and long-term climate goals.

3. What materials is an average EV Lithium-Ion Battery composed of?

Nowadays, different types of lithium-ion batteries are generally used to provide traction for on-road electric vehicles, thanks to their high energy density, long lifetime and superior cycling. As an indication, the following chemical make ups are found in the majority of EVs:

- NMC: Lithium, Nickel, Manganese, Cobalt, Graphite

- NCA: Lithium, Nickle, Cobalt, Aluminium, Graphite

- LFP: lithium, iron, phosphate, aluminium, graphite, copper

A range of different battery technologies (lithium, lead, sodium and nickel-based) are available on the market to serve different applications.

In lithium batteries, lithium ions move between the anode and the cathode, creating electricity flow necessary for electronic applications. The specific materials used define the chemistry of the battery, and offer different combinations in terms of energy density, lifetime, power/energy ratio, etc. There is no one-size-fits-all: each battery technology is designed and best suited for a specific application.

A non-exhaustive list of materials used in different types of lithium-ion batteries include lithium, nickel, manganese, cobalt, graphite, aluminium, copper, iron, plastic.

4. Where do the raw materials for EV batteries come from?

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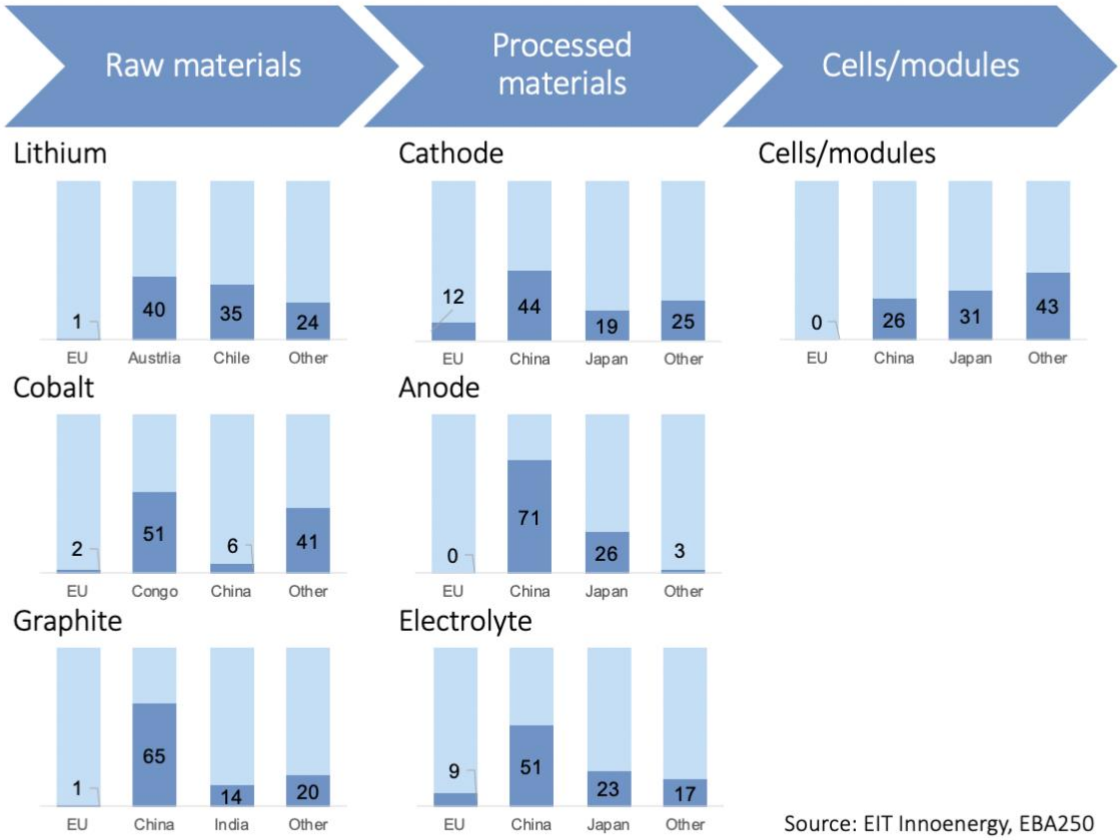

5. Do all batteries use cobalt and does all cobalt come from the Democratic Republic of Congo (DRC)?

Cobalt has shifted from making up about 30% of the active cathode material in a battery to less than 10% in the new generation of cells, and the cobalt share is expected to decrease even further in future chemistries[10].

While cobalt remains a key ingredient in battery cells, securing a certain level of access to cobalt will remain necessary. Cobalt that can be extracted responsibly and in a sustainable way is important, along with the development of technology allowing the use of secondary (recycled) material.

A large majority (64%), but not all, of the global supply of cobalt today comes from the Democratic Republic of Congo[11] (*A full overview of the raw material supply chain including*

[9] Retrieved from Strategic Actionplan on batteries. https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52019DC0176&from=EN, May 2020

[10] Retrieved from: https://www.mckinsey.com/~/media/mckinsey/industries/metals%20and%20mining/our%20insights/lithium%20and%20cobalt%20a%20tale%20of%20two%20commodities/lithium-and-cobalt-a-tale-of-two-commodities.ashx, May 2020

[11] Retrieved from: https://www.reuters.com/article/us-congo-cobalt-ahome/why-the-cobalt-market-needs-congos-illegal-miners-andy-home-idUSKCN1U71VS, May 2020

cobalt can be found in Q4).To a large extent, this material goes to China. Current levels of cobalt in cells are expected to continue to decrease, driven mainly by higher demands on cell energy capacity. The energy density increases with higher nickel content, which in turn decreases the cobalt content of the active cathode material.

At the same time, currently there is an increased global awareness and demands from international and European civil society and industry stakeholders to improve the current situation in the DRC. In fact, some are already taking concrete action to guarantee the safe and ethical extraction of cobalt. Specifically, certain industry stakeholders are ensuring their entire supply chain abides by both international labour and human rights guidelines[12] while others have developed a unique Sustainable Procurement Framework for the ethical sourcing of cobalt in the Congo[13].

6. What is the average lifetime of a lithium-ion EV battery?

The average lifetime of a lithium-ion EV battery is expected to be around 8 years, which is the time covered by most Original Equipment Manufacturer (OEM) warranties. Battery lifetime can also increase through relevant secondary use.

Crucially, the lifetime of a lithium-ion EV battery is expected to increase as battery technologies improve and as global battery prices drop due to the sharp demand expected in the coming five to ten years. Besides, an EV battery can last at least as long as the lifetime of the vehicle itself, essentially guaranteeing a minimum degree of maintenance for consumers.

At the same time, it is key to keep in mind that not all EV batteries are the same and therefore that their lifetime can differ significantly. Key factors, include:

- Cyclical aging (how many full charge-discharge cycles the battery can handle);
- Number of kilometres per full cycle;
- Calendar aging (how quickly the battery degrades over time);
- Charging-rate: power that is on average used to charge the battery;
- Constantly improving with technology.

There are also several factors[14] that affect the batteries' state of health and therefore the overall lifetime of the EV battery. These include:

- External outside temperatures (high or low);
- High discharging/charging current;
- High/low state of charge/discharge
- Driver use;
- Extreme climate and charging type.

Additionally, and as a general rule in terms of battery degradation and therefore important for the overall lifetime of a lithium-ion battery, EV batteries are expected to decline non-

[12] Retrieved from: 'Chapter 2.2.3' https://group.renault.com/wp-content/uploads/2019/03/renault-nissan-csr-guidelines.pdf, June 2020
[13] Retrieved from: https://www.umicore.com/en/cases/sustainable-procurement-framework-for-cobalt/, June 2020
[14] Retrieved from: https://www.geotab.com/blog/ev-battery-health/, May 2020

linearly: starting with an initial drop, which then continues to decline but at a far more moderate pace. Towards the end of its life, a battery is likely to see a final significant drop.

Typical warranty coverage is around 8 years or 160,000 km (100,000 miles), but this varies by manufacturer and country. A guaranteed percentage of battery retention capacity is not always included in all manufacturers' warranties. This is already 2-3 times longer warranty time than the basic warranty coverage of the car they are placed in[15].

7. Will we run out of certain raw materials needed for EV production?

The EU is aware of the scarcity of certain raw materials needed for the production of EVs. For that reason, both the EU and industry stakeholders have been working together through various initiatives (Batteries Europe, European Battery Alliance, Battery 2030+) which are analysing how to ensure the sector increases its sustainable practices and promotes the use of secondary raw materials.

Further to this, the EU is developing legislation in 2020 which will, amongst other things, regulate and incentivize how lithium-ion EV batteries are recycled in Europe.

A sustainable and competitive global raw materials supply chain is key for the accelerated production of EVs across Europe. Currently, the majority of raw materials (i.e. cobalt, lithium, nickel, manganese, and graphite) needed to power electric cars are found and mined outside of Europe, specifically in Asia, Africa, and South America. Notably, the majority of the global supply of cobalt (64%) is found in the Democratic Republic of Congo[16]. (*A full overview of the raw materials used/sourced for EV batteries can be found under Question 4 above)*.

Furthermore, a large increase of metals will be needed for EV batteries in order to meet rising expected demand. Specifically, it has been found that we will need 3 times the amount of cobalt to meet the expected demand by 2025, surpassing actual 2018 global production and 3.5 times for lithium, representing 75% of the global production by 2025[17].

The EU is in the process of taking concrete action to address the potential risk of running out of key raw materials. At the same time, the EU has the ambition to develop its own domestic raw material industry as a lever for economic growth.

In terms of legislation, the EU is in the process of developing an overarching Battery Strategy which will, amongst other things, regulate and incentivize how lithium-ion EV batteries are recycled in Europe. This will be one way for the EU to secure reliable and sustainable access to relevant secondary raw materials and ensure that these materials stay on the continent.

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[15]A full overview of the battery warranties for EVs currently on the market (as of 2019) can be found here: https://insideevs.com/news/342221/which-electric-cars-offer-the-best-warranties/

[16]Retrieved from https://www.reuters.com/article/us-congo-cobalt-ahome/why-the-cobalt-market-needs-congos-illegal-miners-andy-home-idUSKCN1U71VS, May 2020

[17] Retrieved from: https://ec.europa.eu/transport/sites/transport/files/3rd-mobility-pack/swd20180245.pdf, May 2020

Apart from concrete legislation, the EU is supporting various initiatives[18][19][20][21] which are all aimed at bolstering Europe's domestic battery manufacturing and raw materials industries.

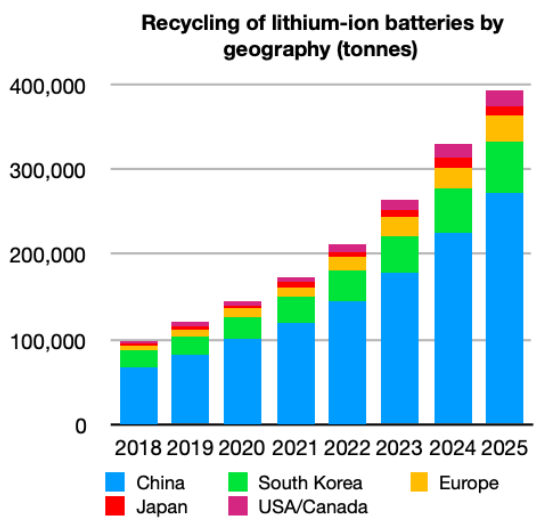
As the industry matures, responsibly sourced materials is in the interest of all OEMs. Recycling and technology improvements of EV batteries will only continue to contribute to a better and more sustainable material sourcing approach.

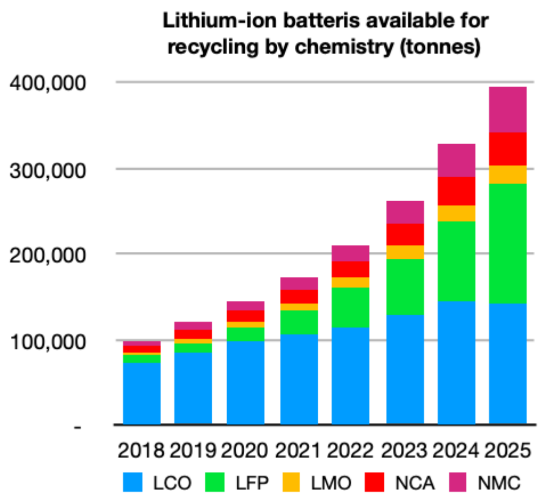
8. Can lithium and other materials contained in the EV batteries be recycled?

The vast majority of today's Lithium-ion batteries are recycled. Recycling is undertaken using efficient technologies that produce large yields of high-quality material, thereby optimising the environmental benefits stemming from the end of the batteries' life.

The situation for EV battery packs is quite different from portable batteries, as they are much larger, more complex in design and build, and feature Lithium-ion cells based around new chemistries. Today, there are around 50 companies around the world that recycle lithium-ion batteries on some scale, mostly located in China, followed by South Korea, EU, Japan, Canada and the US. The structure and methods used for recycling vary based on the specific markets[22].

Moreover, the vast majority of Lithium-ion batteries are recycled, and this recycling is undertaken using effective technologies, producing large yields of high-quality material. A full breakdown of EV recycling by geography and chemistry can be found in the charts below.





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[18] Retrieved from https://eitrawmaterials.eu/, May 2020
[19] Retrieved from EBA250.com, May 2020
[20] Retrieved from https://battery2030.eu/, May 2020
[21] Retrieved from https://www.eera-set.eu/component/projects/projects/20-projects/69-batteries-europe.html, May 2020

[22] Retrieved from: Hans-Eric Melin, 'State of the art in reuse and recycling of lithium-ion batteries – a research review', commissioned by the Swedish Energy Agency, July 2019, May 2020
[23] Retrieved from http://www3.weforum.org/docs/GBA_EOL_baseline_Circular_Energy_Storage.pdf, May 2020

The two main recycling processes for batteries are pyrometallurgic and hydrometallurgical recycling. In these processes battery (active) raw materials are recovered and can be used for the production of new batteries. A full overview of the main recycling processes can be found below.

MECHANICAL	PYROMETALLURGICAL	HYDROMETALLURGICAL	THERMAL PRE-TREATMENT + HYDROMETALLURGICAL
Dismantling to cell or pack level Crushing (hammer mill) Classifying Scrap fractions generated Black mass with valuable metals (Co, Ni, Mn, Li, etc. are recovered)	High-temperature processing aimed at recovery or refinement of metals at elevated temperature Works under a separation principle producing two phases Slag phase where Li, Mn, Al are lost Recovers Co, Ni, Cu, Fe in a metal phase (alloy) Electric arc furnace and shaft furnace are used	Treatment of aqueous solutions to separate components Black mass is treated by leaching, cementation, purification, solvent extraction or precipitation methods to extract valuable components	Low-temperature thermal treatment aimed at removing organic compounds and graphite (carbon oxidation) Allows phase transformation into water soluble lithium carbonate Has low energy requirements

[24]

9. Won't EV batteries just end up in landfills?

The Battery Directive and End of Life Vehicles (ELV) Directive will both be reviewed in 2020. The revision will notably focus on continuously improving collection rates and schemes for EV batteries and vehicles.

A major misconception about EV batteries is that they are not collected and recycled, but rather end up in landfills with negative impact on the environment. From a legislative point of view, the Batteries Directive already forbids landfilling and incineration (Art. 14), resulting in an implicit 100% collection target for automotive and industrial batteries.

EV batteries are also already regulated as part of the vehicle they are placed in. As such, the obligation to collect end of life vehicles is already described in the End of Life Vehicles (ELV) Directive. Involvement of the car owner on servicing electric powertrains currently is and is expected to stay minimal, and professional actors actively participate in the implementation of efficient take-back systems. However, the ELV Directive is expected to be revised to prevent illegal exports of vehicles outside of the EU and make sure that they are properly and effectively tracked and collected.

[24] Retrieved from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Oct/IRENA_Electricity_Storage_Costs_2017.pdf, May 2020

10. Do I need to fully charge my EV battery every day?

No. With ranges higher than 300km[25], in most cases there is no need to fully charge the battery, except if one plans to make a long journey. With such a use pattern, the battery will keep a better state of health. Also, keeping the State of Charge (SoC) of the battery at an intermediate level has the long-term potential to allow owners to make revenues by offering services to the grid through Mobility Service Providers, Aggregators or similar service providers, for instance via smart charging (V1G) and Vehicle-to-grid (V2G).

11. What are the potential business models for EV batteries after their first life?

At the end of their first life, some EV batteries may have the potential to provide useful services as stationary storage to the electricity grid or locally (i.e. to a consumer's house).

The reuse of EV batteries in post-vehicle applications corresponds to what is commonly known as the 'second life' of EV batteries. These 'second life' applications have the potential to create value and potentially amplify the environmental benefits brought by electric vehicles and their batteries over their lifetime, with a potential 42% price reduction compared to new batteries[26] depending on their state of health and on the technological evolution of batteries in the coming years. Some companies are investing in this possibility, while others prefer to recycle the battery at the end of its life to reflect the shorter optimal lifetime expected in future batteries, making recycling more environmentally beneficial from a material and CO2 savings standpoint. Such recycling includes reusing valuable materials to manufacture new batteries.

Second life batteries can be used as stationary batteries on and off grid to store electricity and provide services to the electricity grid. The use of new and second life stationary storage batteries would provide a boost to variable renewable energy sources (VRES) deployment, displace fossil fuels and peaking power plants, reduce energy cost to consumers and reduce CO2 emissions.

The second life market, is however, still an emerging niche sector, with a handful of small-scale European players, and under limited regulatory control[27].

12. How is range affected by extreme ambient temperatures?

Temperature variations can affect battery autonomy, but new homologation testing procedures are more accurate than before.

[25] Retrieved from http://www.trt.it/wp/wp-content/uploads/2012/12/driving-and-parking-patterns-final_online.pdf, May 2020

[26] Retrieved from Element Energy Batteries on wheels: the role of battery electric cars in the EU power system and beyond, 2019", May 2020

[27] For more information regarding the demonstrated benefits of second life, see the 2019 study by Ricardo Energy & Environment 'Circular Economy Perspectives for the Management of Batteries used in Electric Vehicles'

The real autonomy of electric vehicles is affected by temperature conditions, the autonomy of the battery being lower when temperatures go down. Batteries are temperature sensitive but modern electric cars have insulated batteries that are heated in winter.

The autonomy prescribed by OEMs is measured following new procedures. The current WLTP[28] measures are better and more efficient than the previous measures which makes the difference observed in ambient temperatures smaller than before and more accurate to reflect real driving conditions.

13. Isn't Europe lagging behind the rest of the world in terms of lithium-ion battery production?

The European Battery Alliance launched in October 2017 was created for the precise purpose to increase the EU's competitiveness of lithium-ion battery production.

Current lithium-ion battery cell production projections nowshow that Europe will surpass the US by 2024 and claim 17.9% of the global market by 2029.

The European Battery Alliance (EBA), launched by Vice-President Maroš Šefčovič in October 2017 intends to engage the European industry in seizing the opportunity brought by batteries and in particular to support the production of batteries in Europe. In the beginning when the EBA was launched, it was stated that the European market potential for batteries could be worth up to EUR 250 billion annually from 2025 onwards. It is was also estimated that 20-30 giga-factories for battery cells production alone will have to be built in Europe in order to meet the demands stemming the EU's carbon neutrality by 2050 goal[29].

The Commission has also launched a European Technology and Innovation Platform (ETIP) "Batteries Europe" to advance battery research priorities bringing together industrial stakeholders, the research community and EU Member States to foster cooperation and synergies between relevant battery research programmes. This platform enables co-operation between the numerous battery-related research programmes launched at EU and national levels, as well as private sector initiatives.

Progress and latest developments across battery supply in Europe are worth highlighting. Europe has gone from a position of having hardly any lithium-ion battery cell production for the automotive sector to a 5.9% share in 2019. Projections from Benchmark Mineral Intelligence show that Europe will even surpass the US by 2024 and claim 17.9% of the global market by 2029. Moreover, as of 2019, the 260 industrial and innovation actors involved in the EBA have announced a consolidated private investment of up to EUR 100 billion, covering the whole value chain[30].

[28] Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02017R1151-20200125&from=SV, May 2020

[29] Retrieved from https://ec.europa.eu/commission/sites/beta-political/files/report-building-strategic-battery-value-chain-april2019_en.pdf, May 2020

[30] Retrieved from https://www.eba250.com/battery-industry-development-europe-is-gaining-momentum/, May 2020