Electric vehicle life cycle analysis and raw material availability

October 2017

Summary

As the automotive industry is on the brink of a major electric transition, environmental performance of EVs has become a highly debated topic. This briefing addresses two critical aspects of this debate, namely the climate impact of EVs and the use of critical metals, including rare earth minerals.

The lifecycle analysis of EVs shows that even when powered by the most carbon intensive electricity in Europe, they emit less GHG than a conventional diesel vehicle. As more renewable electricity enters the European grid, the climate impact of EV will further diminish. Likewise, technological improvement of battery chemistry, the reuse of battery for storage purposes, and the development of a recycling industry for EV batteries will lead to improvements in their sustainability.

Critical metals and rare earth minerals will not be constrained in the coming decades and won't stop the EV transition, as some have argued. Supply of these materials will have to be closely monitored and diversified to avoid being overly dependent on imports, as is the case with oil today. To this extent, innovation will in the long term contribute to reduce the quantity of critical metals used in EVs.

1. Introduction

This briefing addresses two of the criticisms against electric vehicles (EV), their environmental impact on a lifecycle basis; and the availability and use of critical metals. The analysis of the life cycle emissions of EV is based on a study carried out by Dr. Maarten Messagie, Brussels VUB university MOBI research center.[1] It compares the performance of EVs based upon charging using different electricity mixes across Europe to a conventional diesel vehicle, and demonstrates that a shift delivers climate benefits today, even in countries with the highest grid carbon intensity. Low grid carbon intensity now and in the future delivers substantial climate benefits.

The second part of this briefing looks at the demand and availability of critical raw materials (such as lithium, cobalt, nickel, graphite, and rare earths) used in batteries and electric motors. There can be expected to be a massive increase in demand arising from a growth in electric vehicles. The briefing considers current and projected supply and demand, and concludes that physical shortages of such materials are unlikely. However, the extraction of these metals needs to be certified against high social and environmental standards. In the long term, re-use, recycling, and progressive substitution of these materials should generalise.

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[1] https://www.transportenvironment.org/sites/te/files/2017_10_LCA_of_climate_impact_EVs.pdf

2. LCA performance of electric vehicles

EV LCA is a topic of increasing importance, with an extensive literature in recent years. However, findings do not reflect an entirely consistent assessment of the cradle to grave performance of electric cars mainly because of variations in the assumptions, especially differences in the carbon intensity of the electricity mix used; the inappropriate use of test results; no real world tailpipe emissions; and the lifetime of key components such as the glider or the battery. The boundaries and the scope of the work also account for significant variations between studies. While some studies only consider the Well to Wheel (WTW) performance of EVs covering only the life cycle of the energy carrier used to drive the vehicle; others address the entire life cycle performance (including production of the battery).

WTW studies emphasise the importance of the carbon intensity of the electricity production; and the degree of electrification of the vehicle - full electric (BEV), range-extended (REEV), or plug in hybrid (PHEV) vehicles. Figure 1 illustrates the WTW performance of BEVs depending on the energy source used to produce electricity, and uses the EU mix average to compare the performance of different vehicle electrification levels.[2] Based on the 2015 EU electricity mix, a BEV emits around half of the WTW CO2 emissions generated by a conventional car.[3] If the vehicle was charged exclusively on coal generation the emissions are of a similar order but can be slightly higher in a worst case. Whilst some national grids (like Poland) are highly dependent upon coal it has an average grid carbon intensity of around half dedicated coal generation.

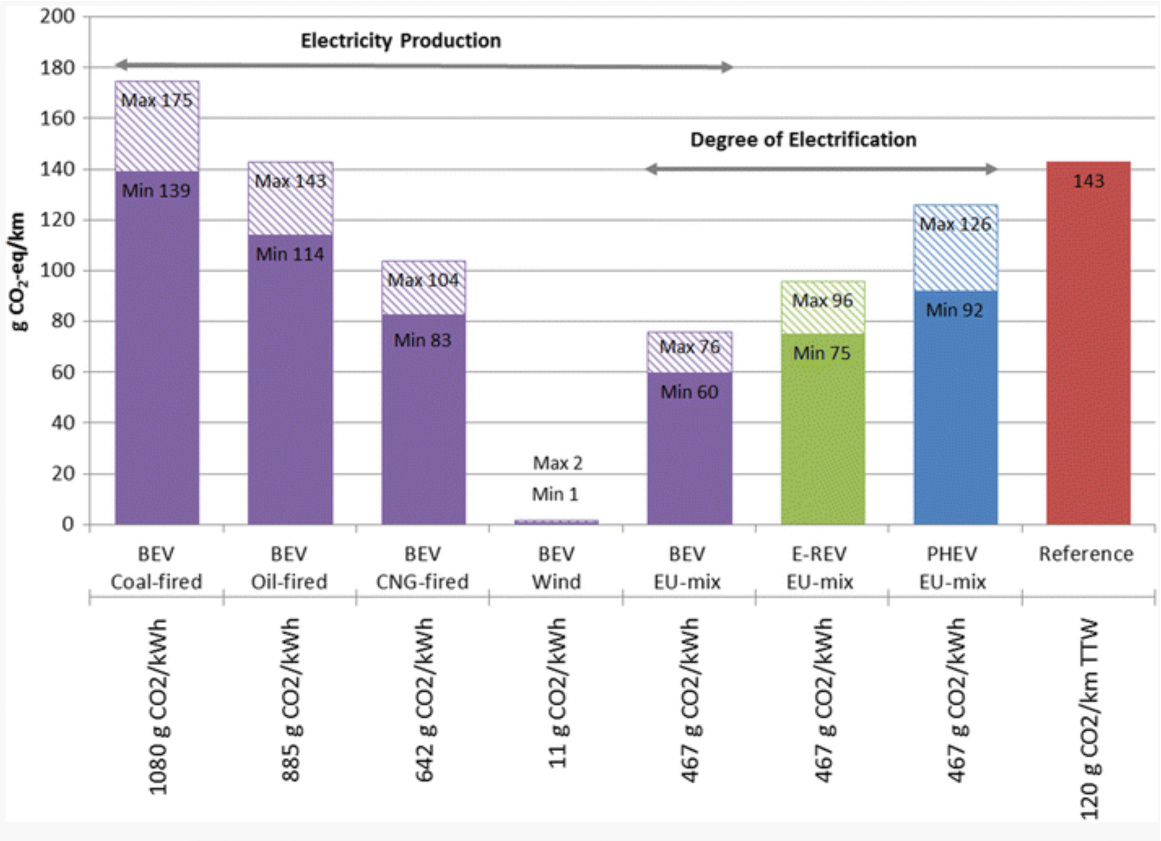

Figure 1: WTW emissions of EVs on different electricity mix compared to other powertrains

Expanding the approach to cover the entire LCA performance of electric vehicles to include the equipment cycle (batteries, powertrain, glider), the climate change impact of a diesel car amounts to 230% that of a BEV (see figure 2). This assumes cells manufactured outside of Europe with a high carbon electricity source.

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[2] Figure 1 aggregates the results of 79 different studies, and specifies the maximum and minimum values. Source: https://link.springer.com/article/10.1007/s11367-014-0788-0

[3] In figure 1, the reference vehicle corresponds to the 2012 EU fleet target for tailpipe emissions of sold cars.

Figure 2 details the contribution of different components of the battery electric and diesel vehicles to the total vehicle GHG emissions. About a third of the emissions in the BEV originate in the production of the vehicle compared to less than 10% for the diesel.

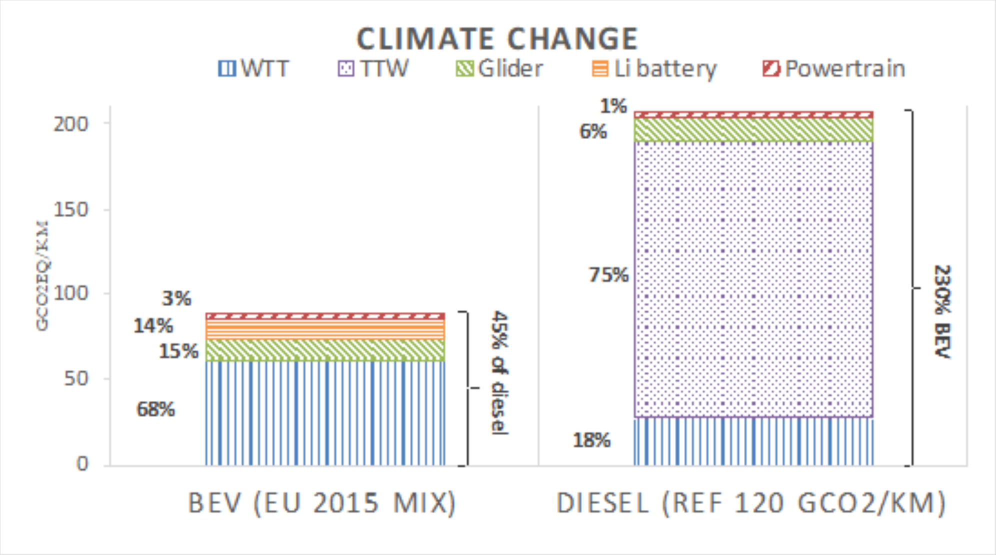

Figure 2: Significance of the various life cycle stages[4]

The battery manufacturing process could improve in coming years, for example cells made largely using renewable electricity. In that case, the impact of battery manufacturing on the LCA would be reduced of 65%.

The source of the electricity production has the greatest impact on the LCA climate performance of BEVs and varies widely between countries depending on electricity mixes.[5] Figure 3 groups countries by their grid average carbon intensity: low (e.g. Sweden, France...); average (e.g. Belgium, Italy…); and high (Germany, Poland...).

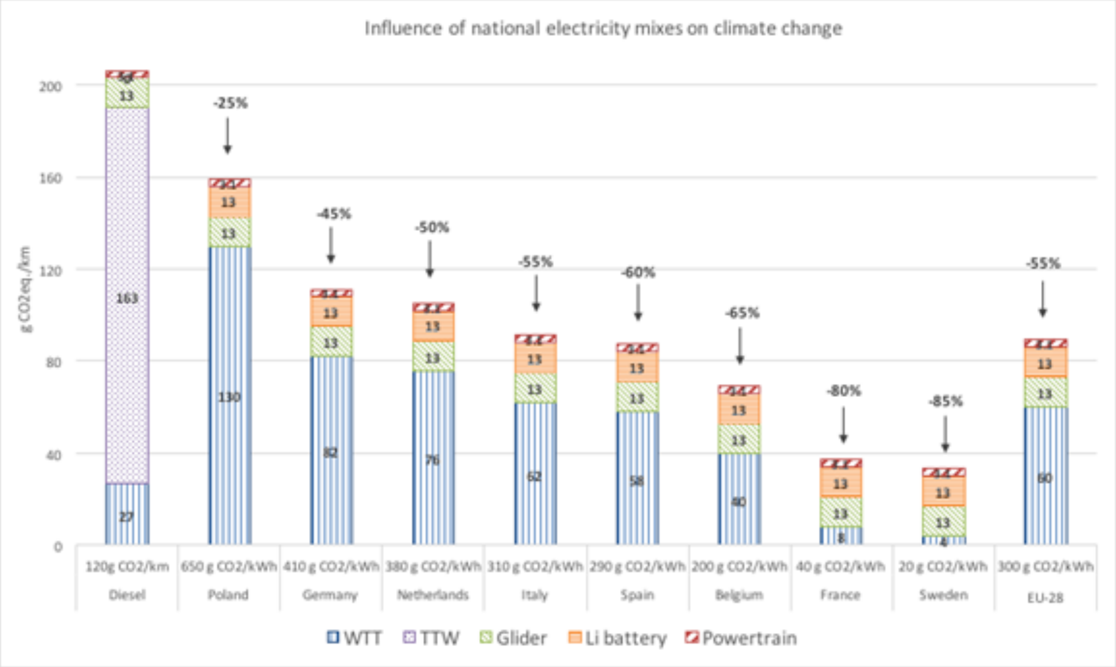

Figure 3: Influence of the carbon footprint of national electricity grid on the comparison of life-cycle GHG emissions of BEVs

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[4] For the production of the battery, following has been assumed: 30kWh LMO battery (average of 55 kgCO2/kWh); 1,5 battery replacement is needed over the life time of the vehicle.

[5] https://ec.europa.eu/energy/sites/ener/files/documents/20160713%20draft_publication_REF2016_v13.pdf

Even in countries with the highest GHG intensity of electricity generation, (Poland and Germany), the BEV performs better on a lifecycle basis than the diesel car. Using the Polish average, an electric vehicle emits 25% less CO2 over its lifetime. The GHG footprint associated with driving a BEV in Sweden is 85% lower than for the benchmark diesel car.

Figure 4 reflects the impact of the energy source on the vehicle carbon footprint. Unsurprisingly, renewable energy sources such as wind and solar lead to the greatest savings. Electricity mixes reliant on natural gas and especially hard coal significantly increase the climate impact of BEVs.
The number of EVs will be increasing in the next decade at a time the electricity generation is improving, with more renewables entering the grid. This means that the lifecycle performance of electric vehicles is only set to improve in coming years, as the prognosis of the EU's carbon footprint indicate.

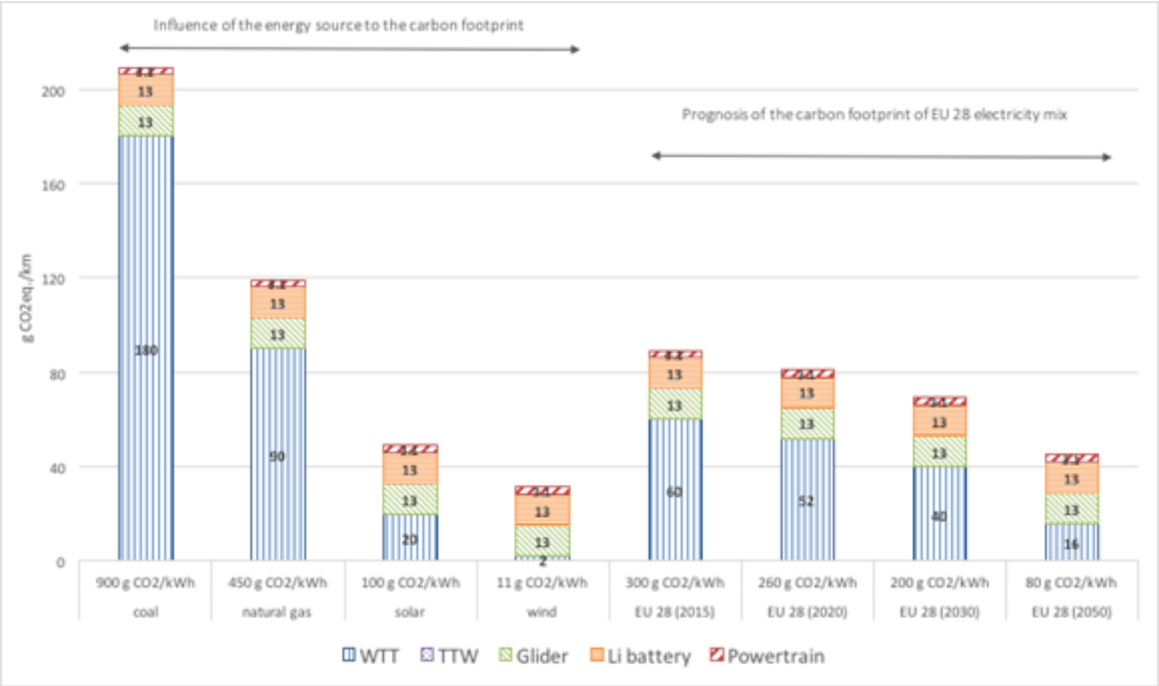

Figure 4: GHG emissions of electric vehicles depending on the energy sources and the prognosis of the reduction in carbon intensity.

Projections are that the EU grid mix will reduce from 300gCO2 eq/km in 2015, to 200 in 2030, and reach 80 in 2050. By then, the WTW carbon footprint of EVs will be dominated by the emissions associated with battery and glider production. Renewable-based battery manufacturing coupled with new chemistries that require less critical, energy intensive metals will however further optimize the LCA of EVS.

As more EV batteries are produced and cars reach the end of their lifetime, a market will emerge for second hand batteries to be used for stationary storage purposes, as is already the case for used Nissan batteries.[6] The reuse of batteries will extend their lifetime before being eventually recycled. This second life for batteries will also reduce the emissions of the battery production since these will be amortised over a longer period. This reuse also is a sustainable solution to reduce demand for critical metals, which also has increasingly attracted public attention lately. They are covered in the second part of this briefing.

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[6] https://www.cips.org/supply-management/news/2017/may/nissan-launches-home-battery-in-the-uk-to-rival-teslas-powerwall/

3. Critical metal availability for electric vehicles

3.1 Demand for critical minerals in EVs

Use of critical metals in EVs

The production of electric vehicles, like a variety of other high-tech applications, necessitate the use of critical metals, including so-called rare earth elements (REE). EV batteries are predominantly Lithium-ion batteries, (e.g. NCA, NMC[7]), which use Lithium, Cobalt, Nickel, and Graphite.[8] The figure below illustrates the composition of a typical Li-ion cell:

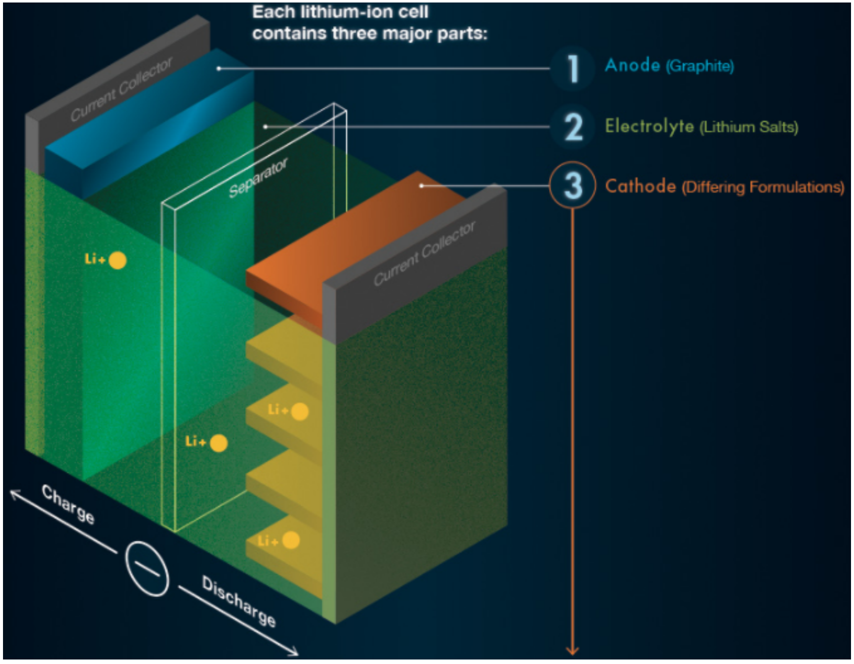

Figure 5: Composition of li-ion cells[9]

Li-ion cells use a cathode (positive electrode), an anode (negative electrode) and electrolyte as conductor. The cathode is mainly composed of Nickel (73%), Cobalt (14%), Lithium (11%), and Aluminium (2%). The anode is usually completely made of graphite.[10] The electrolyte consists of Lithium salts (the most common being lithium hexafluorophosphate, LiPF6) in an organic solvent.[11]

Electric motors include a number of rare earth elements (REE), a group of 17 chemical elements[12] which are despite their name not especially scarce resources but are available in only small amounts dispersed on the Earth's crust. Most electric vehicles (with the exception of Tesla) use Neodymium Iron Boron permanent magnets (NdFeB), which are essential to produce high-performance electric motors.[13] Such magnets contain Neodymium (Nd), Praseodymium (Pr), and Dysprosium (Dy) Rare Earth Elements.[14]

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[7] NCA (Lithium nickel cobalt aluminium oxide) are typically used in Tesla models, while NMC (Lithium manganese cobalt oxide) is the chemistry used for the BMW I3 or Renault ZOE. See: http://www.ivl.se/download/18.5922281715bdaebede9559/1496046218976/C243+The+life+cycle+energy+consumption+and+CO2+emissions+from+lithium+ion+batteries+.pdf

[8] http://www.ivl.se/download/18.5922281715bdaebede9559/1496046218976/C243+The+life+cycle+energy+consumption+and+CO2+emissions+from+lithium+ion+batteries+.pdf

[9] http://uk.businessinsider.com/materials-needed-to-fuel-electric-car-boom-2016-10?r=US&IR=T

[10] https://www.bloomberg.com/graphics/2017-lithium-battery-future/

[11] http://pubs.rsc.org/en/Content/ArticleLanding/2015/EE/C5EE01215E#!divAbstract

[12] http://www.namibiarareearths.com/rare-earths.asp

[13] https://setis.ec.europa.eu/setis-reports/setis-magazine/materials-energy/electric-vehicles-and-critical-metals-jamie-speirs

[14] http://www.sciencedirect.com/science/article/pii/S2214993716300641µ

Current demand for critical metals

The expected increase in EV sales has sparked a vivid discussion regarding the availability of critical metals. However, available reserves indicate that resources of main critical metals (e.g. lithium, cobalt, graphite, and REE) are unlikely to limit increasing EV production although there could be short-term supply constraints if the market increases too quickly.
Worldwide lithium production in 2016 amounted to 35,000 tons. Data from the US geological survey estimate lithium resources worldwide at approximately 40 million tons.[15] According to Deutsche Bank and Bloomberg, these reserves could last for an estimated 185 years, even if the market triples.[16]

For Cobalt, estimated reserves in the three leading countries (DRC, Australia, Cuba) amount to nearly 5 million tons[17]; whereas today, about a little less than 45,000 tons of cobalt refined worldwide goes into EV production.[18] Graphite reserves are estimated at about 250 Mt[19], while Benchmark Intelligence estimates demand for graphite driven by anode manufacturing to reach 250 000 tons in 2020.[20] Likewise, known reserves for Nickel (78,000,000 tons) compared to the 2016 production (2,500,000 tons), suggest that nickel supply will not jeopardize the transition to EVs.[21]

REE are difficult to mine because they are rarely found in concentrations high enough to allow for profitable economic extraction. The European Commission estimates the global reserves of rare earth oxides at more than 80,000,000 tons; whereas average yearly production between 2010 and 2014 amounts to 135,650 tons.[22] But availability varies depending on the type of rare earth: based on known geologic reserves and security of supply issues, the US Department of Energy identified a risk of supply constraints for Neodymium and Dysprosium, two main components of electric magnet rotors (see Figure 6). In 2015, half of the global demand for REE originated from magnets built into permanent electric motors, which are used in most electric vehicles.[23]

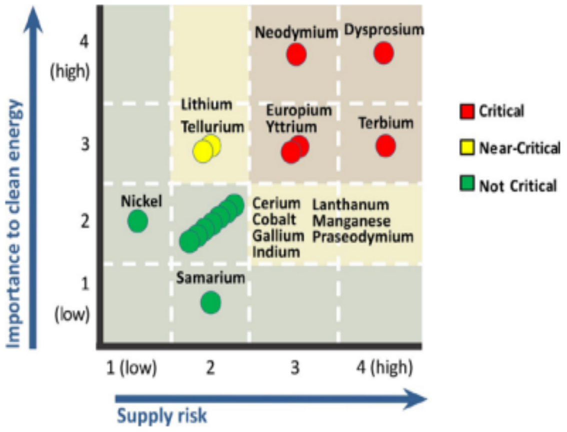

Figure 6: Medium term (5-15 years) criticality matrix, US DOE[24]

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[15] https://minerals.usgs.gov/minerals/pubs/commodity/lithium/mcs-2017-lithi.pdf
[16] https://www.bloomberg.com/graphics/2017-lithium-battery-future/
[17] http://www.bgs.ac.uk/mineralsuk/statistics/worldStatistics.html
[18] https://www.ft.com/content/4f88cb60-f8f7-11e6-bd4e-68d53499ed71
[19] https://www.statista.com/statistics/267367/reserves-of-graphite-by-country/
[20] http://uk.businessinsider.com/materials-needed-to-fuel-electric-car-boom-2016-10?r=US&IR=T
[21] https://minerals.usgs.gov/minerals/pubs/commodity/nickel/mcs-2017-nicke.pdf
[22] https://publications.europa.eu/en/publication-detail/-/publication/7345e3e8-98fc-11e7-b92d-01aa75ed71a1/language-en
[23] http://www.namibiarareearths.com/market-demand.asp
[24] http://www.rareearthassociation.org/DoE%20Critical%20Materials%20Strategy%20Report.pdf

Where do critical metals currently come from?

Most of the known reserves of Lithium are in Bolivia and Argentina (ca. 9 million tons), Chile (7,5 millions), Australia (more than 2 millions) and China (more than 7,5 millions).[25] Current lithium mining takes place today mostly in Australia (14,300 tons) and Chile (12,000 tons). The so-called South-American triangle has the most extensive lithium reserves - still largely untapped - and could benefit tremendously from the soaring demand for Li-ion batteries.

Nickel is mostly found in laterite and sulphide deposits. The biggest producers in 2016 were the Philippine (500,000 tons), Canada (255,000 tons), and Australia (206,000 tons).[26] 65% of worldwide cobalt production comes from the Democratic Republic of Congo, with a third of the global supply secured by Swiss company Glencore.[27] In 2016, China was the world's leading consumer of cobalt, with 80% of its consumption used to manufacture batteries.[28] The disproportionate weight of the DRC in the worldwide cobalt production, and its political instability, could lead to supply risks if cobalt sourcing is not diversified in the future.[29]
The Graphite used in anodes today comes exclusively from China which also supplies about 80% of the available rare earth minerals (see figure 7).[30] This lack of diversified supply is a concern for the EU and trade arrangements are therefore important to ensure availability for EU producers.

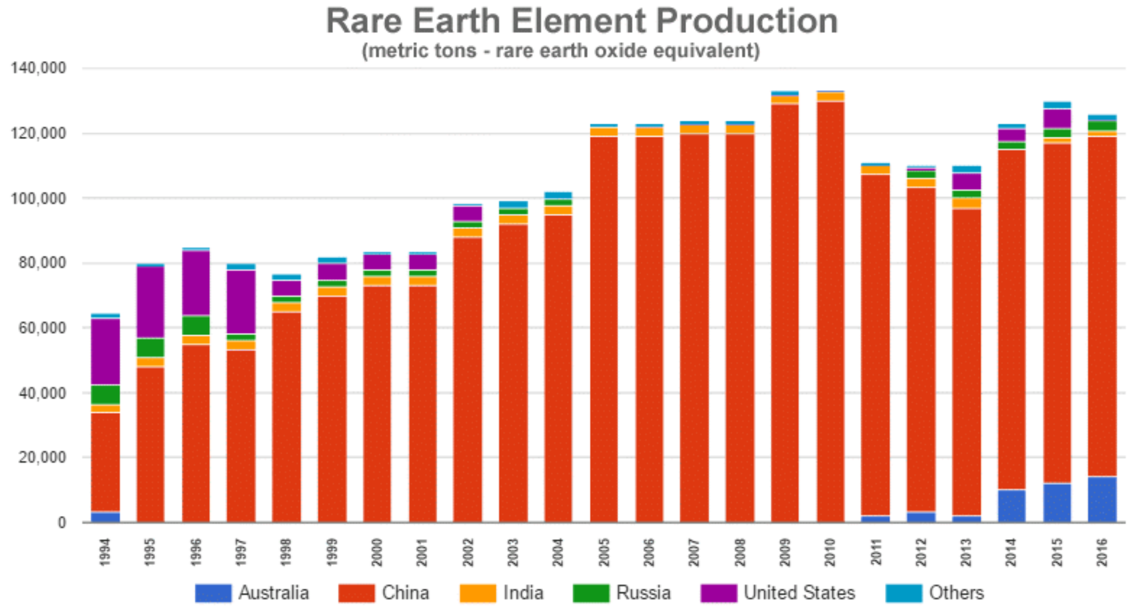

Figure 7: Rare Earth Element production[31]

3.2 What is at stake for critical metals in the transition to electrified transport?

Physical supply of rare earth minerals

The global demand in coming years for critical minerals and REE can be derived from the estimates of the electric vehicle production forecasts, which has recently been calculated by researchers from the EU's Joint Research Center.[32] Taking the International Energy Agency (IEA) estimates of 7,2 million electric vehicles

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[25] https://minerals.usgs.gov/minerals/pubs/commodity/lithium/mcs-2017-lithi.pdf
[26] https://minerals.usgs.gov/minerals/pubs/commodity/nickel/mcs-2017-nicke.pdf
[27] https://www.bloomberg.com/news/articles/2017-06-08/cobalt-upstarts-eye-glencore-s-turf-for-244-billion-ev-spoils
[28] https://minerals.usgs.gov/minerals/pubs/mcs/2017/mcs2017.pdf
[29] https://www.bloomberg.com/news/articles/2017-06-08/cobalt-upstarts-eye-glencore-s-turf-for-244-billion-ev-spoils
[30] http://geology.com/articles/rare-earth-elements/
[31] http://geology.com/articles/rare-earth-elements/
[32] http://www.sciencedirect.com/science/article/pii/S2214993716300641µ

sold worldwide in 2020 (highly ambitious), it is possible to evaluate demand for REE via the quantity of permanent magnets produced (assuming the composition of NdFeB magnets remains constant until 2020):

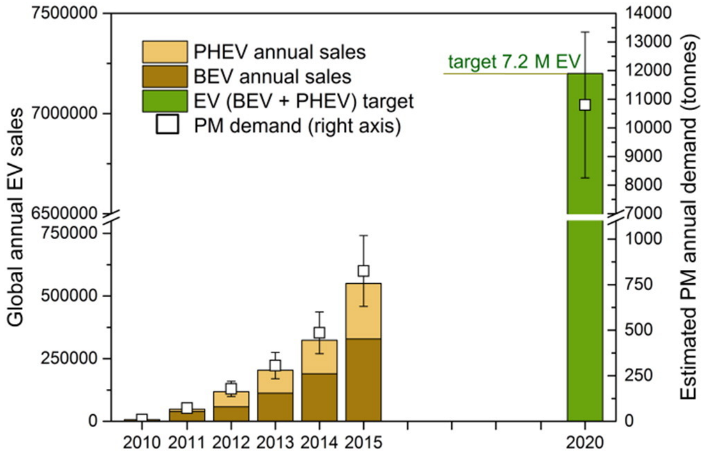

Figure 8: Projected demand for permanent magnets[33]

NdFeB magnet demand in EVs will be 14 times higher in 2020 compared to 2015. This surge in demand is not restricted to rare earth minerals, but is also relevant to other critical metals needed for battery production: in the next ten years, the lithium-ion battery market is expected to grow at a 21.7% rate annually from 15.9 GWh in 2015, to 93.1 GWh by 2024.[34] However, despite this impressive growth rate, shortages are unlikely.

The same conclusion can be made about the physical availability of cobalt: Bloomberg considers the demand resulting from EV production to total over 90,000 tons in 2030.[35] The same trends can be observed for nickel and graphite, with estimates for 2030 reaching respectively 830,000 and 1,6 million tons.[36] Due to nickel's abundance on the Earth crust, and because of the potential to replace natural graphite by synthetic ones, their availability does not jeopardize the transition to electromobility.

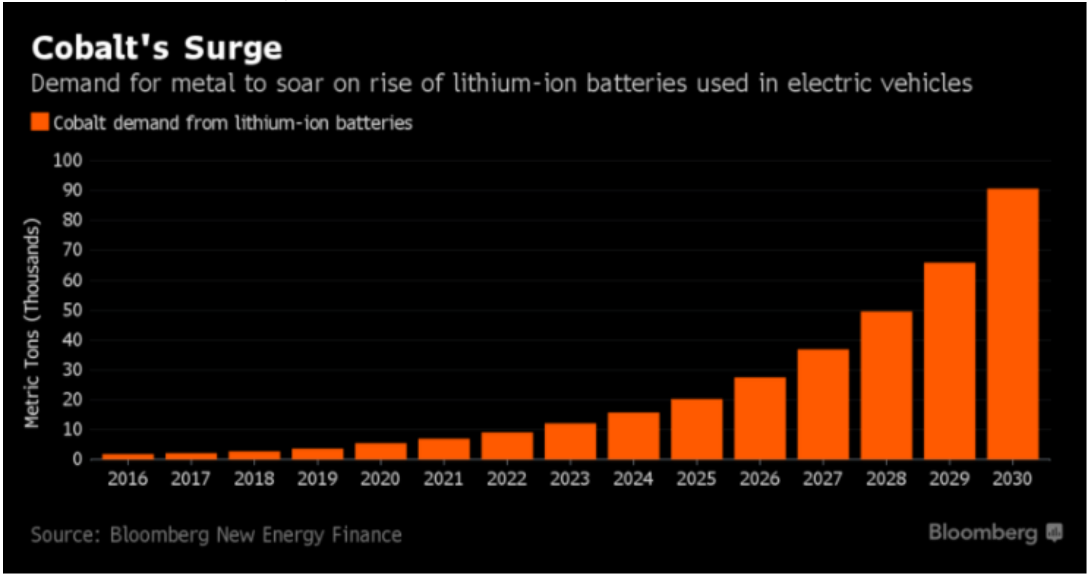

Figure 9: Projected demand for cobalt[37]

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[33] http://www.sciencedirect.com/science/article/pii/S2214993716300641µ

[34] http://uk.businessinsider.com/materials-needed-to-fuel-electric-car-boom-2016-10?r=US&IR=T

[35] https://www.bloomberg.com/news/articles/2017-06-08/cobalt-upstarts-eye-glencore-s-turf-for-244-billion-ev-spoils

[36] https://www.agora-verkehrswende.de/fileadmin/Projekte/2017/Nachhaltige_Rohstoffversorgung_Elektromobilitaet/Agora_Verkehrswende_Synthesenpapier_WEB.pdf

[37] https://www.bloomberg.com/news/articles/2017-06-08/cobalt-upstarts-eye-glencore-s-turf-for-244-billion-ev-spoils

Other metals, such as copper, could see comparable evolutions. Since a battery electric vehicle uses on average four times as much copper than a conventional one (80kg), in wiring, the electric motor, as well as the battery, copper demand in vehicles could double by 2035 compared to current production. This would require new mining capacity, leading to possible timing issues given that it can take up to 30 years between finding a copper deposit and producing the metal at scale. [38] This is expected to create sectoral opportunities linked to exploration, smelting, and refining that will require up to $1trn in new investment by mining companies.[39]

Reliance on imported critical metals will be reduced in the long term

The upsurge in demand for rare earth minerals and critical metals presents both supply challenges and opportunities for the EU. Specifically both mining and chemical companies involved in the manufacture of anodes and cathodes will see demand from cells for battery electric vehicles grow production. There are also some prospects for lithium extraction in Europe, including in the UK (Cornwall), Portugal, Scandinavia and Czech Republic. Cobalt is currently mined as a byproduct of copper and nickel in Finland, but the total production amounts to 1% of the global production.

The literature on critical metals, including the European Commission's Joint Research Center, indicates that substitution of these materials in powertrain and battery manufacturing is the best long term strategy towards a sustainable use of critical metals.[40] For example, LG Chem is reported to be trying to reduce the cobalt component of its battery cells, while continuing to improve their performance.[41]

Replacement or reduction of REE in the electric traction motor is already possible. Asynchronous motors, as well as electrically externally excited synchronous motors have been developed by some manufacturers (e.g. Renault, Tesla, Daimler) and OEMs are also investing in motors that reduce the rare earth intensity in electric motors. For instance, BMW developed a hybrid motor using between 30 to 50% less rare earth.[42] Even if for the moment permanent magnet motors are the go-to solution for most EV manufacturers because of their performance and price, the above mentioned alternatives could mitigate the current reliance on import of REE such as Neodymium, Dysprosium, or Terbium.

Recycling will also develop although not in the short term since many end of life products containing REE will not enter the market for more than a decade.[43] Cobalt is today already recycled, especially in catalysts and superalloys, but also in batteries.[44] Once battery powered vehicle become more widespread we can expect a dedicated recycling industry to emerge, enabling the re-use of critical metals such as lithium and cobalt.

Environmental and social concerns

Currently, nearly all REE used in consumer appliances are processed in China, and are used to manufacture high tech products (e.g. smartphones, computers…) The conditions in which those metals are refined

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[38] https://www.economist.com/news/business/21718532-electric-vehicles-and-batteries-are-expected-create-huge-demand-copper-and-cobalt-mining

[39] https://www.economist.com/news/business/21718532-electric-vehicles-and-batteries-are-expected-create-huge-demand-copper-and-cobalt-mining

[40] http://www.sciencedirect.com/science/article/pii/S2214993716300641µ

[41] https://www.economist.com/news/briefing/21726069-no-need-subsidies-higher-volumes-and-better-chemistry-are-causing-costs-plummet-after

[42] http://www.sciencedirect.com/science/article/pii/S2214993716300641µ

[43] http://www.sciencedirect.com/science/article/pii/S2214993716300641µ

[44] https://www.agora-verkehrswende.de/fileadmin/Projekte/2017/Nachhaltige_Rohstoffversorgung_Elektromobilitaet/Agora_Verkehrswende_Synthesenpapier_WEB.pdf

already raise environmental concerns. Should the composition of EV parts remain the same, the situation could dramatically worsen. Indeed, it is estimated that one ton of rare earth produces 75 tons of acidic waste.[45] To avoid environmental disasters such as the constitution of toxic lakes[46], REE used in electric vehicles will have to be gradually substituted in the long term.

Likewise, the extraction of some essential battery materials, such as nickel, constitutes an environmental challenge if left deregulated: this year, more than 20 mines had to shut down in the Philippines[47] and last year, Russian company Norilsk nickel closed one of its most polluting mine, and admitted a spillage at one of its plan had contaminated a local river.[48]

The production of lithium also has a significant ecological impact, as it is extracted either from crushing rocks (e.g. in Australia) or from the brine available in salt lakes (e.g. in the South American lithium triangle).[49] In the first case, chemicals and high temperatures are used to separate lithium from the rocks, demanding significant amounts of energy. In the case of lithium obtained from brines, it is pumped out of the ground and require chemicals for its purification.

As for cobalt extraction, most of which currently takes place in DRC, it raises both social issues linked to artisanal mining and environmental ones.[50]

Certification schemes can provide efficient instruments to control the way critical metals are sourced. This is for instance the case of the OECD Due diligence guidance[51] or the conflict free sourcing initiative.[52] These schemes are however currently mainly directed at the extraction of tin, tungsten tantalum and gold, and should be generalised to other critical metals.

4. Conclusion

Environmental performance of EVs is today already better than the one of conventionally fueled vehicles. The life cycle analysis shows that even when powered by the most GHG intensive electricity in Europe, the carbon footprint of EVs is lower. This justifies the key role road transport electrification will have in decarbonising Europe, and stresses the benefits of replacing the internal combustion engine by battery electric vehicles. As more renewable electricity enters the European grid, the climate impact of EV will further diminish. Likewise, technological improvement of battery chemistry, the reuse of battery for storage purposes, and the development of a recycling industry for EV batteries will lead to improvements in their sustainability.

Resources of critical metals and rare earth minerals will not be constrained in the coming decades and won't stop the EV transition, as some have argued. Supply of these materials will have to be diversified to avoid being overly dependent on imports, as is the case with oil today. Innovation will contribute to reduce the quantity of critical metals used in EVs.

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[45] https://www.theguardian.com/environment/gallery/2015/apr/15/rare-earthenware-a-journey-to-the-toxic-source-of-luxury-goods

[46] See for instance China's baotou toxic lake: https://www.youtube.com/watch?v=t_UdqZdFr-w

[47] http://www.reuters.com/article/us-philippines-mining/philippines-to-shut-half-of-mines-mostly-nickel-in-environmental-clampdown-idUSKBN15H0BQ

[48] https://www.theguardian.com/cities/2016/sep/15/norilsk-red-river-russias-most-polluted-city-clean

[49] https://theconversation.com/politically-charged-do-you-know-where-your-batteries-come-from-80886

[50] https://www.economist.com/news/business/21718532-electric-vehicles-and-batteries-are-expected-create-huge-demand-copper-and-cobalt-mining

[51] http://mneguidelines.oecd.org/Brochure_OECD-Responsible-Mineral-Supply-Chains.pdf

[52] http://www.responsiblemineralsinitiative.org/

In parallel, ensuring that metals from old batteries are recycled and remain in the EV supply chain is essential to limit EVs' impact on the environment, while at the same time cutting the EU's dependency on import of these metals.[53]

Cleaning up road transport should not come at a price of environmental catastrophes the oil industry has become familiar with, such as the Exxon Valdez or Deepwater Horizon oil spills; or the social and environmental damage in Nigeria. This is why the EV supply chain has to be closely monitored, for instance through certification schemes. In this context, the EU can take the leadership by fostering R&D in electric powertrain and battery technology, and by developing home-based battery production, with high environmental and social standards.

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[53] http://publications.jrc.ec.europa.eu/repository/bitstream/JRC103778/materials%20supply%20bottleneck_online%20version.pdf