The Adoption of Battery Electric Vehicles: A Review Based on Environmental, Infrastructure and Consumer Perspectives

Karl Wezmar

Marywood University

SLAS 6013: Qualifying Seminar

PhD in Strategic Leadership and Administrative Studies

Dr. Alexander Dawoody

Fall 2022

Abstract

This research project examines the various issues and complexities associated with the widescale adoptions of battery electric vehicles (BEVs). There is an enormous number of societal factors that impact the adoption or rejection of BEVs that will be addressed later in this study. Because of greenhouse gas emissions associated with global warming, human health impacts and recent weather-related catastrophes are occurring more frequently and can be much more deadly.

Internal combustion engine (ICE)-powered vehicles are a large contributor to the generation of greenhouse gasses. The use of fossil fuels to power ICE vehicles is not only harmful to the planet, but it also impacts the overall health of its inhabitants and ecosystems. Although the adoption of BEVs will not solve the environmental issues completely, it is important to focus on how the adoption of BEVs can reduce harmful emissions. The widespread adoption of BEVs will have a positive impact concerning pollution and issues associated with it, but it is important to identify the negative impacts of their widespread adoption as well.

This research paper will add to the body of existing knowledge pertaining to the use of ICE vehicles, including issues associated with the barriers to entry and adoption of BEVs. It will recommend changes on various levels, and tie together existing research conclusions to explore the benefits and drawbacks of widespread BEV adoption.

Keywords: battery electric vehicles, internal combustion engines, greenhouse gas emissions, power generation, barriers to entry

Table of Contents

List of Figures

The Adoption of Battery Electric Vehicles: A Review Based on Environmental, Infrastructure and Consumer Perspectives

Battery electric vehicles (BEVs) date back to the mid-1830s (Matulka, 2014). By the 19th century roughly 40% of vehicles on the road were BEVs, and the remainder of vehicles being produced were propelled by an ICE fueled by gasoline, or a steam-powered engine (SPE) fueled by kerosene or coal to heat a boiler for steam generation. Both ICE and SPE propulsion methods had their advantages and disadvantages (Hosseinpour et al., 2015). The sales of SPE-powered vehicles peaked in the 1920s as ICE-powered vehicles became more reliable and affordable. After paved roads were created in the 1920s, motorists were able to travel longer distances, conveniently stopping at one of the many gasoline stations that dotted their neatly folded maps.

Emissions produced by the use of ICE vehicles is a major contributor to the generation of greenhouse gasses. Their widespread use has had an extremely negative impact on the global environment, on every single one of its inhabitants and ecosystems. The transportation sector contributed 27% of all greenhouse gasses created in 2020 according to the Environmental Protection Agency (EPA) (2022b). For well over a century, ICE vehicles have been the primary source of transportation for personal use and the transportation and distribution of goods and commodities globally. With the widespread adoption of BEVs, the reliance on fossil fuels needed to power ICE vehicles would greatly reduce the harmful emissions they produce.

Today, consumers who are environmentally conscious may still be utilizing their ICE-powered vehicles because of their familiarity with them; unfamiliarity of BEVs; and financial, ethical, and infrastructure issues which may outweigh the environmental benefits of an electric vehicle. This paper examines how socio-economic, environmental, and infrastructure perspectives impede and can be improved upon to aid in the widespread adoption of BEVs.

Additionally, this paper will explore the topic in the context of theory. Following the literature review, this paper will present an applicable overview of diffusion of innovation theory, disruption of innovation theory, theory of constraints, and the two-step flow theory. These theories were selected for their relevance to gradual consumer adoption of BEVs, their influences on consumer behavior, and issues related to the manufacturing, sourcing, and maintenance of BEVs. The paper concludes with a review of ethical considerations and policy recommendations that may help inform and shape consumer adoption of BEVs.

Literature Review

While battery electric vehicles (BEVs) have been a mainstream topic of debate and discussion in recent years, the advent of BEV dates back to the mid-1830s (Matulka, 2014). In their infancy, BEVs were little more than a crude battery-powered carriage and an electric motor, instead of the carriage being pulled by a horse. By the turn of the 19th century roughly 40% of vehicles on the road in the United States were BEVs (Hosseinpour et al., 2015). During the same time period, according to Happian-Smith (2001), the remainder of vehicles being produced were propelled by either an internal combustion engine (ICE) fueled by gasoline, or a steam-powered engine (SPE) fueled by kerosene or coal to heat a boiler for steam generation. SPEs operated much like steam powered locomotives proving to be reliable for decades prior to the technology being adapted to personal vehicle use. Regardless of the propulsion system used by vehicles in the early 19th century, each method had specific and significant advantages and disadvantages (Matulka, 2014).

Steam-Powered Engine Vehicles

There are more than a few disadvantages to SPE-powered vehicles. For one, when cold, steam-powered vehicles could take up to 45 minutes to create enough steam pressure to propel the vehicle (Happian-Smith, 2001). When using kerosene to power the SPEs, drivers would often experience unpleasant fumes generated through the combustion process used to heat water to create the necessary steam, and the SPE would often need to be refilled with water every 20 to 30 miles when in use. When powered by coal, SPE-vehicle owners would complain about the amount of soot associated with the combustion of coal and filth of the coal dust itself when fueling the vehicle (Masulka, 2014). There was public fear the boilers used in SPE vehicles could explode, resulting in concern and opposition to SPE powered vehicles (Shields, 2007).

Some advantages of SPE-powered vehicles included quiet operation, ease of operation with the driver only having to operate a valve to adjust the speed of the vehicle as there were no gears to shift, and no laborious cranks necessary to start the engine. At the time the fastest mode of transportation was SPE, with some models reaching speeds of over 120 miles per hour. SPE-powered vehicles proved so appealing to enough Americans that in 1899 more than two dozen manufacturers were producing SPE-powered vehicles (Sovacool, 2009).

Internal-Combustion Engine Vehicles

SPE-powered vehicle sales peaked in the 1920s as ICE-powered vehicles became more reliable and affordable. During the 1920s, many factors contributed to the SPE’s vehicle demise, including dwindling interest resulting in a decline in the sale of SPE powered vehicles. The Ford Model T was introduced in 1908 utilizing an ICE powertrain that ran on gasoline. When introduced, the Model T cost $850.00 while SPE powered personal vehicles ranged anywhere from $1,750.00 to $3000.00. With the development of new technologies and revolutionary production and manufacturing practices, the introduction of assembly line production pioneered by Ford transformed vehicle production to this day. The price of a new Ford Model T dropped to a starting price of $360.00 in 1915 (Guarnieri, 2012). Prior to the Ford Model T, ICE-powered vehicles had a reputation for being loud, unreliable, unrefined, and dangerous while starting the engine with a crank. Once running, vehicles produced prior to the Ford Model T would emit foul-smelling and dirty exhaust fumes (Guarnieri, 2012). Ford had alleviated most of the issues associated with ICE-powered vehicles when designing and marketing the Model T, changing consumers' perceptions.

Roadway Infrastructure Advancements

Paving of American roads started in the 1920s allowing motorists to travel longer distances. Drivers were no longer constrained by the lack of range associated with BEV-powered vehicles with a rudimentary highway infrastructure partially in place. Crude oil used to create cheap gasoline was discovered in Texas, Oklahoma, and California further reducing the overall cost of owning and operating an ICE-powered vehicle (Guarnieri, 2012). When the Ford Motor Company was formed in 1903 there were only 8,000 cars in the United States. With less than 150 miles of paved roads to travel, individuals rarely traveled more than 25 miles from their home in their lifetimes (Brooke, 2008).

Gasoline stations began to spread across the U.S., offering motorists access to cheap gasoline. Individuals living in rural and remote areas, many of whom did not have access to the electric grid at the time to power BEVs, now had the ability to fuel low-cost ICE-powered vehicles. When the Ford Model T ended production in 1927, with more than 15 million units produced, the vehicle solidified that ICE-powered vehicles were going to be the most prominent and practical choice for vehicular mobility (Matulka, 2014). By introducing the Model T, Ford

Motor Company not only solidified the production and adoption of millions of other ICE-powered vehicles produced by many other manufactures, but the vehicle also aided in the creation of societal, infrastructure, and environmental issues still being faced today. As ICE-powered vehicles continued to evolve and gain more popularity, BEVs were generally no longer sought after or purchased by 1935 (U.S. Department of Energy, 2016).

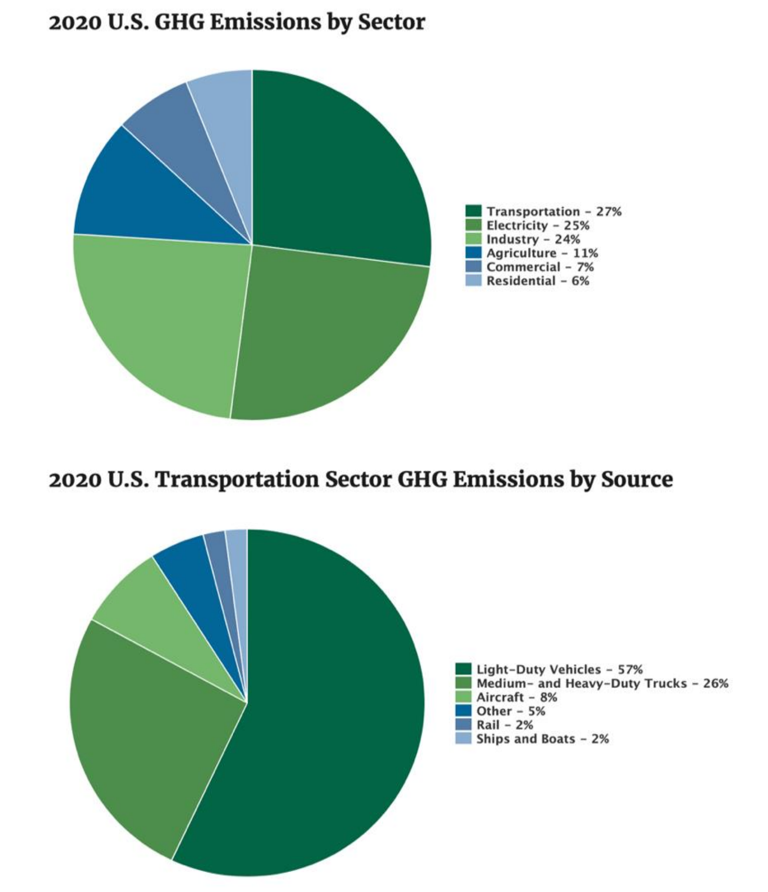
As ICE vehicles became more accessible and well-received by the populace and proliferated on America's roads, the highway infrastructure was rudimentary at best. Most roads and highways were not maintained. Maintenance became the responsibility of individual states or counties. In 1916, the Federal-Aid Road act was passed, authorizing $75 million over a 5-year period to improve, revamp, and expand the country's road systems (Interrante & Yu, 2017). Incremental acts were then passed by the Federal Government to aid in growth of vehicular transportation, but the largest act improving the ability for American to travel was passed in 1956. The Federal-Aid Road Act was amended by the passing of the Federal-Aid Highway Act of 1956, under the presidency of Dwight D. Eisenhower. President Eisenhower saw the advantages of an interstate highway system after witnessing the advantage of Germany's autobahn highway network during World War II. Beside facilitating more rapid deployment and translocation of military personnel and equipment within the U.S, President Eisenhower believed highway systems needed to be more comprehensive and safer, and aid in the mobility of Americans. There were some ethical dilemmas associated with construction of the highway systems. In urban areas in which individuals of lower socioeconomic status resided, numerous neighborhoods were destroyed. Additionally, the construction of new highways paralleled railroad networks that resulted in the circumvention of numerous small towns and their merchants. This issue was partially rectified by the increased mobility afforded to Americans by the growth of interstate commerce and the creation of suburbs as we know them today (National Archives and Records Administration, n.d.).

Pollution Attributed to the Proliferation of the Internal-Combustion Engine

Since ICE-powered vehicles proliferated and became the preferred method of vehicular transportation, they have spewed massive amounts of toxic material into the atmosphere. ICE vehicles grew in size and weight dramatically over time requiring larger ICEs for propulsion. To combat the pollution created by ICE vehicles, The Clean Air Act was passed in 1970, forcing automakers to reduce the emission from their vehicles. By doing so, the Act has resulted in 98–99% less greenhouse gas tailpipe emissions compared with the ICE vehicles of the 1960s. Lead was removed from gasoline and sulfur content has been reduced more than 90% in fuels used today. The result of the Clean Air Act has improved air quality and lowered greenhouse gas emissions with more ICE vehicles on the US roads today than ever before. Although the Clean Air helped to reduce greenhouse gasses, as of 2020, 27% of greenhouse gas was created by the transportation sector. Of that 27%, 57% of light-duty vehicles contributed to the production of greenhouse gasses (Environmental Protection Agency, 2022a) (Figure 1).

Figure 1

2020 Green House Gas Emissions Sector and Mode of Transportation



Note: From *The U.S. Department of Energy: Alternative Fuel Data Center* (https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions)

A study conducted by the Harvard T.H. Chan School of Public Health and The University of North Carolina at Chapel Hill assessed the links between the sources of vehicle emission and the health effects on individuals living in the Northeastern and Mid-Atlantic regions of the United States. In 2016, Arter et al. (2021) found that 7,100 premature deaths occurred due to vehicle emissions in the aforementioned regions. The researchers found emissions from light-duty trucks, which include SUVs, were the largest contributor of premature deaths with light-duty vehicles being the second largest contributor to premature deaths due to vehicle emissions.

New York, Pennsylvania, and New Jersey were found to generate the most toxic emission. Local emissions have an impact of those living in the areas where the pollution is created, but Arter et al. (2021) pointed out that "pollution transport" kills more individuals outside of Pennsylvania and New Jersey than within the state. The researchers expressed the importance of the need to improve air quality in the region to improve and protect the health of the public.

Volkswagen's "Dieselgate"

Three students attending West Virginia University discovered an anomaly when testing Volkswagen (VW) vehicles powered by the company's turbocharged direct injection ICEs powered by diesel (Mackay, 2018). Commonly known as Dieselgate, VW intentionally and unethically programmed their turbocharged direct injection vehicles to perform differently when being tested for emissions, while touting them as "clean diesel" (Mackay, 2018). When being tested for emissions on a dynamometer with the front wheels powering the dynamometer and the rear wheels stationary, the vehicles were programmed to recognize they were being tested and so operate in such a way that they would meet emission regulations.

The students then drove the vehicles on the road and found drastically different tailpipe emission results. It was found that when the turbocharged direct injection VWs were operating under normal driving conditions they would produce up to 40 times the pollution set by federal standards (Bartlett, Naranjo & Plungis, 2017).

Deceptive Emissions Software

To save production costs, VW used an emissions control system that did not require the use of urea fluid, commonly known as AdBlue, which is used by the vast majority of diesel ICEs to scrub nitrogen oxide and nitrogen dioxide from the vehicles' emissions. In the United States alone, over 500,000 vehicles were fitted with the emission-cheating software, including model vehicles under VW's umbrella such as Audi and Porsche as well. Globally, VW sold nearly 11 million vehicles with the deceptive emission control programming. (Nicoleta-Elena & Fang, 2020).

In the end, Dieselgate ended up costing VW over $32,000,000 in damages and many decision-makers that worked for VW were faced with fines or incarceration. Since the scandal, VW has redesigned their logo and identity and have committed to becoming the world's most dominant BEV manufacturer (Nicoleta-Elena & Fang, 2020).

The Rebirth of the Battery Electric-Powered Vehicle

For over 6 decades BEVs were forgotten until General Motors (GM) debuted the EV1. Starting in 1996 and leased only in California, this BEV introduced a battery superior to lead-acid batteries, utilizing nickel-metal hydride batteries which improved the range of the BEV. GM's design of the EV1 was revolutionary in design, aerodynamics, electronics, and many other innovative technologies that are currently being utilized in the BEVs of today. According to the Smithsonian Institution, the EV1 project was eventually abandoned as the project was found to be too costly and had little appeal to the mass market. A majority of these EV1s were destroyed while the remaining few have been preserved as artifacts to showcase the technological and innovative design engineering elements that contributed to the modern-day BEVs (National Museum of American History, n.d.).

After the failure of the GM EV1 in the 1990s, the public perception of BEVs was poor. This changed in 2004 when Tesla Motors (TM) produced its first mass-produced BEV, the Tesla Roadster, based on an existing vehicle chassis sourced from the automobile manufacturer Lotus. After many leadership changes, Elon Musk appointed himself as the CEO of Tesla after he invested $55 million in the company (Khan, 2021). In 2010 Tesla Motors went public with an initial public offering (IPO) that resulted in the acquisition of $226 million to support the company's continued operations.

Although the Tesla Roadster ceased production, TM released the luxury sedan Model S in 2012 while developing and installing a vast network of charging stations in strategic locations. The Tesla charging station, also known as Superchargers, enabled Tesla owners to charge their vehicles rapidly at no cost. This reduced one of the main concerns of BEV adoption, range anxiety. The one caveat is these chargers are proprietary and are incompatible with any of BEV beside Tesla vehicles (Biscontini, 2022).

In 2015, Tesla announced it would be manufacturing a sport utility vehicle, the Model X, as well as a smaller more affordable sedan with a base price of $46,990 named the Model 3. In 2017, a smaller sports utility vehicle, the Model Y, was released (Biscontini, 2022). Tesla Motors looked toward other avenues for battery technology innovation and dropped "Motors" from the TM identity as the company ventured into other markets such as solar battery storage (Biscontini, 2022). While venturing into other markets, Tesla, as of 2020, was the most valuable car company on the according to Forbes (Klebnikov, 2021).

Three million BEVs were sold in 2020 which accounted for 4.1% of auto sales globally. After a decade of increasing BEV sales, there was a decline in sales in 2019 due to the COVID-19 pandemic. According to the International Energy Agency, sales of BEVs doubled in 2021 compared with 2020 (Razmjoo et al., 2022), and it is anticipated that in the United States market BEV sales are expected to triple between 2022 and 2028. Because the BEV market mostly comprised of sedans with only a few manufacturers offering them for sale, consumers had limited options for the configuration of BEVs that would suit their needs. Recently, however, Ford Motor Company started to produce a BEV cargo van called the E-Transit as well as a BEV

F-150 Lightening pickup truck. General Motors has already released the electric Hummer line that is available in either a pickup truck or SUV configuration. Although the introduction of these BEVs give customers more options that suit their needs, the Hummers BEVs cost well over $100,000 and the Ford F-150 Lighting starts at $51,974 up to $96,874 before adding any options, putting them well out of reach for most consumers who could buy a comparable ICE truck or SUV for much less.

The factor which impedes the adoption of BEVs is the style and size of the vehicle manufacturers have chosen to produce. BEVs' efficiency is measured in miles per gallon equivalent, similar to how ICE vehicles are rated for how many miles can be traveled on a gallon of fuel according to the U.S. Department of Energy (2016). Out of all of the BEVs currently on the market, only four sedans are priced under $40,000. As for the 10 other BEV sedans currently available, they range in price from $41,000 to $140,000 without options. There are currently 12 BEVs that are classified as SUVs on the market which range in price from $41,000 to $122,440 without options with miles per gallon equivalent ratings that are significantly lower than those of their sedan counterparts. With increased size and less aerodynamics shapes, the miles per gallon equivalent of the BEV SUVs drops dramatically with the increased weight of the heavy batteries needed to power them; this defeats the purpose and intent of BEVs. For example, according to GM, the Hummer BEV weighs in at 9,063 pounds compared with a similarly sized truck, the Ford F150 weighing at most 5,740 pounds (National Museum of American History, n.d.).

There are many variables that influence the adoption of BEVs. Cox Automotive is a conglomerate based in Atlanta, Georgia, that analyses the United States vehicle market and has companies such as Autotrader, Manheim, and Kelly Blue Book under its company portfolio. Cox conducted a study that was published by Kelly Blue Book that examined the cost associated with the acquisition of a new vehicle. The average price paid for BEVs has increased in price from $58,914 in June of 2021 to $66,997 in June of 2022, representing an increase of 13.7% (Kelly Blue Book, 2022). Kelly Blue Book also reported that the average price of a full-size ICE sedan was $42,498 in June of 2021 and jumped to $44,632 in 2022, representing a 5% increase. With a disparity of roughly $24,000 between ICE vehicles and BEVs, many individuals of lower socio-economic status are unable to afford a BEV. Based on extensive research conducted by the Fuels Institute's Electric Vehicle Council (Fuel Institute, 2022), the organization was able to identify the demographics of BEV buyers which help to explain barriers to entry and adoption. They identified some statistics related to BEV buyers that are skewed: 44% of buyers are between the ages of 25 and 54, 57% of buyers have an annual household income of over $100,000 a year, 75% of buyers are male, 87% are White, 41% hold a 4-year degree with 36% holding graduate degrees, and 78% have two or more vehicles in the household. The research revealed that political affiliation had very little to do with the adoption of BEVs. With demand high and supply low, the cost of BEVs is continually increasing. For example, the highly acclaimed and modestly priced Kia EV6 jumped from a starting price of $42,695 to $49,795. To make matters worse, as with any BEV vehicle that is imported from outside the United States, it is ineligible for the $7,500 tax credit.

A study by Guo & Kontou (2021) found that lower-income households were disadvantaged by the tax credit program. Ninety percent of the BEV purchase tax credit went to the wealthiest of buyers who did not need to wait to file their taxes to receive the full $7,500 tax credit as they had the means to pay for their BEV upfront. The tax credit was based on tax liabilities which vary by income level and availability of other tax credits. For example, only 23%-45% of the population in lower tax brackets in Atlanta, Georgia would be eligible for the full tax credit, with percentages even lower for the minority population (Liu et al., 2020). Potential BEV buyers are more interested in tax exemption at the point of sale compared with post-sale tax credits. This is explained by the “present bias” that explains that money is valued more in the present than the future (Bisin & Hyndman, 2014). Roberson& Halheston (2022) found in their sample group that an upfront incentive of $1,450 on average was more favored amongst those sampled than the potential and variable tax credits they would receive when filing their taxes. The researchers calculated that by using this incentive model, $2.07 billion would have been saved by the government on new BEV incentives. With the introduction of the Inflation Reduction Act of 2022, a $4,000 tax credit was announced for used EVs designed for those of lower socio-economic status to help acquire BEVs.

With the information, history, and current status of the BEV market and their adoption rate provided in the literature review, perspectives will be covered next. Emerging themes will also be identified and discussed, and theories applied.

Perspectives

Since the inception of the BEV there has been a multitude of issues and developmental challenges preventing their widespread adoption and acceptance. With the identification of existing, historical, and emerging problems associated with BEVs’ widespread accessibility and adoption, the intention of this literature review is to examine how socio-economic, environmental, and infrastructure perspectives impede and can be improved upon to aid in the widespread adoption of BEVs.

Infrastructure Perspective

The ability to recharge a BEV is a key barrier to BEV adoption. One survey concluded that 54% of respondents were unwilling to consider the purchase of a BEV until charging stations are as easy to access as gas stations (Hosseinpour et al., 2015).

Charging BEVs Residentially

A large majority of BEV owners prefer to charge their vehicles at home (Hosseinpour et al., 2015). Much like the issues associated with charging BEVs in the early 1900s, a similar situation exists today. Homeowners have two options when charging their BEVs: Level 1 and Level 2 chargers. Level 1 chargers utilize typical household 120-volt outlets. The United States Environmental Protection Agency website states that electric vehicles can be charged by the same outlet used to power a toaster (Environmental Protection Agency, 2022b). If a Ford Mach-E BEV were to rely on a 120-volt charger, it would take 95 hours to charge from zero to 100% for the long-range variant (Ford Motor Company, n.d.). This would make home charging by this method unfeasible and detract from the appeal and the adoption of the Mach-E BEV or any BEV that requires days to completely recharge. This charging rate equates to roughly three miles of range for every hour the vehicle is plugged in. The charge rate of recharging a BEV is a large contributor to decision in the purchase of a BEVs. An unacceptably long charge time is a deterrent for a consumer considering a BEV (Theil et al., 2012).

Level 2 chargers utilize a 240-volt outlet much like one used to power electric clothes dryers or electric ovens. For direct comparison, the charging rate for the Ford Mach-E BEV long-range variant utilizing the 240-volt mobile charger included with the purchase of a Ford Mach-E is 15 hours to charge the vehicle from zero to 100% state. Unfortunately, it is difficult to locate and access a 240-volt outlet to connect the charger to. At an additional cost of $799.00, Ford offers a hardwired 240-volt charger that can replenish the vehicle in 10.9 hours (Ford Motor Company, n.d.). To utilize either of the 240-volt chargers at a residence, it is required that a licensed electrician perform the installation of the electrical requirements at an additional cost.

For BEV owners who rent their residences or for individuals who do not have a driveway or garage to rely on for dependable access to charging, BEV adoption is especially challenging. In certain areas of the United States such as San Diego, individuals who live in apartment buildings or condominiums make up approximately 50% of the population. An alternative to having little to no access to a BEV charger at an individual's residence is workplace charging or charging their BEVs in parking garages that have charging stations in place (Botsford & Edwards, 2016). To offset the inaccessibility of charging BEVs at an individual's residence, the U.S Department of Energy passed Public Law 109-58, giving priority to cost-effective charging solutions to individuals without access to home charging (Alternative Fuels Data Center, 2022).

Charging BEVs Publicly

There are currently no standardized methods or charging equipment established globally for BEVs. In the United States alone there are five chargers currently in use according to the United States Environmental Protection Agency (2022). These chargers include Level 1 J1772, Level 2 J1772, and the fast charging direct-current CCS, CHAdeMO, and Tesla Charger. Tesla has a comprehensive and far-reaching proprietary fast charging network in place that can only be used by BEVs manufactured by Tesla. Conversely, Tesla BEVs can use an adapter to enable charging at other charging stations that are not proprietary to Tesla vehicles. It is vital to continue to work toward standardizing the charging network for BEVs to allow greater accessibility, acceptance, and convenience; reduce pollution; and minimize range anxiety as the adoption of BEV vehicles continues to increase (Peter et al., 2016).

Direct-current fast chargers are available to non-Tesla owners but are in short supply with about 14% of all public chargers being part of the fast-charging infrastructure (Funke et al., 2019). If applicable and depending on the model, battery size and design of the BEV, the utilization of a fast charger can add between 180 to 240 miles of range per hour, or from zero to 100% charge between 20 minutes to roughly an hour according to the U.S. Department of Transportation (2022). With the installation and proliferation of a more comprehensive charging network, BEV drivers could theoretically spend around the same amount of time charging a BEV utilizing a DC fast charger as they would filling their fuel tank in ICE-powered vehicles thereby reducing the hesitancy to BEV adoption.

BEV charger reliability and availability is crucial to the adoption of BEVs. A recent study conducted in California to test the functionality of BEV chargers operated by various charging station companies revealed some disconcerting findings. The study identified that 9% of charging plugs were broken, unexpected charging shut off took place 6% of the time, 22% of charging stations were not functioning at all, payment problems were experienced 18% of the time, and researchers needed to contact the charging stations customer service center 53% of the time (Rempel et al., 2022). This data does not take into account whether other BEV drivers are utilizing the chargers to replenish their BEV batteries rendering them inaccessible.

Refueling an ICE-powered vehicle is typically conducted and located adjacent to a store with an employee who can assist with fueling issues. Charging stations typically consist of kiosks in obscure areas of parking lots with little technical support besides the screen interface used on the charger itself, and the phone application that enables payment, charging, troubleshooting, and communication with the charging station. When all those measures fail, BEV owners in need of assistance must rely on a customer service call center operated by the company that owns or leases the charging station. The refueling process of an ICE vehicle is relatively straightforward and seldomly has issues. The access, process, and reliability related to BEV charging needs to be addressed and improved upon to promote widescale adoption and reduce range anxiety.

The Duck Curve

The duck curve, named as such due to the graphical representation of electrical consumption in a 24-hour period that resembles the body of a duck, explains issues surrounding the electrical supply and demand issues related to when BEVs are being charged at residences. Focusing on California's electrical grid specifically, nearly 40% of the state's power is produced using photovoltaic power, otherwise known as solar power, during the day. Issues arise as the sun sets when individuals typically return to their homes and plug in their BEVs. This causes a large draw on the electrical infrastructure when there is no solar energy being generated. With the continued adoption of BEVs, these issues will eventually overwhelm the electrical grid in areas where solar energy is heavily relied upon. When there is no sun, no power is produced by solar panels. There is currently no concrete solution besides the suggestion to have BEV owners charge their vehicles while at work during daylight hours or program their BEVs to charge when there is lower energy consumption (Jones-Albertus, 2017).

Government Actions Relating to BEV Adoption and Production Perspective

On September 14, 2022, The White House published a fact sheet outlining President Bidens's future plans to drive America's BEV manufacturing boom (Biden, 2022). A bevy of agendas and goals are outlined in this declaration of the $7.5 billion Bipartisan Infrastructure Law. They include:

- Building 500,000 charging stations ensuring that charging a BEV is more predictable, reliable and accessible
- Allocating $7 billion to obtaining critical materials to produce batteries for BEVs
- Allocating $10 billion for clean public and school buses

The Inflation Reduction Act is designed to entice potential buyers to purchase new and used BEVs and also support manufacturing in the United States with the help of grants that would aid in the production and development of heavy-duty vehicles that emit zero emissions. The CHIPS and Science Act was introduced to allow for semiconductors, a critical component to the production of BEVs, to be produced in the United States lessening the reliance of the importation and reliance from foreign countries.

As of August 17, 2022, the Inflation Reduction Act of 2022, now known as the Clean Vehicle Credit, was amended resulting in Federal tax credits up to $7,500.00 for BEVs assembled in the United States that were acquired by owners after December 31, 2009. Once a United States BEV manufacturer sells over 200,000 BEVs, the tax credits are no longer available to the consumer. At the time of this writing, out of the 42 BEVs manufactured in the United States that are eligible for federal tax credits, only General Motors and Tesla motors are excluded as both manufactures have exceeded the 200,000 BEV sales threshold (Sherlock, 2022). In addition to available federal tax credits, some states offer tax credits or rebates for new and used BEVs.

New BEV and Battery Production by Foreign BEV Manufacturers Based in the United States

Since President Biden took office and implemented new regulatory changes related to the manufacturing of BEV vehicles, a multitude of large and well-established foreign automobile manufactures have established plans to shift the manufacturing of BEV vehicles and the batteries necessary to produce them to the Unites States. Based on current data retrieved from the White House's website (United States Government, 2022) detailing plans to manufacture BEVs and their batteries, various foreign manufactures can become eligible for tax incentives not available to vehicles produced outside of the United States.

Toyota will invest $2.5 billion to create a manufacturing facility in North Carolina; Honda and LG Energy Solutions will commit to a $4.4 billion investment at a location in the United States that has not yet been disclosed. Panasonic is working on a $4 billion investment in battery production in Kansas that is anticipated to create 4,000 jobs. Vinfast, one of many new entries to the BEV market, announced it will be investing $5 billion to produce a factory that will manufacture BEVs and batteries. Located in North Carolina, the facility is expected to create 13,000 new jobs. Hyundai revealed the company will be investing $5.5 billion to create a facility that will manufacture BEVs and batteries in Georgia. Samsung DSI America is set to invest $3.1 billion in Indiana in conjunction with Stellantis which is the parent company that produces Fiat, Dodge, and Chrysler products.

New BEV and Battery Production by Domestic Manufactures Based in the United States

Ford Motor Company is planning to open assembly plants in Michigan and Ohio for vehicle and battery production at a cost of $3.7 billion which will create 6200 new jobs. In July of 2022, General Motors was granted a loan through the Department of Energy's Advanced Technological Vehicle Manufacturing program for $2.5 billion. These funds will enable General Motors to create battery manufacturing facilities in Ohio, Tennessee, and Michigan.

Environmental Perspective

While there are no direct exhaust emissions associated with the use of BEVs, vehicle production, power generation, and various other factors contribute to pollutants emitted by BEV manufacturing and use. The impact that manufacturing and the use of BEVs have on the environment are multifaceted, complex, and vary greatly based on many factors.

Cradle-to-Grave Emissions

The production of BEVs and ICE-powered vehicles are very similar regardless of the method by which they are propelled. BEVs use high density battery packs and electric motors whereas ICE vehicles utilize an engine that burns either gasoline or diesel and a transmission to control the power produced by the ICE. Whereas ICE vehicles are mainly composed of various common and easily accessible metals, BEV batteries require a far greater amount of materials from various geographic locations (Väyrynen & Salminen, 2012). The pollution created by the BEV manufacturing process is recovered relatively quickly resulting in a net gain in the reduction of pollutants.

The production of a smaller BEV emits approximately one ton or 15% more pollutants into the atmosphere compared with a similarly sized ICE vehicle (Nealer et al., 2015). The production of a full-sized long-range BEV with substantially more driving range emits approximately six tons of pollutants, an increase of 68% during the production process compared with their ICE vehicle equivalent. However, to emphasize the long-term environmental impact of the production of BEVs, it is important to consider how rapidly the use of a BEVs offsets the net emissions that would have been produced by an ICE-powered vehicle over its life cycle. For the smaller BEV, it would take 4,900 miles or about 6 months of average driving to offset the elevated emissions emitted by the production of the BEV versus an equivalent ICE-powered vehicle. In the case of the long-range BEV, it would take 19,000 miles or about 16 months to offset the elevated emissions emitted by the production of the larger BEV powered vehicle.

These figures take into consideration the emissions generated by power plants to fuel the BEVs (Nealer et al., 2015).

Lithium Extraction Use and Recycling

A remote region that connects the borders of Argentina, Bolivia, and Chile has become known as the Lithium Triangle. This area contains more than half of the world's lithium reserves which are vital to the construction of lithium-ion batteries utilized by BEVs. The demand for lithium is predicted to quadruple by 2030 and its prices on global markets have increased by a factor of nearly 10 in the last year due to the expectation of lithium demand. The low-tech method used to extract lithium in this area consists of pumping water from low-lying water tables into evaporation pools. Roughly a half million gallons of water pumped into the evaporative pools generates one ton of lithium. For perspective, the average BEV battery requires roughly 130 pounds of lithium, about 20,000 times more than is required to produce a battery for a mobile phone. Hydrologists, conservationists, and environmentalists are concerned about the antiquated practices used in lithium extraction and production in the Lithium Triangle that could deplete water needed by indigenous communities and thereby destroy the ecosystem in the Lithium Triangle, all due to the increased demand of lithium for BEV and other battery production (Pearce, 2022).

Looking toward the future, it is essential to consider the ever-increasing demand for lithium used to produce lithium ion batteries (LIBs) that power not only BEVs, but also smaller electronic devices. Beyond the harmful methods used to extract and refine lithium to produce LIBs, consideration must be given to the environmental impact they will have at the end of their functional lifecycle when recovered from BEVs. According to a recently published journal article (Mrozik et al., 2021), there are no uniform standards for recycling or disposal of LIBs globally. Inappropriate methods of disposal lead to life threatening air, water, and soil contamination (Mrozik et al., 2021). In 2019, it was found that 53% of LIBs in the Unites States were improperly disposed of in landfills (Sun et al., 2019) and less than 5% of LIBs in the United States and United Kingdom are currently being recycled There are various ways to recycle LIBs although each method creates pollution in different ways. Fossil fuels used to generate electricity for recycling plants to operate generate greenhouse gases themselves during the recycling process, and water pollution can also be a result of LIB recycling based on the methods used to do so (Mrozik et al., 2021).

When a LIB is no longer viable for BEV use as their performance inevitably deteriorates over time, there are alternatives to recycling or dismantling them to extract the materials used in their manufacturing process. LIBs can have a second purpose when no longer viable for use in a BEV. Used LIBs that cannot adequately power a BEV can be repurposed as an electric storage device for lower power-demand applications (Frick, 2022). For example, they could be used to supplement the electrical grid when solar arrays are no longer producing energy at sundown and throughout the night. The same is true for power generating wind turbines that are not spinning at a velocity needed to generate enough power to meet electrical demands. The use of LIBs that are no longer suitable to BEVs would offset the need to produce electricity by the burning of fossil fuels resulting in less pollution. This is beneficial not only in the reduction of greenhouse gasses produced by power generation, but also by eliminating emissions that would have been generated in the LIB recycling process itself (Ahmadi et al., 2017).

Cobalt Extraction

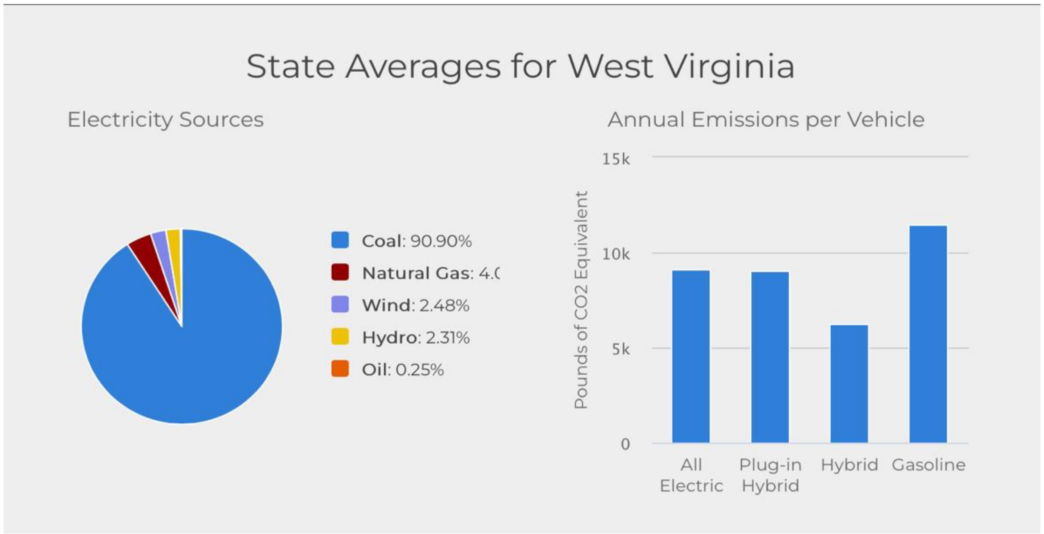
Cobalt is in extremely high demand as it is a critical component used in the fabrication of LIBs used in BEVs and other electronic devices. More than 50% of cobalt used in LIBs originate from the Democratic Republic of Congo (DRC). In mining communities, roughly 60% of the population surrounding the cobalt mining areas rely on the mining industry to support their household (Krummel & Siegfried, 2021). In the DRC, 20% of cobalt mining operations are conducted in artisanal and small-scale mines. These mines are often linked to human rights violations and inadequate or nonexistent safety measures. What is more disturbing is that poverty, socio-cultural factors, lack of educational structure, and legal enforcement have led to the unethical exploitation of children in mining operations. Approximately 14% of all cobalt obtained from the DRC was the direct result of child labor in 2012 (Liwanga, 2014).

Power Generation

According to the Office of Energy Efficiency and Renewable Energy (Department of Energy, 2022), the agency conducted a study in 2015, identifying the national average amount of carbon dioxide produced by driving the average BEV as 4,815 pounds per year compared with 11,435 pounds of carbon dioxide produced annually by driving an ICE-powered vehicle. Upstream emissions, also known as well-to-wheel emissions, is a term used to describe the amount of pollution and greenhouse gases generated by the generation of electricity that is used to charge a BEV. The amount of pollutions varies wildly from state to state and is directly related to the type of fuel used to generate electricity. West Virginia uses coal for 95.7% of the state’s energy production (Figure 2) with the highest annual carbon dioxide emissions equivalent to 9,451 pounds of well-to-wheel emissions per BEV driven. On the other end of the pollution spectrum, Vermont has the lowest annual carbon dioxide emissions equivalent of under one pound of well-to-wheel emissions per BEV driven. No coal and under 1% of power generation comes from the use of oil and gas (Figure 3) with the rest of the state’s energy produced by nuclear, biomass, wind and solar sources (U.S. Department of Energy, 2022). Based on this data, driving a BEV in the state of West Virginia generates nearly as much pollution as driving an ICE powered vehicle. When compared with the pollution generated in Vermont, there is virtually no pollution associated with driving a BEV.

Figure 2

West Virginia Fuel Mix For Power Generation

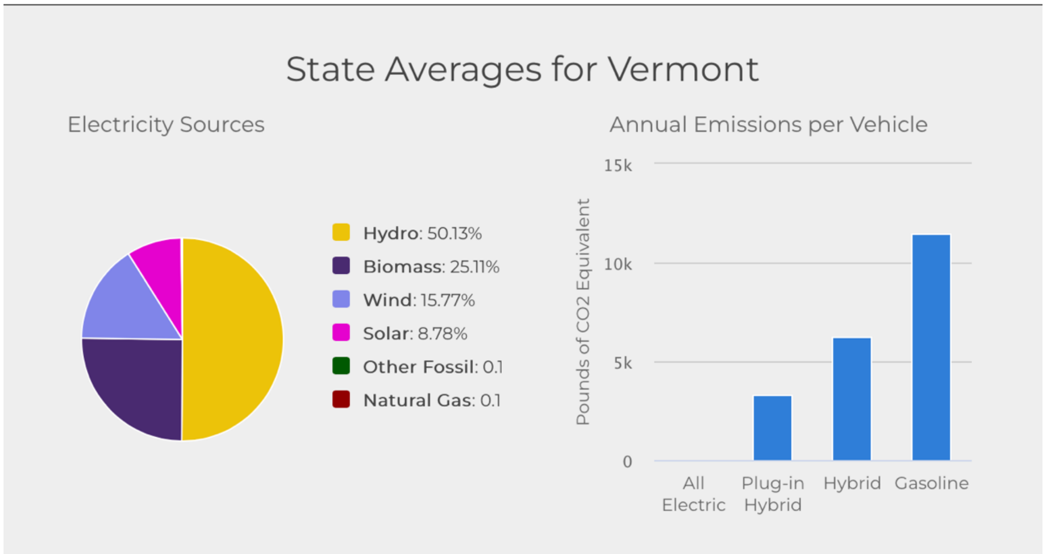


Note: From The U.S. Department of Energy: Alternative Fuel Data Center

https://afdc.energy.gov/vehicles/electric_emissions.html

Figure 3

Vermont Fuel Mix For Power Generation



Note: From The U.S. Department of Energy: Alternative Fuel Data Center

https://afdc.energy.gov/vehicles/electric_emissions.html

Consumer Perspective

There is a tremendous amount of data and research surrounding the adoptions of BEVs. From the consumer perspective, there is a large number of factors associated with the acceptance and adoption of BEVs such as age, household income, home ownership, socio-economic status, ethnicity, and charger location and accessibility, among other determining factors. Numerous studies have found that a lack of knowledge and understanding of BEVs leads to a lower adoption rate. For perspective, one study indicated that less than half of U.S consumers could name the manufacturer of any BEV (Singer, 2015). To combat the lack of information in the public about the benefits and functionality of BEVs, those interested in learning more about BEVs can utilize General Motor's (GM) EV live video chat platform allowing prospective buyers to connect with a BEV specialist. When connected with a BEV specialist, interested customers with a lack of knowledge have the ability to discuss various aspects of BEVs manufactured by the company and which, if any, model is an option for them (General Motors, n.d.)

The EPA has a dedicated website to help dispel myths surrounding BEVs (Environmental Protective Agency, 2022b). The site first addresses a belief by some that BEVs are worse for the environment than their ICE counterparts. Users are able to input their zip code to see how their power is generated and how much greenhouse emission are attributed to its generation. Secondly, the EPA then addresses life cycle emission graphically which is logical as the production process of BEV batteries does indeed contribute to greenhouse gasses. Charging is then addressed as the site states that BEVs can be “plugged into the same type of outlet as your toaster.” Although this is true, using a household outlet takes an unacceptable amount of time to charge a BEV as stated earlier. Range is then addressed, which is a topic that often comes up when researching BEVs. The website describes various classes of BEVs to choose from. The site then provides a link to examine a BEV that a buyer may be interested in, displaying annual costs associated with charging. Safety is also addressed with an explanation that BEVs must meet the same safety standards as ICE vehicles do.

Analysis

Diffusion of Innovation Theory

Diffusion of Innovation (DOI) seeks to describe the propensity of individuals to accept and adopt technological change. Rogers (2003) stated that even if new technology or innovation show clear advantages, their widespread adoptions and utilization could take years to be universally adopted. Rogers (2003) described that in order to decrease hesitation toward the adoption of innovation, adopters must understand the relative advantage, compatibility, complexity, trialability, and observability of the innovation. Communication with social systems is an element associated with diffusion activity and human behavior. DOI is influenced by the social structure of a group as diffusion takes place in the social system by way of communication between different members within the social system leading to individuals or groups to adopt or reject innovation (Goss, 1979). This led Rogers (2003) to classify adopters of innovation into five categories to better understand DOI.

According to Rogers, the first classification of adopters is called innovators, who are often open to experiencing new ideas and are willing to take risks when adopting new or novel technical innovation. Innovators only represent 2.5% of adopters and develop an understanding of new and novel technologies. Because of their enterprising nature, innovators can lose the respect of those who do not fall within this group or social system (Rogers, 2003). Individuals who adopted the first mass produced electric vehicle in the 1990s, the GM EV1, would be considered innovators due to their novelty and extreme departure from the ICEs that powered nearly every vehicle at that time. Given the EV1 was a failure, the buying behaviors and early adoption of innovators associated with risk taking aligns with innovators' behaviors outlined by Rogers (2003).

Early adopters represent 13.5% of the second classification of individuals facing innovation. Early adopters are less hesitant about the adoption of the innovation (Rogers, 2003). They consider innovators a source of information and guidance, therefore their acceptance of new technology is influenced and formed based on the experiences of innovators (Rogers, 2003). Early adopters are seen as leaders (Valente, 1996) and revered as influencers in social systems, therefore early adopters' hesitancy toward the adoption of innovative technology is reduced when information is shared within social systems (Rogers, 2003). Rogers also stated that "early adopters put their stamp of approval on a new idea by adopting it." As early adopters are viewed as leaders and approve of new technology such as BEVs, the next group, early majority adopters, are more likely to follow early adopters' acceptance of BEV technology to guide and aid them in their adoption of innovative technology.

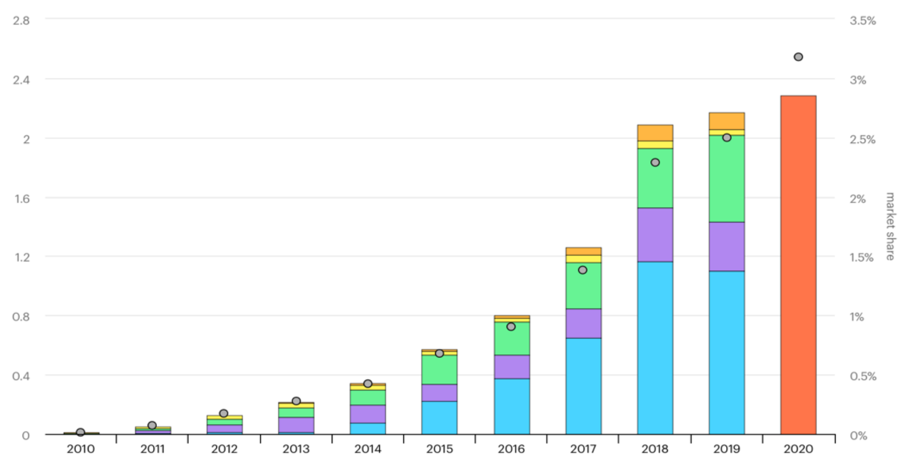
Making up 34% of adopters, early majority adopters tend to have positive interaction with others in their social systems although they lack the leadership roles that early adopters do (Rogers, 2003). At the point in which early majority adopters accept the innovative change, roughly half their peers have already done so. Based on the behaviors of the early majority, it is safe to assume this group waited to examine how the innovations impacted the innovators and early adopters. Making up another 34% of adopters, late majority adopters hesitate until a majority of their peers adopt. According to Rogers (2003) this group may have adopted the innovation due to reasons such as influence from their social system, acquisition of items inclusive of innovation out of need, and proven functionality of the innovation based on the experiences of and communications with earlier adopters of the innovation.

Laggards make up the 16% of adopters and are the last group of adopters to accept new innovation. Rogers (2003) explained there may be various elements that contribute to the lack of acceptance of innovation. Members of this group may interact with members of the social system without having much exposure to other groups of the social system. Rogers (2003) noted that lack of resources, awareness, and reliability of the innovation lead to a longer than average adoption period.

According to the International Energy Agency (2021), the worldwide market share of BEVs was roughly 2.75% in 2020 (Figure 4). In examining the DOI bell curve mapping the five categories of adopters, it can be seen that in 2020, the worldwide market share of BEVs was roughly just entering the early adopters state (Figure 5). While DOI may not be the only cause of the low adoption of BEVs, one quantitative study showed that technological innovation, including whether BEVs were better for the environment, lack of public charging, lengthy charging duration, lack of charging possibility at home, and lack of range were the second through fifth top reasons preventing those surveyed from adopting innovative technology (Wicki et al., 2022). Given those statistics, it does seem relevant to apply DOI to adoption of BEVs.

Figure 4

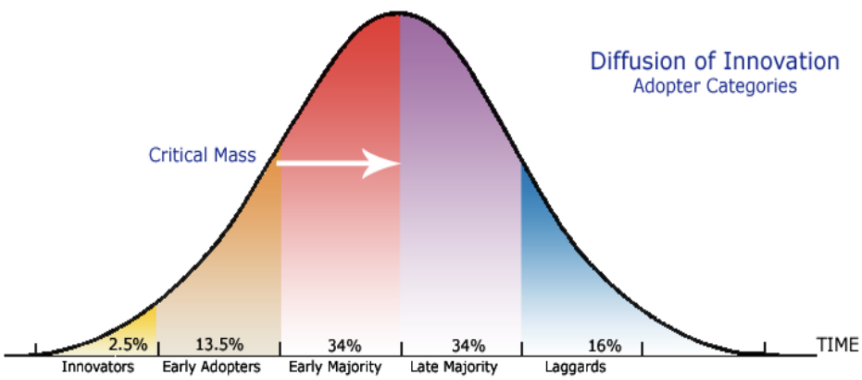
Percentage of BEVs Purchased Worldwide



Note: From "Global Electric Car Sales by Key Markets, 2010-2020" by The International Energy Agency. (https://www.iea.org/data-and-statistics/charts/global-electric-car-sales-by-key-markets-2015-2020) License: CC BY 4.0

Figure 5

Diffusion of Innovation Bell Curve



Note: From "Diffusion of Innovation Theory," by J. Kaminski, *The Canadian Journal of Nursing Informatics*, 2011, *6*(2), p. 1444. Theory in Nursing Informatics Column. (https://cjni.net/journal/?p=1444) Copyright 2022 by The Canadian Journal of Nursing Informatics.

Disruption of Innovation Theory

Disruption of innovation (DOI) describes the process in which less established companies with fewer resources are able to compete with more established ones while improving upon their incumbents' products and services. While more established companies focus on their more demanding and profitable customers, the DOI theory has shown that disrupters target overlooked portions of markets. Companies that embody the DOI theory typically target the production of goods that are overlooked by well-established manufacturers and focus on more obtainable, functional and lower priced offerings (Christensen et al., 2013). DOI predicts that when a new competitor or entrant arrives to the market, the organization that originates the disruption will motivate the incumbent organization to offer better products or services, as well as produce more attritive, updated, and novel deliverables. If process does not take place, it is assumed the disruptor will be acquired by the incumbent, or the incumbent will be forced to defeat the disrupter by providing a better product or service at better price (Christensen et al., 2015).

Currently, because there are many BEVs about to be introduced to the market with similar performance and range with a lower price point, it is important to identify Tesla Motors from a DOI perspective. Tesla Motors took a different approach with the introduction of their BEV offerings by aiming at the high end of the vehicle market. Tesla introduced its first mass-market vehicle in the form of an expensive large luxury car, the Model S, in 2012, that cost $69,900 when introduced and was designed to compete with rivals like Audi and BMW. According to Cox Automotive Incorporated (2022), across the board, prices of expensive BEVs have increased. For example, sales of the Model S increased over 150% in the third quarter 2022, compared with the second quarter of 2022. What makes those numbers even more staggering is that currently, the Tesla Model S starting base price is $104.990 and soars to $161,440 when fully equipped.

The introduction of an expensive BEV is not the only measure of disruptive behavior; the innovative nature of the Tesla sales process is disruptive as well. Tesla utilizes the unorthodox method of selling vehicles to the market through the direct sales approach. A *New York Times* article outlined that with only a limited number of retail stores and service centers, Tesla still dominated the BEV vehicle market while other vehicle manufacturers struggle to produce and sell vehicles due to supply shortage issues. With other high-end BEV manufacturers such as Lucid and Rivian entering the market, they too are adopting the same ordering and direct-sales strategy although there some states that prohibit the direct-sales model (Barmore, 2013).

Theory of Constraints

With lessons learned from the failure of the GM EV1, a little-known startup BEV manufacturer Better Place was founded in 2007. Better Place claimed bankruptcy in 2013, along with many other defunct automobile manufacturers which led to the successful and profitable existence of BEV manufacturers today. The GM EV1 mentioned previously in the literature review failed for many reasons, one being lack of driving range. GM decided to switch from a lead acid type battery to a nickel metal hydride battery to extend the range of the EV1. Through their supply chain, GM relied on an outsourced third-party supplier that manufactured the nickel metal hydride batteries in an attempt to speed up charging times through advancements in technology, but it was incapable of doing so. GM scientists realized that recycling process of the toxic materials contained within the GV1's batteries also proved to be too expensive and far too challenging, so the program was eventually abandoned (Johnson, 1999).

According to the theory of constraints (TOC), the goal of a company is to generate profits from the sales of its products despite the limitation of constraints, which in the case of BEVs, refers to the form of raw materials and reliance on outsourced vendors used for key components. Referencing the theory of DOI, when disruptive technologies appear, bottlenecks often accompany their emergence and organizations must be highly adaptable (Naor et al., 2001). Tesla Motors has created a "closed-loop, green, vertically integrated supply chain consisting of batteries, electric cars and charging infrastructure to meet its customers' evolving needs" (Naor et al., 2001). The benefit of vertical integration in the case of Tesla Motors lies in its lesser reliance on outsourcing of components from other suppliers. Instead, what the company has done is built its own massive in-house battery factories or "gigafactories," focused on product development, deployed their own proprietary charging network, and circumvented the conventional traditional dealer retail network by the direct-sales model (Naor et al., 2001). While not immune to material shortages due to situations such a global-pandemics, wars, and rising raw material prices, Tesla Motor's innovation and application of processes and theories aids in the production and adoption of BEVs by enabling it to operate more autonomously than traditional automotive manufacturers, demonstrating the application of the TOC.

Two-Step Flow Theory

The two-step flow theory (TSF) developed by Lazarsfeld et al. (1948) examined what influenced individuals' voting decisions. The researchers focused on how voters received the information that ultimately determined their voting decisions. At the time of the study, it was found that voters' decisions were more likely to be influenced by interpersonal communication rather than outlets of information, such as newspapers and radio broadcasts.

The study identified two groups: opinion leaders and opinion followers. Opinion leaders who regularly relied on media sources to receive information were more concerned with and formed opinions based on mass media at the time. Compared with opinion followers, they were found to be less influenced by mass media in their decision-making processes. The stature of opinion leaders was perceived by opinion followers to be influential as they were viewed as being more informed and trustworthy by opinion followers (Turcotte et al., 2015). At the time, opinion leaders often used print media and radio broadcasts to gain information pertinent to the election, which prompted opinion followers to use opinion leaders' knowledge in their-decision making processes (Turcotte et al., 2015). The group of individuals identified as opinion followers became the second element, or second step, that exemplifies the assumptions of the TSF theory.

The research conducted by Lazarsfeld et al. (1948) was grounded in a socio-political study using mass media as a point of reference. During presidential administrations in the 2000s, Twitter as a platform was used in an attempt to influence followers and voters. As of May 17, 2021, 69% of Twitter users stated they acquired breaking news from the platform (Mitchel et al., 2022). To add to the complexities of how social media influences society from a BEV perspective, Elon Musk, the CEO of Tesla Motors, recently purchased Twitter. Through the lens of TSF, Elon Musk has now become a major opinion leader.

Tesla Motors currently has dominance in the BEV market with Elon Musk at the helm as the CEO. With the recent acquisition of Twitter and Tesla Motors being the most valuable automotive company in the world valued at nearly $76 million dollars (Carlier, 2022), there is reason for concern: Tesla's BEV dominance and Twitter's social influence may play a deciding and/or detrimental role in BEV adoption, by way of Elon Musk as an opinion leader through the lens of TSF.

Ethical Implications

While there are many positive attributes associated with adoption of BEVs, there are some negative aspects and ethical issues associated with their adoptions as well.

BEV Weight

A study conducted by the National Bureau of Economic Research (Anderson & Auffhammer, 2011) measured the correlation between vehicle weight and fatalities in multi-vehicle collisions. For every 1,000 pounds of increased vehicle weight the fatality rate for those in the struck vehicle increased by 47%. They also indicated that when the striking vehicle is a pickup truck or SUV its raised height increases the probably of fatalities in the struck car even more. Being this article was published 11 years ago, BEVs on the road then were the Nissan Leaf and the Tesla Model S that weighed 3,400 and 3,835 pounds respectively. With no extremely heavy, fast, and powerful BEV on the roads the study did not take into account that vehicles like the GM Hummer, a BEV weighing a staggering 9,063 would be available in the future (General Motors, n,d.).

In an interview posted on Jalopnik.com, Michael Anderson, one of the researchers, stated, “There could be a window where it’s pretty unsafe to be driving (small, gas-powered vehicles) and getting into multi-vehicle accidents” (Hodge, 2022). Hodge (2022) indicated that with over 20 new BEV trucks and SUVs about to be introduced to the public, road safety is about to become a much larger issue due to increased fatalities for those who drive older ICE-powered vehicles.

Cobalt Mining

The Democratic Republic of the Congo (DRC) accounts for over 50% of the world cobalt reserves which is an essential element in the production of batteries used in smartphones, computers, and BEV (United States Department of Labor, n.d.). Officially, there are rules in place prohibiting children from working in mines, but due to poor oversight and enforcement, children routinely work in artisanal and small-scale mines. These mines often collapse, present hazards with little to no safety equipment and have negative health impacts. Children aged between 3 and 17 are sometimes forced to work 12-hour days and are paid $1 to $2 per day. Many of them use their income to pay for school or buy food and clothing. An action plan was created in 2011 to combat the unethical treatment of children but it has not been made official by the DRC (Tria, 2021).

Lithium Mining

An area known as the “Lithium Triangle” located in Chile, Argentina, and Bolivia holds more than 75% of the earth’s lithium used in the production of lithium batteries used in BEVs. The market for lithium has risen 8.9% annually. Lithium is extracted by pumping water from deep within in the ground in one of the driest places on earth and left to evaporate until it can be processed. The runoff from the exaction process leads to other toxins polluting the surrounding air and water. The author of a journal article published by Harvard International Review stated that while the use of lithium may save the planet from global warming by way of manufacturing BEVs, it should not come at the cost of destroying an ecosystem (Ahmad, 2020).

BEV Demographic Adoptions

A study has shown that 75% of BEV buyers are White, own their own homes, own multiple vehicles, are wealthy, and possess a college degree. An example of how minorities living in disadvantaged communities in Maryland is that only 4% of BEV owners are African American while comprising 30% of the overall state's population. (Hardman et al., 2021). Most new BEVs that are arriving to the market are luxury vehicles with high asking prices which has created barriers to entry for the minority population. It was also found that individuals in lower socio-economic brackets rent their residences and have limited access to chargers for BEVs. The issues associated with the charging of BEVs are exacerbated by the fact that the charging infrastructure in minority communities is severely lacking (Hardman et al., 2021).

Policy Recommendations

The recent announcement of the Inflation Reduction Act, Bipartisan Infrastructure Law, and CHIPS and Science Act includes ambitious goals designed to increase sales of BEV to 50% of all vehicles sold in in the United States by 2030. While the introduction of these acts and laws will certainly increase BEV production, there is much more that needs to be done to aid in the adoption of BEVs and lower greenhouse gas emissions.

Charging Infrastructure

With various charging plug types used by different BEV manufacturers which add to the complexity of the charging network and as well as to the hesitancy of BEV acquisitions, a unified platform of charging stations and plug type adaptability should be put in place. Instead of the fragmented system of BEV public chargers owned by various companies and a somewhat unreliable charging networking that is in place today, an oversight agency should be created to unify the charging network and monitor its operation. This oversight agency should also monitor the needs of the drivers in different geographic areas to ensure that adequate chargers are available. By doing so, more drivers would have the ability to adopt and charge their BEVs in areas that were not previously suitable for BEV adoption. This would help serve those in more rural areas, and in areas where the population of lower socioeconomic drivers live.

Less Expensive BEVs

Vehicle manufacturers should be incentivized and urged to produce more reasonably sized and priced BEVs. Not all BEV buyers enjoy or desire the extreme amount of technology utilized in the interior of the vehicles. According to Barry (2020), out of 73,000 individuals surveyed in regard to their in-car technology, many had issues related to their vehicle's interface. Many drivers are distracted and frustrated by the touch screen used in 97% of new vehicles. BEV manufactures should consider reverting to conventional buttons and knobs to control various vehicle functions such as the stereo, heating, cooling and other systems. With smart phone integration such as Apple Carplay and Android Auto, there is no need for BEV manufacturers to install systems such as voice recognition and navigation as those functions are built into smartphones. Also, by focusing on power consumption versus acceleration, greater range would be established while lowering the size and weight of the BEV's battery further reducing the price of the vehicle. By reducing the new cost of BEVs, there would be fewer barriers to entry by minority groups and individuals of low socio-economic status.

Supply Chain Oversight

With various materials needed to manufacture BEVs, manufacturers need to source their products from across the globe. Previously in this paper acquisition of cobalt using child labor in the DRC was addressed, which is inexcusable, immoral, and unethical. The lithium production process and its impact on the local environment is unethical and dangerous. BEV and all vehicles manufacturers should be self-regulating and held responsible to ensure they are acquiring necessary materials from sources that do as much as possible to avoid negatively impacting the environment or supporting human rights violations vicariously. If a vehicle manufacturer is found in violation by a newly formed governing body, there should be penalties associated with the acquisition of unethically sourced materials.

Lithium Recycling

In 2020 a new recycling facility was constructed in Rochester, New York. Older BEV's battery performance degrade over time and they often are no longer viable. With the recent increase in BEV sales and the expectation of a larger number of BEV sales in the near future, there will be many more lithium batteries that will need to be recycled instead of ending up in a landfill. More recycling facilities must be constructed that utilize techniques that can profitably recycle BEV batteries in an ecologically friendly way.

Summary

With the continuous rise in global warning due to emission produced by the burning of fossil fuels it is important to address one of its main contributors, the ICE vehicle. Since the introduction of the Ford Model T, ICE-powered vehicles have been the preferred mode of vehicular transportation. The pollutants produced by their use have significant negative impacts on ecosystems, air quality, and human health. Consumers who are environmentally conscious may still be utilizing their ICE-powered vehicles because of their familiarity with them; unfamiliarity of BEVs; and financial, ethical, and infrastructure issues outweighing the environmental benefits of an electric vehicle. Socio-economic, environmental, and infrastructure perspectives impede and can be improved upon to aid in the widespread adoption of BEVs.

The literature review discusses that BEVs have been a mainstream topic of debate and discussion in recent years, even though the advent of BEV dates back to the mid-1830s (Department of Energy, 2014) but were mostly abandoned in the 1930s with the introduction of the Model T. President Eisenhower saw the advantages of an interstate highway system after witnessing the advantage of Germany’s autobahn highway network during World War II. Besides facilitating more rapid deployment and translocation of military personnel and equipment within the U.S, President Eisenhower believed highway systems needed to be more comprehensive and safer, and aid in the mobility of Americans.

As the adoption of ICE vehicles grew, pollution grew exponentially. The Clean Air Act was passed in 1970, forcing automakers to reduce the emission from their vehicles. By doing so, the Act has resulted in 98–99% less greenhouse gas tailpipe emissions compared to the ICE vehicles of the 1960s. Lead was removed from gasoline and sulfur content has been reduced more than 90% in fuels used today. The Clean Air Act has improved air quality and lowered greenhouse gas emissions with more ICE vehicles on the US roads today than ever before. Although the Clean Air helped to reduce greenhouse gasses, as of 2020, 27% of greenhouse gas was created by the transportation sector. Of that 27%, 57% of light-duty vehicles contributed to the production of greenhouse gasses (Environmental Protection Agency, 2022a). VW selling nearly 11 million vehicles with deceptive emission control programming certainly exacerbated the issues of tailpipe emissions (Nicoleta-Elena & Fang, 2020).

After the failure of the GM EV1 in the 1990s, the public perception of BEVs was poor. This changed in 2004 when Tesla Motors produced its first mass-produced BEV, the Tesla Roadster. Tesla Motors released the luxury sedan Model S in 2012 while developing and installing a vast network of charging stations in strategic locations. Although it was very expensive compared with other vehicles, the Model S's success led TM to release three more models. Tesla Motors changed the BEV which helped gain public acceptance and adoption of BEVs. This is evidenced by three million BEVs sold in 2020, which accounted for 4.1% of auto sales globally. Due to the success of Tesla Motors many other existing and startup BEV manufacturers are releasing their own versions of BEVs.

A large majority of BEV owners prefer to charge their vehicles at home (Hosseinpour et al., 2015). Much like the issues associated with charging BEVs in the early 1900s, a similar situation exists today. Homeowners have two options when charging their BEVs: Level 1 and Level 2 chargers. Level 1 chargers utilize typical household 120-volt outlets. Level 2 chargers utilize a 240-volt outlet much like one used to power an electric clothes dryer or an electric oven. For BEV owners who rent their residences or for individuals who do not have a driveway or garage to rely on for dependable access to charging, BEV adoption is especially challenging. As far as public chargers, a more reliable and accessible system needs to be in place with consideration given to the power grid. The United States government has recently released many acts and laws to facilitate BEV adoption through a more robust charging network.

There are some negative impacts associated with the production and adoption of BEVs. Hydrologists, conservationists, and environmentalist are concerned about the antiquated practices used in lithium extraction and production in the Lithium Triangle that could deplete water needed by indigenous communities and destroy the ecosystem there, all due to the increase in demand of lithium for BEV production and other battery production (Pearce, 2020). Beyond the harmful methods used to extract and refine lithium to produce LIBs, consideration must be given to the environmental impact they will have if not recycled at the end of their functional lifecycle when recovered from BEVs. More than 50% of cobalt used in LIBs originate from the DRC. These mines are often linked to human rights violations and inadequate or nonexistent safety measures. How energy used to charge BEVs is a major contributor to pollution and varies greatly by region.

There is a tremendous amount of data and research surrounding the adoptions of BEVs. From the consumer perspective, there are a large number of factors associated with the acceptance and adoption of BEVs such as age, household income, home ownership, socio-economic status, ethnicity, charger location and accessibility amongst other determining factors.

The Diffusion of Innovation Theory, Disruption of Innovation Theory, Theory of Constraints, and the Two-Step Flow Theory were all used to identify and elaborate on major emerging themes from the literature review to make connections between the adoption of BEVs and the aforementioned theories. This paper examined the ethical implications of BEVs and the dangers associated with them, the human rights violations from the mining of cobalt for BEVs as well as the hazards of lithium mining used in the production of BEV batteries, and barriers to

BEV adoption of those with lower incomes levels. Policy recommendations for better oversight of the current charging network, the availability of lower cost BEVs, and the increased accessibility were discussed last in the policy recommendation section of the paper.

References

Ahmad, S. (2020). The lithium triangle: Where Chile, Argentina, and Bolivia meet. *Harvard International Review*. https://hir.harvard.edu/lithium-triangle/

Ahmadi, L., Young, S. B., Fowler, M., Fraser, R. A., & Achachlouei, M. A. (2017). *A cascaded life cycle: Reuse of electric vehicle lithium-ion battery packs in energy storage systems. International Journal of Life Cycle Assessment*. SpringerLink. https://link.springer.com/article/10.1007/s11367-015-0959-7

Alternative Fuels Data Center. (2022). Electric vehicles with final assembly in North America. https://afdc.energy.gov/laws/electric-vehicles-for-tax-credit

Alternative Fuels Data Center. (n.d.). Electricity laws and incentives in Federal. https://afdc.energy.gov/fuels/laws/ELEC?state=US

Anderson, M., & Auffhammer, M. (2011). *Pounds that kill: The external costs of vehicle weight*. NBER. https://www.nber.org/papers/w17170#:~:text=We%20show%20that%2C%20controlling%20for,pickup%20truck%2C%20or%20minivan.

Arter, C. A., Buonocore, J., Chang, C., & Arunachalam, S. (2021). Mortality-based damages per ton due to the on-road mobile sector in the Northeastern and Mid-Atlantic US by region, vehicle class and precursor. *Environmental Research Letters*, *16*(6), 065008.

Barmore, C. (2013). Tesla Unplugged: Automobile Franchise Laws and the Threat to the Electric Vehicle Market. *Va. JL & Tech.*, *18*, 185.

Barry, K. (2020). *Screen stars: Which infotainment system deserves a leading role in your next car?* Consumer Reports. https://www.consumerreports.org/infotainment-systems/screen-stars-in-car-infotainment-systems/

Bartlett, J. S., Naranjo, M., & Plungis, J. (2017). *Guide to the Volkswagen emissions recall*. Consumer Reports. Retrieved November 30, 2022, from https://www.consumerreports.org/cars-guide-to-the-volkswagen-dieselgate-emissions-recall/

Biden, J. R. (2022, September 14). *Remarks by President Biden on the electric vehicle manufacturing boom in America* [Speech transcript]. The White House. https://www.whitehouse.gov/briefing-room/speeches-remarks/2022/09/14/remarks-by-president-biden-on-the-electric-vehicle-manufacturing-boom-in-america/

Bisin, A., & Hyndman, K. (2014). *Present-bias, procrastination and deadlines in a field experiment* (No. w19874). National Bureau of Economic Research.

Botsford, C., & Edwards, A. (2016). An integrated global philosophy of EV charging. *World Electric Vehicle Journal*, *8*(2), 495–500. http://dx.doi.org/10.3390/wevj8020495

Brooke, L. (2008). *Ford model T: the car that put the world on wheels*. Motorbooks.

Carlier, M. (2022). *Topic: Tesla*. Statista. Retrieved November 30, 2022, from https://www.statista.com/topics/2086/tesla/#topicOverview

Christensen, C., Raynor, M. E., & McDonald, R. (2013). *Disruptive innovation*. Brighton, MA, USA: Harvard Business Review.

Cox Automotive. (2022). *General Motors holds onto top spot, EV sales hit new record, Tesla is luxury leader: Takeaways from Q3 2022 U.S. auto sales*. https://www.coxautoinc.com/market-insights/10-takeaways-from-u-s-auto-sales-q3-2022/

Environmental Protection Agency. (2022a). *History of reducing air pollution from transportation in the United States*. https://www.epa.gov/transportation-air-pollution-and-climate-change/history-reducing-air-pollution-transportation

Environmental Protection Agency. (2022b). *Electric vehicle myths*. EPA. https://www.epa.gov/greenvehicles/electric-vehicle-myths

Ford Motor Company (n.d.). *2022 Ford Mach-E: EV charging: All you need to know*. https://www.ford.com/mustang/ev-charging/mache/

Fricke, L. (2022). The long-term problem with electric vehicle batteries: A policy recommendation to encourage advancement for scalable recycling practices. *Seattle Journal of Technology, Environmental & Innovation Law*, *12*(1), Article 2. https://digitalcommons.law.seattleu.edu/sjteil/vol12/iss1/2

Fuel Institute (2022). *Driver demographics.* https://www.fuelsinstitute.org/Research/Reports/Driver-Demographics-The-American-Population/Driver-Demographics_Report

Funke, S. Á., Sprei, F., Gnann, T., & Plötz, P. (2019). How much charging infrastructure do electric vehicles need? A review of the evidence and international comparison. *Science Direct* (Transportation Research Part D: Transport and Environment), *77*, 224–242 https://doi.org/10.1016/j.trd.2019.10.024

General Motors. (n.d.). *EV Live to offer innovative EV education platform for everyone*. https://www.gm.com/newsroom.detail.html/Pages/news/us/en/2022/jul/0725-evlive.html

Goss, K. F. (1979). Consequences of diffusion of innovations. *Rural Sociology*, *44*(4), 754.

Guarnieri, M. (2012). *2012 Third IEEE history of electro-technology conference*. IEEE.

Guo, S., & Kontou, E. (2021). Disparities and equity issues in electric vehicles rebate allocation. *Energy Policy*, *154*, 112291.

Happian-Smith, J. (Ed.). (2001). *An introduction to modern vehicle design*. Elsevier.

Hardman, S., Fleming, K. L., Khare, E., & Ramadan, M. M. (2021, December 20). A perspective on equity in the transition to electric vehicles. *MIT Science Policy Review*. https://sciencepolicyreview.org/2021/08/equity-transition-electric-vehicles/

Hodge, L. (2022, April 7). *Heavy-ass EVs are going to kill us all*. Jalopnik. https://jalopnik.com/heavy-ass-evs-are-going-to-kill-us-all-1848764045

Hosseinpour, S., Chen, H., & Tang, H. (2015, August). Barriers to the wide adoption of electric vehicles: A literature review based discussion. In *2015 Portland international conference on management of engineering and technology (PICMET)* (pp. 2329–2336). IEEE.

International Energy Agency. (2021). *Global EV outlook 2021*. https://www.iea.org/reports/global-ev-outlook-2021

International Energy Agency. (2022). Global electric car sales by key markets, 2010-2020, https://www.iea.org/data-and-statistics/charts/global-electric-car-sales-by-key-markets-2015-2020

Interrante, E., & Yu, B. (2017). *Contributions and crossroads: Our national road system's impact on the U.S. economy and way of life (1916-2016)*. United States Federal Highway Administration. https://rosap.ntl.bts.gov/view/dot/50514

Johnson, B. C. (1999). Environmental products that drive organizational change: General motor's electric vehicle (EV1). *Corporate Environmental Strategy*, *6*(2), 140-150.

Jones-Albertus, B. (2017). *Confronting the duck curve: How to address over-generation of Solar Energy*. U.S. Department of Energy. https://www.energy.gov/eere/articles/confronting-duck-curve-how-address-over-generation-solar-energy

Kelly Blue Book (2022). *New-vehicle prices set a record in June, according to Kelley Blue Book, as luxury share hits new high*. Kelly Blue Book. https://mediaroom.kbb.com/2022-

07-12-New-Vehicle-Prices-Set-a-Record-in-June,-According-to-Kelley-Blue-Book,-as-Luxury-Share-Hits-New-High

Khan, M. (2021. A critical analysis of Elon Musk's leadership in Tesla motors. *Journal of Global Entrepreneurship Research.* https://doi.org/10.1007/s40497-021-00284-z

Klebnikov, S. (2021). *Rocket Elon: How tesla's eccentric Boss became the number two richest on Forbes' 2021 billionaires list*. Forbes. Retrieved November 30, 2022, from https://www.forbes.com/sites/sergeiklebnikov/2021/04/06/rocket-elon-how-teslas-eccentric-boss-became-the-number-two-richest-on-forbes-2021-billionaires-list/

Krummel, D. & Siegfried, P. (2021) The dark side of Samsung's value chain: The human costs of cobalt mining. *Journal of Geoscience and Environment Protection*, *9*, 182–203. https://doi.org/10.4236/gep.2021.92011.

Lazarsfeld, P., Berelson, B., & Gaudet, H. (1948). The people's choice: How the voter makes up his mind in a presidential campaign. Columbia University Press,

Liwanga, R.-C. (2014). Economics of child mining labor: Estimation of corporation's profits. *Slavery Today Journal*, *1*(2), 119–133. https://doi.org/10.22150/stj/momn7156

Mackay, S. (2020, September 22). *The college students who exposed Volkswagen - EIT: Engineering Institute of Technology*. The college students who exposed Volkswagen. Retrieved November 30, 2022, from https://www.eit.edu.au/the-college-students-who-exposed-volkswagen/

Matulka, R. (2014). The history of the electric car. *Department of Energy*. https://www.energy.gov/articles/history-electric-car

Mrozik, W., Rajaeifar, M. A., Heidrich O., & Christensen, P. (2021). Environmental impacts pollution sources and pathways of spent lithium-ion batteries. *Energy & Environmental Science, 14*, 6099-6121. https://doi.org/10.1039/d1ee00691f

National Archives and Records Administration. (n.d.). *National Interstate and Defense Highways Act (1956)*. National Archives and Records Administration. https://www.archives.gov/milestone-documents/national-interstate-and-defense-highways-act

National Museum of American History. (n.d.). *EV1 electric car, 1997*. https://americanhistory.si.edu/collections/search/object/nmah_1293145

Nealer, R., Reichmuth, D., & Anair, D. (2015). *Cleaner cars from cradle to grave: How electric cars beat gasoline cars on lifetime global warming emissions*. Union of Concerned Scientists.

Nicoleta-Elena, P., & Fang, M. (2020). Basic Public Welfare Research Project of Zhejiang Province A Review of the Emissions Scandals and their Impact on Volkswagen.

Pearce, F. (2022). *Why the rush to mine lithium could dry up the high Andes*. Yale E360. https://e360.yale.edu/features/lithium-mining-water-andes-argentina

Peter, V. D. B., Tom, T., Noshin, O., & Joeri, V. M. (2016). Developments and challenges for EV charging infrastructure standardization. *World Electric Vehicle Journal, 8*(2), 557-563.

Razmjoo A, Ghazanfari A, Jahangiri M, Franklin E, Denai M, Marzband M, Astiaso Garcia D, Maheri A. A Comprehensive Study on the Expansion of Electric Vehicles in Europe. *Applied Sciences*. 2022; 12(22):11656. https://doi.org/10.3390/app122211656

Rempel, D., Cullen, C., Bryan, M. M., & Cezar, G. V. (2022). Reliability of Open Public Electric Vehicle Direct Current Fast Chargers. *Available at SSRN 4077554*.

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). Free Press.

Sherlock, M. F. (2022). *Clean Vehicle Tax Credits in the Inflation Reduction Act of 2022*. Congressional Research Service. https://crsreports.congress.gov/product/pdf/IN/IN11996

Shields, W. (2007). *Theory and practice in the study of technological systems* (Doctoral dissertation, Virginia Tech).

Singer, M. (2015). *Consumer views on plug-in electric vehicles: National benchmark report.* National Renewable Energy Laboratory. http://www.afdc.energy.gov/uploads/publication/consumer_views_pev_benchmark.pdf

Sovacool, B. K. (2009). Early modes of transport in the United States: Lessons for modern energy policymakers. *Policy and Society, 27*(4), 411–427. https://doi.org/10.1016/j.polsoc.2009.01.006

Sun, W., Wang, X., DeCarolis, J. F., & Barlaz, M. A. (2019). Evaluation of optimal model parameters for prediction of methane generation from selected U.S. landfills. *Waste management, 91*, 120–127. https://doi.org/10.1016/j.wasman.2019.05.004

Thiel, C., Alemanno, A., Scarcella, G., Zubaryeva, A., & Pasaoglu, G. (2012). *Attitude of European car drivers towards electric vehicles: A survey*. EUR 25597 EN. Publications Office of the European Union. JRC76867.

Tria, E. (2021). *The impact of covid-19 on child labour in Cobalt Mines in the DRC*. Humanium. https://www.humanium.org/en/the-impact-of-covid-19-on-child-labour-in-cobalt-mines-in-the-drc/

U.S. Department of Energy. (2016). *Well-to-wheel emissions from a typical EV by state, 2015*. https://www.energy.gov/eere/vehicles/fact-950-november-7-2016-well-wheel-emissions-typical-ev-state-2015

United States Department of Labor. (n.d.). *Combatting child labor in the Democratic Republic of the Congo's Cobalt Industry*. https://www.dol.gov/agencies/ilab/combatting-child-labor-democratic-republic-congos-cobalt-industry-cotecco

United States Government. (2022, September 15). *Fact sheet: President Biden's economic plan drives America's electric vehicle manufacturing boom*. The White House. https://www.whitehouse.gov/briefing-room/statements-releases/2022/09/14/fact-sheet-president-bidens-economic-plan-drives-americas-electric-vehicle-manufacturing-boom/

Valente, T. W. (1996). Social network thresholds in the diffusion of innovations. *Social networks*, *18*(1), 69–89.

Väyrynen, A., & Salminen, J. (2012). Lithium ion battery production. *The Journal of Chemical Thermodynamics*, *46*, 80-85.

The Whitehouse Briefing Room. (2022). *Fact Sheet: President Biden's economic plan drives America's electric vehicle manufacturing boom*. https://www.whitehouse.gov/briefing-room/statements-releases/2022/09/14/fact-sheet-president-bidens-economic-plan-drives-americas-electric-vehicle-manufacturing-boom/

Wicki, M., Brückmann, G., & Bernauer, T. (2022). How to accelerate the uptake of electric cars? insights from a choice experiment. *Journal of Cleaner Production*, 355, 13354. https://doi.org/10.1016/j.jclepro.2022.131774