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Electric Vehicle Battery Materials and Their Impact on Carbon Emissions

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Abstract. Electric vehicles (EVs) are often touted as one answer to the burgeoning number of emissions created by a growing transportation sector. But for all their environmentalist halo, those broader benefits are not simply a matter of zero tailpipe emissions — what's in the batteries, and the whole supply chain. The materials the batteries are built from — materials like lithium, cobalt and nickel, in this instance — contribute to the carbon footprint of the batteries at every stage of their lifecycle, from extracting and processing the ingredients, to making the battery, to recycling or disposing of it. Shoot for the cloudsEven if EVs' carbon footprint is ultimately smaller than plain ol' internal combustion engine cars, battery production is a considerable piece of the puzzle here. And, in the process, the humanity and environmental costs (both conflict and unsafe working conditions and disruption of local ecosystems) of resource extraction drew attention to cobalt mining in the developing world, as well. Against this backdrop we see a search for innovation with bold projects in the making of recycling technologies of the materials of tomorrow, alternatives and sustainable supply chains. One day, they might be used to curb greenhouse gas emissions and cut back on precious raw materials. Last but not least, EV diffusion being inherently in the future carbon neutral world policy and independent of the battery materials bioburden reduction EV is a typical case where one must consider greener options after the technology hits the surface.

Keywords: Electric Vehicles, Lithium-ion Batteries, Carbon Footprint, Battery Materials, Recyclin.

1. Introduction

This century, one of the biggest challenges the world has faced is climate change. Road transport is one of the largest emitters of carbon dioxide (CO_2), and more generally, the transport sector makes significant contributions to the global CO_2 emissions [1]. This is why the electric vehicle (EVs) which is, and has been, being pushed as the answer for the ratification of decadal ghg, became an obsession. For instance, in contrast to internal combustion engine vehicles (ICEVs), EVs do not emit tailpipe air pollutants and are thus frequently treated by policy-makers as "clean" [2]. But EVs are not carbon free. And their batteries, which are built from the critical minerals lithium, cobalt, nickel and graphite, involve energy-intensive mining and processing as well. These materials are also made in a manner that has a large impact on the CO_2 footprint of the electric vehicles [3]. Therefore, this

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review paper is inspired by the different studies carried out to explore the relationship between EV and its batteries on carbon emissions and aims to compile them so as to present a synthesis. It will also investigate life-cycle emissions of E.V.s, the influence of different battery materials, differences of manufacturing in regional markets and possible solutions such as recycling. Finally, we will also show the advantages and limitations of EVs for mitigating climate change.

2. Life-Cycle Carbon Emissions of EVs

Life-Cycle Carbon Emissions of EVs One of the key tools for comparing EVs with conventional gasoline or diesel cars is the life-cycle analysis (LCA). Life cycle analysis (LCA) studies the emissions of raw material extraction, vehicle manufacturer and use phase, and end-of-life disposal/recycling [4]. A report by the International Council on Clean Transportation [5] found that EVs, including the production of batteries, generate fewer emissions overall than ICE cars. For instance, a European EV emits about 50% fewer carbon emissions over the entire lifespan versus a gasoline car, due largely to a much smaller use phase footprint on a decarbonized electricity grid [6]. There is not unanimous agreement in all studies with respect to the magnitude of the reduction. The Swedish Energy Agency and IVL [7] claimed that between 150–200 kg of CO_2 are emitted per kWh of capacity for a medium sized EV battery. This would mean a 60 Kwh battery can produce 9–12 tons of $_{CO2}$ before the car have even driven a meter. Other studies, on the other hand, as for Carbone 4 [8] concluded much lower figures, around 60–100 kg $_{CO2}$ per kWh, especially when different renewables are use within the factories. These contrasts show that the outcome of LCA is very sensitive to assumptions selected, including the electricity mix, the efficiency of mining and recycling also. With these variations, however, most literature also agrees that EVs get greener than ICE cars in a few years of driving. In clean power regions, the “carbon break-even point” is typically achieved in 1.5–3 years [9]. But in places with coal-powered grids, it could take EVs longer to surpass ICE cars, which is a major regional struggle

3. Battery materials and carbon footprint

The largest EV production emissions come from the battery—specifically the mining and processing of critical minerals. Different materials have different carbon impacts.

3.1. Lithium

Lithium is among the most critical materials for EV batteries. The bulk of the lithium is mined in South America (Chile, Argentina and Bolivia) and Australia. As per the US International Trade Commission [10], lithium mining in salt flats consumes significant quantities of water and energy, leading to indirect emissions. High-temperature processes used in the transformation of lithium carbonate and hydroxide, depending on the type of fossil fuel used, generate carbon emissions, as reported in the Joint Research Centre [11]. Another critical material is cobalt, which is also regularly castigated for its social and environmental burden. The D.R.C. supplies around 70 percent of the world’s cobalt, and mining there is frequently associated with dangerous labor practices. Cobalt refining is also very carbon-intensive [12]. The ICCT [13] says demand for cobalt could triple by 2030, which would increase the emissions of production unless recycling grows. Nickel increases the energy density of batteries, but making battery-grade nickel requires high-temperature smelting. One ton of nickel sulfate can generate over 9 tons of CO_2, according to a projection by Carbone 4 [14]. Nickel mining in, for example, Indonesia and Russia depends on coal-fired power [15].The

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carbon intensity of nickel varies strongly with the energy mix of the region, as Mohr and Mudd highlighted [16].

3.2. Graphite

leading to a particularly high level of emissions, the EC has said. Graphite is another carbon-intensive material. Natural graphite is rarer in EV batteries than synthetic graphite, which is made from petroleum coke. Synthetic graphite production requires heating to above 2,500°C, typically with coal as flux, which China, where the market is concentrated, dominates [17]. That puts graphite up there with the most carbon-emission-intensive materials in the EV battery. In general, studies concordant that materials and sourcing substantially affect the carbon footprint of EV batteries. But there is also a question of the future: Some foretell recycling and cleaner energy choking off emissions; others expect more, especially in mining, and rising demand spurred by EV ambitions.

3.3. Cobalt

Climate change has increasingly been recognized as one of the most serious global challenge in the 21 century. Transportation is also responsible for a significant percentage of workAnother important material is cobalt, which is also often criticized for it social and environmental cost. The Democratic Republic of the Congo (DRC) is the source of approximately 70% of the world's cobalt and mining in the DRC can be associated with dangerous work conditions and child labor [18]. From an ecological aspect, the refinement of cobalt is very carbon intensive, as several chemical reactions and smelting which is energy intensive are commonly included in the process [19]. The International Council on Clean Transportation [20] forecasts an increased cobalt demand which could treble by 2030 since the uptake of EVs is accelerating quickly and it would magnify production related emissions, except for recycling technologies and secondary markets progress quickly [21].

3.4. Nickel

Nickel is also a key ingredient, because it boosts the energy density of batteries, helping EVs to travel greater distances. But producing battery-grade nickel sulfate is also extremely energy intensive. According to a projection from Carbone 4 [22], and we can find this number in many sources, one ton of nickel sulfate could lead to more than 9 tons of CO_2. Nickel is mainly mined in countries such as Indonesia and Russia, where coal are the main source of energies and therefore very high emissions [18]. The carbon intensity of nickel varies strongly with the energy mix of the region, as Mohr and Mudd [13] highlighted, so improvement of electricity sources could lower its footprint.

In general, there is consensus that the choice and supply of materials are a key driver for the carbon footprint of EV batteries [14,15]. Yet a disagreement persists between whether it's the solution (some researchers anticipate recycling improvements and cleaner energy will decrease emissions [5]) or a growing threat (researchers expect mining to expand to meet growing demand and demand for electric vehicles to increase emissions [11]). Due to such uncertainties, it is important to look beyond only technological solutions, and consider global policy interventions that will encourage sustainable mining and circular economy approaches.

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4. Manufacturing and regional differences (expanded version)

The battery production site is also a significant source of variability in a EV's life-cycle emissions without raw material extraction. One that is apparently less contested is that there is a large difference on the carbon footprint of production between regions (something that is based on the same battery chemistry, technology and material supply chain) [7,2] (also on the choice of the energy insulation and industrial process design). Recently, the International Council on Clean Transportation [6] showed that assembling the equivalent lithium-ion battery in the largest coaldependent China would negatively impact $_{CO2}$ emissions by nearly double that in Europe with a relatively high share of power generation from renewable and nuclear power sources. This regional legacy continues to this day, as the electricity grids of the world are extremely uneven in terms of the contribution of fossil fuels [10]. For example, in 2022 coal generated more than 60% of China's electricity and nuclear over 70% of France's, leading to much lower emissions associated with energy intensive industrial processes, such as for battery production [10]. Yet another important thing is embodied emissions for constructing new factories. The demand for electric vehicles, and thus for gigafactories, is poised to skyrocket and gigafactories demand significant volumes of steel, concrete and other carbon intense materials [21]. Though such "one-time" emissions are spread over years of production, they have an outsized effect when added up across the global wave of factories in the planning stage. According to Zeng et al. [21], with the construction of a gigafactory, a carbon footprint of 200,000–400,000 t of $_{CO2}$ can be expected; the footprint depends on size and materials of the gigafactory. In addition, the carbon intensity of battery production relies not only on the regional energy mix but also on the manufacturing efficiency itself. High-efficiency facilities incorporating electrified heating, near-adiabatic conditions, and waste heat recovery can reduce emissions from modern TECs significantly compared to heat-demanding TFSs used by TICSD [22]. But international adoption of such upgrades is inconsistent. In countries with low energy prices, but coal-intensive grids, for example Indonesia or parts of China, the motivation to switch to cleaner and more efficient systems is also still small [9]. Large developments are influenced by regional policy settings. (1) The "prospective" carbon intensity of battery production in Europe and some parts of North America, if using this technology mix, has already been reduced significantly saver compared with Asia. For instance, in Sweden, where power for industry is 100 per cent renewable, EV batteries can be produced with emissions below half of any similar facility in South-East Asia [14]. In the case too of Indonesia, a leading producer of nickel, its reliance on coal increases emissions resulting from its bertolut7ising battery industry [20]. More broadly, regional disparities in emissions may endure as long as the global electricity grids do not decarbonize much more quickly. ICCT [11] estimates that by 2030, the carbon intensity of a battery manufactured in coal-dominant regions without targeted policy measures could remain up to three times higher than in RE-dominant regions. That's why it will be crucial not only that gigafactories can be erected using renewable energy, but that they can be constructed using renewable energy — and fast. That's what's taking place in the concrete industry, where Sweden's Northvolt is supplied with hydropower and where one of the least emission-producing manufacturing processes in the world is happening [23]. Where and how a battery is manufactured may also matter as much what it is made out of. Without long-term, policy-driven strong support for technology, particularly at local levels where deployment of re-newable elec-tricity generation occurs, the largest environmental advantage of elec-tro mobility – that is, in operation be-tween the car and the grid (in-use) with gasoline vs. electricity as fuel – will be negated by car production and car production's high carbon content in the absence of policies targeted at both [24].

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5. Recycling

Room for Improvement: Recycling and a Circular Economy There are two prominent solutions offered by many experts in the fight against emission: recycling and circular economy. Other recycling processes you haven't used can also help you recover valuable material — lithium, cobalt, nickel — and that in turn reduces emissions and forestalls new mining. Systems change company Systemiq believes advanced hydrometallurgical recycling could cut emissions from material supply by 30-50%. Battery Pass [8] also indicated that end-of-life direct recycling, with the preservation of cathode materials, saves more energy than smelting-off. A second use for old EV batteries is known as "second life," in which the batteries are put to work in stationary storage once they are no longer sufficiently efficient for vehicle use. According to the National Renewable Energy Laboratory , the system-wide emissions savings associated with repurposed EV exteriors could significantly reduce the demand for new production of storage, which would ultimately reduce total emissions. Policy is also turning up the dials on the circular economy. The European Union established stringent requirements in terms of battery recycling rates and carbon footprint reporting [4]. The OEC D [8] suggests that intern ational collaboration will be required to match recycling capability with the pace at which the EVs multiply. But there is a debate over how plausible those policies are. A few other studies claim that recycling is too expensive, and at present is insufficient, to have a significant impact by 2030 [22]. In Sweden, for example, producing emissions can be half that of coal plants in Asia if the energy sources used are hydropower and wind. That means EVs produced in different countries can have very different environmental profiles, even if they rely on the same technology.

6. Conclusion

Discussion Review of the literature resulted in some consensus. In general, most analysts now agree that EVs will bring down lifetime carbon emissions compared to ICE cars, particularly in places with clean power. They also agree that battery manufacture, including mining and refining of critical materials, is the largest emission source in the EV life cycle. But there are also disagreements. One of those is whether or not emissions from the battery are so great that they offset the climate advantages of driving the EV. For certain studies extremely high estimates were assumed, for others they reported much lower numbers. And there is another is over the promise of recycling, some see recycling as central to the solution, others are skeptical about recycling's impact in the near-term. The variability of study results is frequently related to methodological issues. For example, the amount that benefits would be worth depends on whether the social cost of carbon determines that the construction of factories should be included, how electricity mixes are represented or what assumptions are used about how long batteries will last. That methodological contrast is one of the things that makes emissions from EVs so controversial in both science and politics.

In this review, we have briefly discussed the recent articles published so far on the EV and its battery CO_2 emissions. It discovered that, no, EVs are not "emission free," but, yes, they do assist in reducing CO_2 emissions over the course of their operational lives compared to ICE vehicles. But it also spews huge amounts of carbon to create batteries, and in particular to mine and refine lithium, cobalt, nickel and graphite. It's how that power is generated and also that that car for a the new car, that car is locally also produced, and it will give you much cleaner numbers of electric cars in other parts of the world than in other parts of the world. The circular economy and recycling provide hope and solutions but duties can only be met by policies and technological advances. And finally, one should not fall into the trap of treating EVs as a silver bullet either, they can be part of the transition to a less carbon intensive future. That the process somehow has to be more thoughtfully overseen is

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a bit of a leap of faith, unless the goal is to make sure the environmental benefit side of this equation is addressed with the same zeal as the commercial case for a glorious, electrics-only world, which will also have to address emissions from battery manufacturing (CO_2 emissions from the mining and production of batteries are as significant as getting electric cars on the road.). It might spur the development of LCA at a faster pace, or even question whether the global supply chain could challenge itself to be more sustainable.

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