

Analyzing the Environmental Sustainability of Using and Manufacturing Electric Vehicles

Anushka Gautam *

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Abstract

In the past five years, the demand for electric cars has increased tremendously, and it is expected to increase further in the next ten years. Electric cars (EC's) play a vital role in future mobility scenarios. It becomes crucial to assess their environmental impacts. This paper will be reviewing and collecting data from different academic sources to examine the ecological impact of the production of electric cars. Even though EC's do not emit CO₂, their batteries do use lithium. Improper lithium disposal can lead to contamination of water and soil. Lithium can cause landfill fires and release toxic chemicals that negatively affect our breathing, and further contribute to global warming. It doesn't stop there, lithium demand is expected to increase more than 300 per cent over the next five years, and this number is largely driven by the growth in the production of EC's. Apart from lithium, many other raw materials are used in the production of the battery, such as Rare Earth Element (REEs), which could lead to many environmental consequences due to mining, etc. The purpose of this paper is to evaluate the potential environmental impacts of increasing production of EC's keeping in mind the latest advances in electric car technology. This paper will further explore possible solutions to make electric cars a feasible alternative to ICEVs.

1 Introduction

Out of the 42 GT (Giga Tonnes) of CO₂ (Carbon dioxide) eq (unit) released in 2010, 14 per cent was released by vehicles according to the Intergovernmental Panel on Climate Change (IPCC) [Ouy14]. This number has increased over the past ten years and furthermore does not take into account CO₂ emissions caused by the complete life cycle. Electric vehicles (EVs) are becoming a crucial part of the transportation future. They seem to be a great solution to fight climate change. Despite having chemically stored energy, electric cars release it electrochemically without any combustion, thanks to lithium-ion batteries.

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This means that there is no fuel being burned and no air pollution through CO₂ happening while driving. They are also more efficient than cars that run on fossil fuels. So, does this indicate that electric vehicles are a more environmentally viable choice? As electric vehicles are becoming more popular, it becomes imperative to compare and contrast the environmental impact of EVs and internal combustion engine vehicles (ICEVs).

Although EVs may not release CO₂ emissions while driving, the car's production cycle is a concern for the environment. Raw materials such as lithium and other rare earth elements (REEs) are extracted, transported, and manufactured into several components. Mining's environmental effects can result in erosion, sinkholes, loss of biodiversity, or soil, groundwater, and surface water contamination by the chemicals emitted from the mining processes at the end of the manufacturing process, including the extraction of metals. Apart from the weight of the REE, the energy used to produce the batteries plays a significant role in their environmental impact since most of this energy does not come from low carbon sources.

Another source of EV carbon footprint is charging. If EVs are not charged from renewable energy sources, like solar power plants, wind turbines, or hydroelectric, their CO₂ emissions will be much higher [Nea15]. There is pollution released by some distant power plants that provide the energy required to charge the cars with fossil fuels. Furthermore, the battery of an EV is a feat of intricate engineering. When this battery comes to the end of its life, its disposal is less environmentally sound than the ideal. If it ends up in a landfill, its cells can release problematic toxins. Recycling the battery can be a hazardous business as well. If we cut too deep into the battery, it might release toxic fumes.

Being an essential part of future mobility, EVs are being remodeled and designed to be more efficient and environmentally sound. Some countries, such as Germany and Norway [Gon20], are trying to power the car with clean electricity by using renewable energy sources. As the market for EVs increases, it becomes interesting to explore the ways to recapture and recycle the REEs and make them a more viable option.

This paper will assess the environmental impacts of manufacturing electric vehicles, with particular emphasis on the metals used along with the engine designs and components used in the batteries, keeping in mind the latest advances in electric car technology. Moreover, it will explore possible solutions to make electric cars a more feasible alternative to ICEVs, by reviewing and collecting data from different academic sources.

2 Discussion

2.1 Why is this important?

Global Electric Vehicles (EVs) sales increased by more than 0.8 million units from 2017-18: an increase of 63 per cent on a year-on-year basis. With a compound annual growth of 59 per cent, we could see over 70 per cent penetration

by 2050 [Her19]. As the global market for Electric Vehicles (EVs) continues to grow exponentially, the need to analyze the environmental impacts also becomes increasingly necessary.

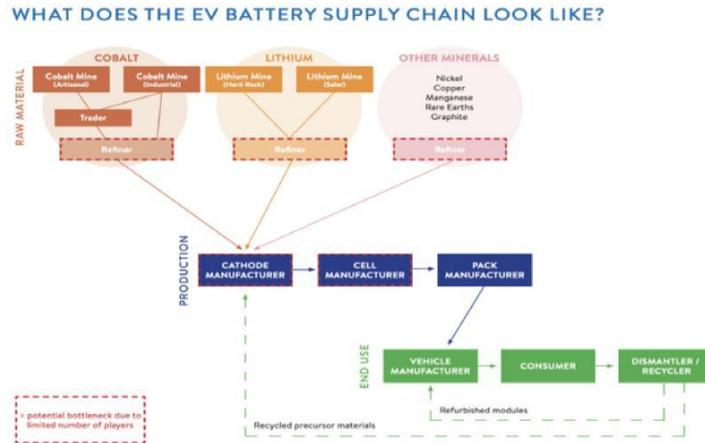


Figure 1: EV Battery Supply Chain [Elk20]

The EV supply chain depicts the need to assess the sustainability and compatibility of EVs, comparing them to fuel-based cars. The difference between internal combustion engine vehicles (ICEVs) and Electric Vehicles (EVs) is the process by which the engines release the chemicals. Cars transform the potential energy into kinetic energy; in ICEVs, this process is done by storing the chemical form and is released through a chemical reaction inside the engine. On the contrary, EVs release the chemically stored energy electrochemically without any combustion. As there is no fuel burned, no pollution is released while driving.

Furthermore, they are more efficient than ICEVs. The engine of an EV is considerably more environmentally sound in comparison to ICEVs. But if we consider the entire life cycle of the EV, the calculation of the pre (manufacture) and post (disposal) driving of the EVs might render different results.

2.2 lifecycle

The complete emission chain gives us an idea that, although EVs might not cause any environmental harm during driving, they have a significant amount of emissions from the entire life cycle. This flow chart does not consider some emission values to add to the complete cradle to grave assessment, such as assembling the engine. An electric vehicle's engine is a feat of intricate engineering. The emissions, depending on certain situations such as that of the

FIGURE 6. Drivetrain Components of Battery-Electric Vehicles

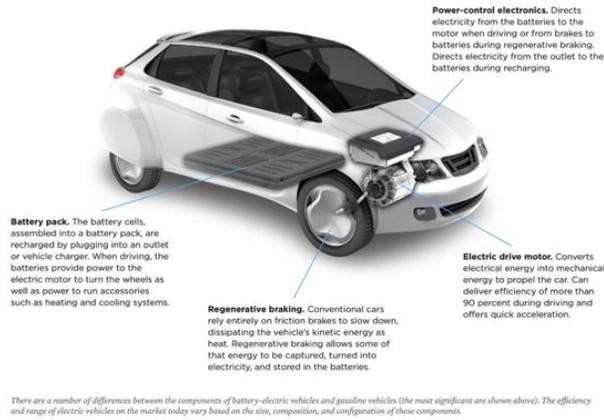


Figure 2: Components of BEVs [Nea15]

car model, the charging port sustainability, the disposal method, whether we are recycling the engine parts or reusing, etc. might be equivalent to that of ICEVs, which then makes us consider the cost feasibility of EVs. This paper will further discuss the specific emissions of the car during manufacturing and the recycling and reusing aspect of EVs in greater detail while addressing the different situations.

The charging ports have a great influence on the life cycle emissions of EVs. Although EVs do not release emissions while driving, how the car is charged could significantly impact the total emissions. If the vehicle is powered with energy from burning fossil fuels, it is still releasing CO₂ in the atmosphere, not from the tailpipe but some distant power plant. Some countries already realize this, and that's why they are fostering the growth of the electric cars market, primarily by giving fiscal benefits that make the cars economically more competitive. Countries like Norway, Germany, or Costa Rica are simultaneously increasing their bet on renewable energies and setting deadlines for the end of conventional cars on their roads [Gon20]. They have implemented new policies and aim to build cost-efficient EVs.

2.3 Emissions during manufacture

The manufacturing process used to make an electric vehicle is as intricate as the vehicle design. It takes multiple workstations to create the body of an electric car. Each station is equipped with one torque wrench with numerous heads; when the assembler locks on the appropriate head size, computer controls for the machine select the correct torque setting for the fasteners that fit that head. The battery pack is unique; it comprises rechargeable secondary-type batteries that act as storage cells. Batteries are situated in T-formation down

ELECTRIC VEHICLE LIFE CYCLE

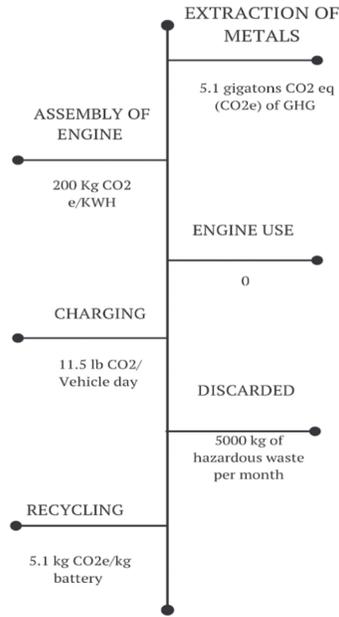


Figure 3: Life cycle emissions at each step [Dun12] [Mcl16] [Jac19] [Age21]

the middle of the car, with the top of the "T" at the rear to provide better weight distribution and safety [Sha79].

The most significant difference in the manufacture of BEVs compared with gasoline vehicles is the required type and size of batteries. Gasoline vehicles only have a small lead-acid battery for starting the engine and powering accessories while the engine is off. In contrast, BEVs rely on much larger lithium-ion batteries to power the vehicle itself.

To measure the impacts of battery production on the emissions of EVs, we can divide it into four steps: Mining and Refining, Battery material production, Cell production, and battery pack assembly. The means might vary between two batteries created in a similar mainland, country, or even plant. One justification behind this is because of contrasts in material sourcing. There is likewise frequently more than one substance measure pathway to get the ideal item. The transportation strategies and courses can likewise be different for various wellsprings of similar material.

A simplified outline of the steps in Battery Material Production can be given by:

1. NMC Powder Production
2. Co-precipitation
3. 1st stage calcination
4. 2nd stage calcination [Emi19]

And that of Cell Production Battery Pack Assembly can be given by:

1. Mixing
2. Coating
3. Drying
4. Calendaring
5. Notching
6. Stacking
7. Welding Sealing
8. Electrolyte filling
9. Final sealing
10. Pre-charging
11. Dry Room
12. Battery pack assembly [Emi19]

These steps give a better idea to fully understand the detailed emissions that are usually not calculated in the emissions of EVs. Cell production occurs in a laboratory facility that needs strict controls on humidity, temperature, and cleanliness. The cell manufacturer can do battery pack assembly, or the battery pack components can be assembled by the automobile manufacturers [Ell18]. Pack assembly doesn't have the exact stringent requirements of cell production as the most sensitive parts have already been sealed in the cell production step.

Since different steps can occur in other locations, choosing the local energy mixes for each processing step will affect the resulting Global Warming Potential (GWP). Naturally, the choice of energy mix becomes more critical for the actions that require more energy because the final GWP-value depends on the most on their values [Emi19].

Electric vehicle batteries are predominantly lithium-ion batteries (e.g., NCA, NMC7), which use lithium, cobalt, nickel, and graphite. The demand for raw materials used to manufacture rechargeable batteries is growing rapidly as the importance of oil as a source of energy recedes, as highlighted recently by the collapse of prices due to oversupply and weak demand resulting from COVID-19, according to a new United Nations Conference on Trade and Development (UNCTAD) report [Amu20].

Additionally, if the batteries are not disposed of properly, their cells can release problematic toxins, including heavy metals. Considering the fact that EV engines are a feat of intricate engineering, disposal is a difficult task. Even after proper recycling, a lot of the battery elements cannot be reused or recycled.

The raw materials used to design EV engines include lithium and other Rare Earth Elements (REE). They are extracted, transported, and manufactured into several components. Mining's environmental effects can result in erosion, sink-holes, loss of biodiversity, or soil, groundwater, and surface water contamination by the chemicals emitted from the mining processes.

| Table 2. Components of a lithium ion battery, functions and materials | | |
|---|---|------------------------------------|
| Components | Functions | Materials |
| Cathode | Emit lithium-ion to anode during charging Receive lithium-ion during discharging | Lithium metal oxide powder |
| Anode | Receive lithium-ion from anode during charging Emit lithium-ion during discharging | Graphite powder |
| Electrolyte | Pass lithium-ions between cathode and anode | Lithium salts and organic solvents |
| Separator | Prevent short circuit between cathode and anode Pass lithium ions through pores in separator | Micro-porous membranes |

Figure 4: Components of lithium-Ion battery, functions, and materials [Amu20]

The mining of many of these materials can raise ethical and environmental concerns, and some of these metals could face a global shortage given potential battery demand. Additionally, while nearly all - 99 per cent - of lead batteries are recycled, few lithium-ion batteries are. According to some estimates, the rate could be less than 5 per cent [BCI17].

At the end of the manufacturing process, including the extraction of metals, electric cars generate more carbon emissions than fossil-fueled cars, according to the Union of Concerned Scientists [Nea15]. Apart from the weight of the REE, the energy used to produce the batteries plays a significant role in their environmental impact since most of this energy does not come from low carbon sources.

2.4 Rare Earth Elements

Rare Earth Elements (REEs) are 17 components with comparative compound properties, including 15 for the lanthanide group, yttrium, and scandium. Because of their one-of-a-kind physical and synthetic properties, REEs acquire expanding significance in numerous new energy advancements and frameworks that add to diminish ozone harming substance emanations and petroleum product exhaustion (e.g., wind turbine, electric vehicles, high productivity lighting, batteries, and hydrogen stockpiling).

Nonetheless, it is notable that the use of REEs is a long way from sustainable as it requires critical material and energy utilization while producing a lot of air/water emanations and strong waste. Although life-cycle assessment (LCA) has been accepted as the most comprehensive approach to quantifying the environmental sustainability of a product or process, to date, there have been only minimal LCA studies on the production of REEs [Nav14]. Even in the manufacturing process of EVs, REEs play an essential role.

Although REEs are critical for future energy supply, the production of REEs itself incurs significant environmental damages. Furthermore, while REEs are not exceptionally scarce resources but are available in only small amounts dispersed on the Earth's crust. Large-scale REE production could lead to issues regarding heavy metal and radioactive emissions in groundwater, rivers, soil, plants, and the atmosphere [Lia13]. The Chinese Society of Rare Earths estimates that a ton of REE produces 8.5 kg of fluorine and 13 kg of flue dust

while refining with H₂SO₄ generates 9,600–12,000 m³ of gas containing flue dust concentrate, HF, SO₂, and H₂SO₄ [RN13].

In addition, long-term mining dust inhalation can cause pneumoconiosis (black lung). Overall, the production of REEs involves a large number of process steps, out of which many incur significant material/energy consumption and environmental release [Gol14].

While the high demand and small supply of many metals and REEs make the processing a very lucrative business, the environmental impact has become a major concern. More than 20 nickel mines had to shut down in the Philippines and last year, Russian company Norilsk Nickel closed its most polluting mine, admitting that a spillage at its plant had contaminated a local river [Evt15].

In recent times, REE disposal has not been efficient. Rather than recycling, recovering, or reusing the metals, they are being discarded [RN13]. REE recycling will have a significant impact on the life cycle emissions of EVs. Although recyclers may not see immediately increased profits, since many end-of-life products containing metals and REE will not enter the market for more than a decade, the early preparation and fine-tuning of recycling capabilities could prove to be a boon in the long run. The key to their success will be the extraction of REEs, lithium, cobalt, and other superalloys from batteries and other parts of electric vehicles.

Only a few industrial recycling activities are currently implemented for rare earth. Until now, there has been no large-scale recycling of rare earth from magnets, batteries, lighting, and catalysts. The recycling processes for the rare earth are quite complex and extensive if reuse is not possible and physical and chemical treatment is necessary. Most of the recycling procedures are energy-intensive processes. The main post-consumer activities – the recycling of rare earth from electric motors, hard disks, and other electronic components – will require intensive dismantling. Several constraints for wider recycling of rare earth were identified: the need for an efficient collection system, the need for sufficiently high prices for primary and secondary rare earth compounds, losses of post-consumer goods by exports in developing countries, and the long lifetime of products such as electric motors in vehicles and wind turbines of 10 - 20 years before they could enter the recycling economy [RN13] which is a long term effort, appearing as a challenge to businesses.

2.5 Lithium

Demand for lithium in the form of lithium carbonate and lithium hydroxide – key ingredients in these batteries – is rising rapidly: up almost 20 per cent in 2019. Prices doubled between 2016 and 2018 in anticipation of increased demand brought on by the EV revolution [Kat18]

Lithium changes chemical energy into electrical energy very efficiently. Analysts project that battery-powered lithium-particle (Li-ion) batteries have the most elevated potential for future energy stockpiling systems. Inside each cell, lithium atoms move through an electrolyte between a graphite anode and a cathode sheet composed of metal oxide.

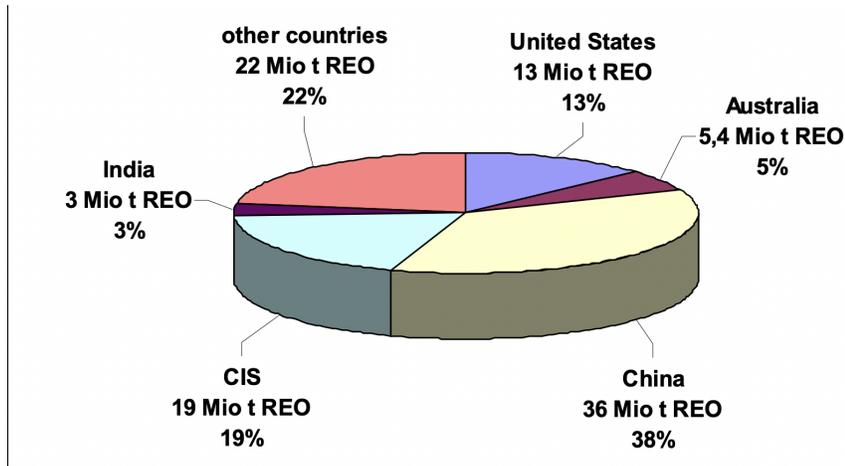


Figure 5: Global rare earth reserves by country estimated [SM11]

Batteries are usually defined by the metals in the cathode. Lithium is consequently popular, particularly to power individual electronic merchandise like cell phones, energy stockpiling frameworks, and (mixture) electric vehicles. Accessible, excellent lithium is generally amassed in a couple of Andean nations, fundamentally Bolivia and Chile.

Miners have to step into delicate regions, some with government cover on the measure of lithium that can be uncovered. A large portion of the world's stores is in Chile, prevalently in the bone-dry Atacama Plateau, which rides the boundary with Argentina and is home to herders stressed over the contamination and water deficiencies that will, in general, go with the mining system, just as the likely harm to locales they consider holy. Another deposit is in the picturesque English county of Cornwall, famed for its clotted cream and pirate cove beaches [J.17]



Figure 6: Identified lithium resources worldwide, 2012 [Zac13]

The worldwide pandemic acquaints extra vulnerabilities with the manageability of existing inventory chains. A significant number of the producers were hesitant to put resources into the business even before the flare-up because of the monetary strains between the United States and China. Organizations may lose future benefits because of a solitary mark of disappointments in the production network, as seen with Audi and Jaguar Landrover. China is the biggest purchaser of EVs internationally yet, delivers the majority of the world’s lithium. Last year alone, it created 79 per cent of the lithium hydroxide utilized in electric vehicle batteries [Coh20]

Moving towards the mining of lithium, the impacts are affecting communities where these extractions take place, jeopardizing their access to clean water. Current levels of lithium collection in the EU are deficient. In the case of batteries, this amounts to an estimated 5 per cent of the lithium-ion batteries put on the European market. Most of the current lithium is either dumped in landfills or incinerated, contributing to Europe’s dependency on lithium supply.

The extraction of lithium has significant environmental and social impacts, especially due to water pollution and depletion. In addition, toxic chemicals are needed to process lithium. The release of such chemicals through leaching, spills or air emissions can harm communities, ecosystems, and food production. Moreover, lithium extraction inevitably harms the soil and also causes air contamination [Emi19]

2.6 Solutions and Recycling

Depending upon the scenario, EV emissions might equate to that of ICEVs. Considering the fact that EVs are the future of mobility, the need to make them more environmentally sound is vital. The battery of an EV is a feat of intricate engineering. When this battery comes to the end of its life, its disposal might not be as environmentally sound as we would hope for. If it ends up in a landfill, its cells can release problematic toxins. Recycling the battery can be a hazardous business as well. If we cut too deep into the battery, it might release toxic fumes.

This is partly because lithium-ion batteries can be costly and difficult to recycle (Simmons, R., 2019). While you can re-use most parts in EVs, the batteries aren’t designed to be recycled or reused. Once in landfills, metals from the batteries can contaminate both water and soil [Jac19]

Different companies across the globe have come up with different methods to recycle EV batteries, such as, Redwood Materials, which is a Nevada-based company that hopes to create a circular supply chain for EVs by retrieving, recycling, and recirculating raw materials such as cobalt, copper, nickel, etc. In 2020, the company was on target to recycle more than 1GWh-worth of battery scrap materials.

Another such company is Aceleron, a United Kingdom-based clean technology company aiming to create the world’s most sustainable lithium battery packs. The company has created batteries that are prepared for their next life cycle. They are easier to disassemble and thus encourage reuse and support a

circular ecosystem. It will also build additional storage capacity as batteries could be repurposed to help store electricity at EV charging points.

The Global Battery Alliance (GBA) argues that a circular battery value chain is a key way of realizing the Paris Agreement’s 1.5C climate goal in the transport and power sectors. The GBA also estimates that batteries could enable 30 per cent of required cuts in carbon emissions in the two industries to reach the 2° goal of the Paris Agreement. They could also provide 600 million people with access to electricity and create 10 million sustainable jobs worldwide – by 2030. Its Battery Passport initiative seeks to create a digital representation of a battery that will provide consumers with a “quality seal” in terms of sustainability.

Lithium mining has been environmentally costly; considering this, in 2020, a site near the Wheal Clifford has been confirmed as having some of the world’s highest grades of lithium in geothermal waters. Lithium is currently sourced mainly from hard rock mines which leave scars in the landscape, require a large amount of water, and release 15 tonnes of CO2 for every tonne of lithium. Extracting lithium from geothermal waters – found not just in Cornwall but Germany and the US as well – has a tiny environmental footprint in comparison, including very low carbon emissions. This would be a viable alternative to extract lithium. [WEF21]

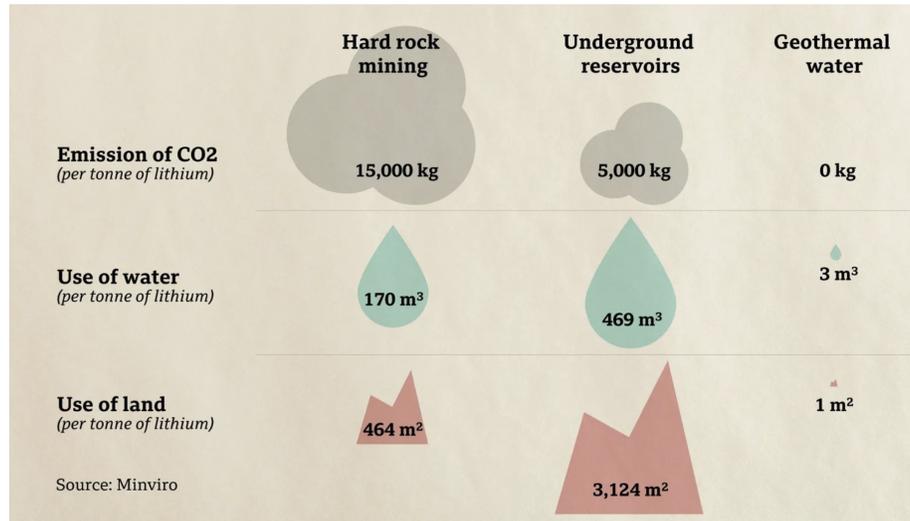


Figure 7: Environmental impacts of different methods to extract lithium [Ear20]

EVs require charging, due to which many charging ports have been built. Any source of energy can power these charging ports but usually use coal power plants for the same. There is pollution released by some distant power plants that provide the energy required to charge the cars with fossil fuels.

So another solution could be using renewable sources to power the charging

ports, which could also make the life cycle of EVs more sustainable. We could power the charging ports with green energy sources like solar power, windmills, hydroelectricity, etc. Some countries, such as Germany and Norway [Gon20], are trying to power the vehicle with clean electricity by using renewable energy sources.

It is evident that changes in the design and efficiency of engines can only go so far. We need to take other steps, some more detailed steps, to reduce the emissions of EVs. They can be a viable alternative to ICEVs in the future. We could achieve this by considering EVs' entire life cycle and moving towards a more sustainable world.

3 Conclusion

In this paper, we discussed that as the popularity of EVs continues to increase, including the new policies that promote EVs, such as that of the Biden administration which is imposing federal policies to accelerate the role of electric vehicles [Kap21] assessing the environmental impacts becomes imperative. The illusion of EVs being extremely environmentally sound arises as they do not release emissions while driving. We found that, on a complete Life Cycle Assessment, EVs do release emissions, and depending on the scenario they might even release emissions equivalent to that of ICEVs [Rei21].

Humans, animals, and all other living organisms are impacted by these emissions. The earth is impacted. The mining of the raw materials itself can result in erosion, sinkholes, loss of biodiversity, or soil, groundwater, and surface water contamination by the chemicals emitted from the mining processes. Mining is a very small part of the life cycle. Further, depending on the method by which the charging ports are powered such as that with coal. The car might not release emissions, but a distant coal power plant does. These raw materials might not be enough either, finding sustainable alternatives for the same is also a necessity.

As the EV engines are a feat of engineering, even the slightest cut too deep could release toxic chemicals which makes EVs difficult to recycle. Furthermore, if the batteries are not disposed of properly it could lead to other emissions as well. On the other hand, reusing many parts of EVs is a sustainable option.

It is important to understand that although EVs might not be as sustainable as they must be if we are to switch to entirely EV use. However, with a few changes in the life cycle, it is still important to be switching. EVs are more efficient and if the correct steps are implemented they could be a viable option in comparison to ICEVs till we work towards a more sustainable chain.

Solutions to make EVs more sustainable could include working towards better recycling. This entails making the engine in such a way that they are more sustainable and can be recycled easily, while still trying to maintain the efficiency of the engine. But, enhancements in vehicle designs or engines are not enough to make EVs more sustainable. Governments need to commit to shifting their power grids off of fossil fuels and on to renewables. It doesn't matter if we

all use electric vehicles if they're powered by coal plants. That's a larger grid design and power structure problem that will influence the success of EVs in the future. Even the best-designed car will still need a clean grid in order to be a clean car.

We need to realize that the most complicated variables are humans. To completely understand how EVs could be made more sustainable, we need to understand the complete life cycle in detail, and then work towards each and every small detailed step. EVs are the future of mobility, and it should be one of our prime goals to make it our most sustainable model for the protection of our earth. We could achieve this by cutting the costs and the environmental damage that come with manufacturing EVs, further promoting the adoption of EVs and driving transportation towards a more sustainable future.

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