A Future for Transportation: A Sustainability Assessment of Electric Vehicles

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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INTRODUCTION

The continued use of fossils fuels to power modern society is not sustainable. Given the current trends of production and consumption the EIA projects that the worlds demand for hydrocarbons and biofuels is only maintainable through 2050 (2021). In addition to their finite nature, the use of these fuels actively damages the ecological systems which are necessary for life on this planet. Over the last four decades average global temperatures have increased at a rate of 0.32° F per decade. Additionally, nine of the ten warmest years on record happened within the last ten years (NOAA National Centers for Environmental Information, 2021). Avoiding a future environmental and energy crisis requires action to change the way society operates. Despite this, action to improve global sustainability within the energy sector has been slow. In 2019 oil, coal and natural gas still combined to account for 80.9% of energy production worldwide (IEA, 2021). The next largest energy source is biofuel which accounts for 6% of global energy production.

Potentially the largest area of concern aside from energy is the transportation sector. According to a report by the International Energy Administration the transportation sector generated 7.7 billion tons of carbon dioxide emissions in 2021 with road vehicles accounting for 76% of that figure (2022). However, in contrast to energy, transportation appears to be rapidly shifting towards improved sustainability through the growth of electric vehicles (EVs). Electric vehicles are defined as either plug-in hybrid electric vehicles (PHEVs) or battery electric vehicles (BEVs).

In recent years the rate of adoption of EVs has greatly increased. In 2022 five percent of all car sales in the United States were electric vehicles. In Europe that portion was even larger at sixteen percent while they represented nine percent of sales globally (IEA, 2022). Importantly, support for EVs is coming from both manufacturers and consumers. Many established auto manufacturers have been developing EVs for their lineups and the industry is prepared to invest over 1.3 trillion dollars into EV development over the next 7 years. Reuters projects that by 2030 half all cars sold globally will be some form of electric vehicle (Lienert, 2022).

With manufacturers positioning EVs as the sustainable cars of the future it is important to consider whether electric vehicles truly fulfill the requirements for long term sustainability. There are several existing concerns which warrant discussion. One must consider the long-term viability of lithium-ion energy cells employed by electric vehicles. In the following section a basic sustainability assessment framework will be outlined to aid the analysis of the impact of electric vehicles on the sustainability of transportation.

SUSTAINABILITY ASSESSMENTS

Sustainability frameworks are complex analysis tools due to the inherently intricate nature of what they examine. In order for sustainability to be achieved a practice must ensure the long term prosperity of several overlapping pillars of interests. Three commonly defined pillars are the ecological, social, and economic pillars. When assessing a decision for sustainability the interactions between the different pillars must be carefully considered. They cannot be viewed as independent entities. It cannot be ignored that fundamentally humans are dependent on the condition of our habitat to survive. Without environmental flourishing any economic or social improvements would be for naught, and this applies in the other directions as well. Sustainability requires mutually beneficial outcomes for all three pillars.

Gibson (2005) outlines several basic requirements for sustainability frameworks two of which will be focused on. The first focuses on the social and ecological balance of human behaviors. Gibson writes of socio-ecological integrity as “build[ing] human-ecological relations to establish and maintain the long-term integrity of socio-biophysical systems and protect the irreplaceable life support functions upon which human and ecological well-being depends.” This requirement brings the attention of sustainability focused decision making upon the mutual dependence of human and ecological security on the basic functions of the biosphere. Both humans and the environment are impacted by changes to things such as water sources and their integrity cannot be compromised. This involves better understanding the systemic implications of human activities and the need to reduce existing anthropogenic threats to these life support systems.

The second requirement which will be focused on is intergenerational equity. The requirement of intergenerational equity requires decision makers to favor present options and actions which preserve the ability of future generations to live sustainably. Satisfying this requirement involves ensuring that resource exploitation is not occurring at rates which exceed the capacity of the system. For example, ensuring the fishing industry does not overfish during a season so that stock levels remain high enough to ensure healthy fish populations in the future. Intergenerational equity brings attention to economic and social sustainability in a different way then the first requirement. Economic and social flourishing cannot be only considered in present terms. Sustainability requires a forward-looking lens.

These two requirements will guide the assessment of electric vehicle sustainability and provide a useful overview of how the technology interacts with the three pillars of social sustainability, ecological sustainability, and economic sustainability. EV technology will be analyzed to determine to what extent the artifact succeeds in its goal of overall increasing sustainability of transportation.

ANALYSIS

Energy Sources

From a sustainability perspective the two most significant differences between electric vehicles and internal combustion engine vehicles are their fuel sources and energy storage systems.

ICEVs use liquid fuel, which is converted to mechanical energy using the namesake internal combustion engine. This makes them directly reliant on highly combustible, energy-dense, liquid fuels. Traditionally, these fuels have been gasoline and petroleum-based diesel fuels. Though other energy sources have been explored, such as ethanol and biodiesel, the EPA reports that 95% of the world's transportation energy currently comes from petroleum-based fuel (2022). The use of petroleum-based fuel places the energy storage of ICEVs in opposition to both the requirement of intergenerational equity and the requirement of socio-ecological integrity. The heavy utilization of hydrocarbons for transportation is inherently inequitable for future generations due to their finite nature. Additionally, the burning of these fuels produces severely negative effects on global ecological systems due to the greenhouse gas emissions that are produced as a result. Greenhouse gas emissions harm local ecology through things such as smog and manifest in global impacts such as climate change and ocean acidification.

Electric vehicles attempt to remedy this conflict by using a different energy source. Utilizing battery storage instead of combustible fuel allows for vehicles that do not directly produce carbon emissions. Additionally, electricity is not an inherently limited resource. It seems that by changing the fuel source, electric vehicles are able to greatly improve the sustainability of transportation technology. However, it is important to consider the systems which generate the electricity to be used in EVs. Electricity is mostly generated using the same petroleum-based fuels and other hydrocarbons that EVs are attempting to avoid. As stated previously, natural gas, coal, and oil are responsible for 80.1% of all electricity used in the United States. Currently, EVs are still indirectly dependent on these non-renewable fuel sources to operate. This begs the question: do EVs remedy the sustainability issues posed by using petroleum-based fuels in traditional combustion engine cars?

The requirement of preserving socio-ecological integrity is seemingly at odds with EV energy storage systems when considering the ways in which electricity is generated. Grid electricity production accounts for 25% of all greenhouse gas emissions in the United States (EPA, 2022). If all combustion vehicles were immediately replaced with EVs then the problem would seem to simply have been displaced from the transportation sector to the power grid. Electric vehicles are only zero emission vehicles at the tailpipe. One may be able to argue that rapid electrification of transportation is actually less sustainable at the current moment. Perhaps it may be wiser to prioritize plug in hybrid electric vehicles or cleaner combustion vehicles until the energy grid is more able to support the aspirations of battery electric vehicles.

Within a sustainability framework, however, consideration of the future is more important than present conditions. The development of fully electric vehicles must be viewed with future opportunities in mind. If cars are going to remain a large factor in everyday transportation, investment into vehicles that have the potential to become independent from petroleum resources is necessary. If the industry was unable to develop electric vehicles beyond hybrid models, then the technology would become unsustainable once oil reserves become depleted in the future, even though they would be 'more' sustainable than ICEVs. EVs are therefore the most sustainable option because they preserve the opportunity of a future where car usage may become wholly sustainable. Sustainable, clean energy is possible and may be developed in the future. By contrast, any combustion-based vehicle will create atmospheric byproducts regardless of the fuel. While the current portfolio of energy sources does not mean that EVs necessarily have lower life cycle carbon emissions than ICEVs it does open the door for them to in the future as clean energy continues to expand.

This last point is important in the way it ties into satisfying the intergenerational equity requirement for sustainability. The use of electricity instead of gasoline provides more opportunities for sustainable development by future generations. Continuing to further develop technology and infrastructure around cars in a world without investing in electric vehicles would be irresponsible and inequitable for future generations. At some point in the future, petroleum-based fuels will no longer be producible. Additionally, switching ICEVs entirely to biofuels would not adequately protect socio-ecological integrity. The sustainability framework calls for the implementation of electric vehicles due to their greater future potential.

Battery Technology

The other aspect of electric vehicles which requires assessment is the energy storage technology itself. Lithium-ion batteries (LIBs) possess higher energy density than nearly all other currently usable battery technologies and are utilized by nearly all commercial electric vehicle manufacturers (Goldman et al, 2019). Many different compounds are used as the cathode of LIBs, but the first successful batteries produced for EVs utilized cobalt and it is still widely used. Nickel- Magnesium-Cobalt (NMC) cathodes were the most produced cathodes in 2018, accounting for 41% of the global market share (Pillot, 2019). Nickel-Cobalt-Aluminum (NCA) cathodes are also popular for their capacity retention capabilities. Cathodes which do not use cobalt exist with Lithium-Iron-Phosphate (LMP) cathodes chief among them. At this point in time LMP cathodes cannot match NMC or NCA cathodes in terms of energy density though their lower cost has made them desirable in some applications.

Modern electric vehicles are highly dependent on lithium-ion technology and are currently unlikely to employ any alternative battery systems. In addition to energy density, LIBs perform well in a wide range of temperatures and have long operational lives. This means that the prevalence of rare elements such as cobalt in LIBs has real implications for the sustainability of EVs. With the demand for electric vehicles expected to drastically increase in the coming years, the supply chain for lithium and cobalt will be strained. Lithium and cobalt have both been identified as critical materials by the United States government (DOI, 2018). Critical materials are very important to the nation but have highly vulnerable supply chains. Over 50% of all lithium and cobalt are mined in one country, Chile, and the Democratic Republic of the Congo respectively (U.S. Geological Survey, 2022). Applying the sustainability assessment framework to the use of minerals in LIBs immediately calls attention to the requirement of intergenerational equity. Intergenerational equity requires that actions taken do not hinder the abilities of future generations to live sustainably. Overdependence on rare elements is at odds with this. If electric vehicle adoption continues in the way which it is projected, then the supply of cobalt and lithium will be strained and could potentially lead to vehicles' inaccessibility. The sustainability framework requires that electric vehicle developers take actions to prevent this to ensure the long-term viability of electric vehicles.

Two options are available to EV manufacturers: increased recycling efforts or the development of alternative battery technologies. Recycling is seen as important in ensuring the long-term supply of lithium and cobalt in the United States (Ambrose and O'Dea, 2021). Regardless of the cathodes being used within the batteries, lithium is a resource will need a secondary production process to meet battery supply. The last year has seen the price of lithium skyrocket, preventing many EV manufacturers from fully meeting consumer demand. Recycling of batteries would provide countries without lithium and cobalt deposits with a domestic supply and would help preserve future prospects for increasing EV usage sustainably.

When considering the socio-ecological integrity requirement of the sustainability assessment, it becomes clear that the specific mining practices surrounding lithium-ion batteries must be discussed. Cobalt mining within the DRC raises social and environmental concerns that threaten the sustainability of LIBs. Large-scale mining operations have caused conflicts between foreign investors and local communities in the DRC (Prause, 2020), and artisanal and small-scale mining (ASM) operations frequently exploit workers, violate child labor laws, and place women in situations with dangerous power dynamics (Sovacool, 2021). The importance of mineral mining and refinement to the Congolese economy also generates pressure to continue current destructive mining practices.

The nature of cobalt mining has caused some EV manufacturers to explore different battery technologies; however, LIBs with NMC and NCA cathodes, which are the top-performing batteries currently in use, are highly unlikely to be abandoned soon. To approach the goal of social and ecological integrity, action must be taken to address the problems associated with cobalt mining. While improved recycling efforts may reduce some of the strain, effort must be made to address the social and economic problems surrounding mining. Mining operations must not simply focus on the removal of minerals from the mining sites but also improve the conditions of the people working in or living near the mining operations. Sustainability is holistic, and it not only requires mining operations to be conscious of their impacts on local ecology but also the people in the nearby communities.

CONCLUSIONS

Applying the outlined sustainability framework to electric vehicles has provided many insights into the actions and developments needed within transportation technologies to ensure long-term viability. The future-looking lens shows clearly that transportation sustainability requires the development of vehicles that are not directly dependent on nonrenewable resources to operate. Additionally, the new vehicles that are developed cannot negatively disrupt socio-ecological integrity. Due to their relative independence from liquid hydrocarbons, electric vehicles are a viable option for the future of transportation. Another advantage is that electric vehicles do not negatively affect ecological systems during their use. Despite this, actions must be taken to address issues produced by the development of car battery systems. If the sustainability framework is used as a decision-making tool, electric vehicle manufacturers must choose to increase the recycling of lithium-ion batteries and investigate alternative battery chemistries to alleviate the impacts of cobalt and lithium mining. Electric vehicles cannot simply settle for being more sustainable than the technologies that have come before; they must strive to reach true long-term viability by taking into account the way the technology interacts with both people and our environment.

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