Alternating to the Future: Electric Vehicles

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Executive Summary

For this paper, we decided to focus on the personal use of electric vehicles as the focal point. Currently, electric vehicles make up a minimal portion of all motor vehicles in the United States. We were tasked with finding the practicality of converting to 50% electric vehicles by 2030. We found that it is not practical to convert to EVs as there would be a need to update power infrastructure among other things. We were also tasked with finding the implications on the environment of changing to 50% electric vehicles by 2030. Where we found the environmental benefits of this transition outweigh the emissions made by the production of electric cars. Finally, we were tasked with giving a set of recommendations and push-pull factors that would influence the adoption of electric vehicles. Among these, we found that reducing prices for consumer vehicles, competing with internal combustion manufacturers, and even starting production with plans to improve technology are all factors that would benefit the appeal of electric vehicles. We came to the consensus that although electric vehicles are more eco-friendly, we lack the infrastructure, consumer tastes, and technology to not only provide the upkeep but the innovation needed, therefore, we believe that the change to electric vehicles should be left to market trends.

Alternating to the Future: Electric Vehicles

Background Information

In recent years, the idea of climate change has become commonplace in the eye of the public. That being the case, many have searched for ways to reduce emissions, so that the environment can recover from the outflow of waste made in the production of new items. As a result of these environmental considerations, electric vehicles (EVs) have become more developed to use as a solution to combat climate change instead of their propellent-fueled counterparts with internal combustible engines (ICE). Therefore, the current administration has set a target for the industry share of EVs to be 50% by 2030. With this goal in mind, many underdeveloped infrastructures must be upgraded if we are to meet that goal.

Restatement of the Question

In this analysis, our team was asked to determine the general purpose of EVs. Then, we were asked what changes to the current situation in the EV industry need to occur to allow for the transition of 50% EVs by 2030. We were also asked to find the environmental impact of switching to 50% EVs by 2030. Finally, we were asked to determine an achievable goal for the share of EVs by 2030 in the US, a timeline of how to reach this share percentage, and any alternative factors and situations that may hinder or accelerate this timeline.

Global Assumptions

1. The volatility and security of gas prices and the cost to charge an EV, respectively, have no bearing on our solutions and recommendations. The average cost to charge 1 kWh is about 13.75 cents, while will yield about 4 miles, and thus $3.43 for 100 miles, while the average cost for a gallon of gas nationwide is $4.25 with an average mile per gallon of about 25 mpg which $17 for 100 miles (AAA, 2016; Bruzek, 2022; Sergeev, 2021).
2. The upfront cost of an EV is substantially more than that of the ICE and eventually, the price gap evens out thus it does not affect our predictions in the model as it takes roughly 15 years for the cost to even out (Winters, 2021).
3. Once an individual changes from gas to electric their previous vehicle does not influence the total amount of vehicles on the road as the number of cars in circulation would have to double to meet the 50% EV goal.
4. Due to the recent growth of our economy, we will not include the current supply chain crisis as we believe it will be resolved relatively quickly.

5. Due to the low yearly changes in environmental impacts and the volatile nature of these, we will not adjust our model for the changes in emissions across the years.

Analysis of the Problem and the Model

Purpose

Our model is based on the use and introduction of electric personal use vehicles because of the wide array of plug-in EVs available. The decision was made as there is more data available from companies like Tesla. Owning an EV provides an individual incentive through tax credits, and there is a greater number of cars designated for personal use compared to other identified areas such as delivery drivers (Edmunds, 2011). In 2019, only 8.6% of households in the US had no access to a personal vehicle and over 50% of households had access to two or more vehicles (Borrelli, 2021). Therefore, we made the reasonable assumption that not only would this be the most convenient and direct line of research, but it would also provide the greatest shift toward electric transportation in the automotive industry.

Practicality

One of the biggest factors in meeting the goal of a 50% share of EVs is the charging infrastructure as it is responsible for powering EVs. We assumed that if the consumer can afford an EV which requires a considerable income as shown in Table 1 and pays for the constant maintenance required, then they have the infrastructure required in their home to charge their EV. This indicates that the consumer would not need to worry about stopping at a charging station to fill up their battery because they would instead charge their EVs at their house. This is practical because, on average, people drive around 40 miles per day, and this is well below the smallest battery capacity, being around 57 miles (MYEV.com, 2019; Ryan, 2020). This means that the infrastructure required for the charging EVs is already available by the consumer in their own home, which while affecting the power grid does not do so more than standard charging stations. The current charging stations and additional future charging stations can then be marketed toward customers who travel more than their battery will allow, that being the median battery range of 234 miles (Edelstein, 2022).

Average New Vehicle Costs Breakdown	
ICE	$46,329
EV	$56,437

Table 1: Average New Car Costs (Winters, 2021)

Due to improving technology, the emissions caused by the production of EVs have decreased in comparison to emissions made by ICE vehicles (*True Cost of EVs*, n.d.). However, due to the current state of EVs, it is evident that most consumers prefer ICE in 2019 4.7 million cars were sold in the United States of which 93.2 % were ICE vehicles (Gohlke & Zhou, 2021; Kopestinsky, 2022). From this, we can insinuate that due to high pricing, there has not been enough incentive to purchase more environmentally friendly vehicles with the cost of ICE vehicles being cheaper compared to EVs, as shown in Table 1. Most people choose ICE as the more affordable option despite the eventual trade-off environmental. Thus, for there to be a 50% EV share by 2030, there needs to be more of an incentive to make larger payments, because the cost of an EV is nearly the same as the average yearly income. This means roughly half of the US population lacks the proper purchasing power to afford an EV. Nor is there an incentive to consider EVs as an asset as cars depreciate the longer, they are owned, making it an unlikely investment for prospective customers ("*Should I Buy a New or Used Car?",* 2021).

As it takes anywhere from 30 minutes to 12 hours to fully charge an EV battery which is too slow to utilize electric charging stations properly there needs to be some major technological innovation in this sector to be viable for the consumer (*How Long Does It Take to Charge an Electric Car? | Pod Point*, 2021). The full breakdown of charging rates can be found in Table 2.

Miles of Range added per hour of charging	
3.7kW slow	Up to 15 miles in 30 minutes
7kW fast	Up to 37 miles in 30 minutes
22kW fast	Up to 90 miles in 30 minutes
43-50kW rapid	Up to 90miles in 30 mins
150kW rapid	Up to 200 miles in 30 min

*Table 1: Range of EV After Charging (*How Long Does It Take to Charge an Electric Car? | Pod Point*, 2021)*

Ideally, the speed of the charge would match that of filling up a gas tank as it makes life more convenient for the consumer. However, as this is not feasible at the moment the more promising option would be to increase battery life. Both in range and longevity as the cost of a battery ends up being anywhere from $0 to $20,000, which is an exorbitant amount of money for a single part of a vehicle that will likely be the first to become unusable as the power source (Witt, n.d.). Fortunately, such technology exists as Tesla's promise of a 620-mile range battery appears in the new 2021 Tesla Roadster (Tesla, 2019). However, with a cost of $200,000 which is almost 4 times the average income of $67,500 (Shrider et al., 2021). This is not feasible for most consumers; therefore, the battery would not only have to be made more available across models, but it would also need a lower price. The Roadster has a 200-kWh battery and weighs about average (4400) (*Tesla Roadster*, n.d.). The average weight of an electric car is 3,300 – 4,400 lbs. (Martynyuk, 2021). This means the battery could be used in other cars which would potentially increase the range of the EV and solve part of the problem. Lighter alloys for the body and frame could also increase battery efficiency by minimizing the amount of power needed to move the car.

The first part of answering this question is modeling how many EVs are needed to reach the 50% threshold. To find this, we used the data in Table 3 to graph Figure 1 which gave us the equation:

$$T(y) = 1.0269q + 270$$

The table below is the quarterly statistics of the vehicles in circulation from 2017 to 2020

Vehicles per Quarter (Millions)			
2017 Q3	271	**2019 Q2**	279.2
2017 Q4	271.4	**2019 Q3**	280.6
2018 Q1	272.1	**2019 Q4**	281.6
2018 Q2	273.9	**2020 Q1**	281.4
2018 Q3	275.3	**2020 Q2**	280.6
2018 Q4	276	**2020 Q3**	282.8
2019 Q1	278.1	**2020 Q4**	283.8

Table 3: Vehicles per Quarter (Carlier, 2021)

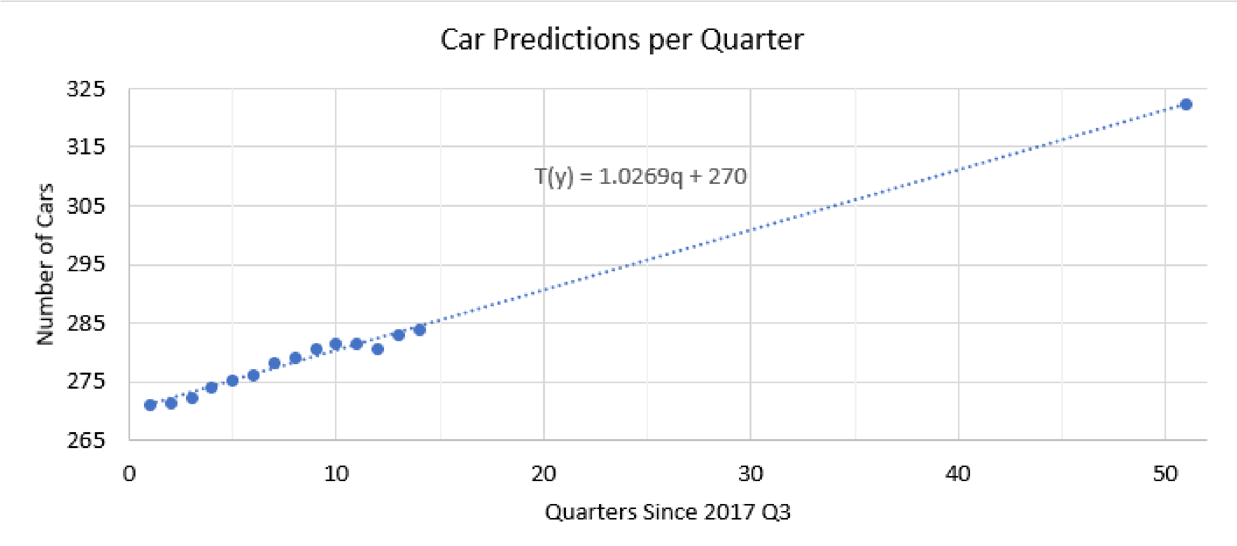

Figure 1: Car Predictions per Quarter

With this data, we extended the graph to include 2030 Q1, which helps in explaining the number of EVs in 2030, T_{EV}. The function in Figure 1 gives us the total number of vehicles in circulation at any given point in time, T(y), assuming the assumed linear relationship holds. To find this number exactly, we need the number of quarters, q, from 2017 Q3. This is determined by the equation listed below. With a year and quarter in mind, we can find the number of quarters since 2017 Q3, which means we don't have to count out how many quarters until the desired time we are predicting. Since we are predicting the number of Vehicles in 2030 Q1, we find T (2030) by using the equations below. Then, to find out the number of EVs. T_{EV}, needed to achieve the 50% share goal, we divided T (2030) by 2.

$$T(y) = 1.0269q + 270$$

$$q = (y - 2017) * 4 + (desired\ Q - 2)$$

$$T_{EV} = \frac{T(2030)}{2}$$

The table below shows the previous equations worked out.

Number of Cars to Meet 50% Goal			
Total number of cars in circulation (Millions)		T(y)	283.80
Quarters between 2017 Q3 and 2030 Q1	q		51
Vehicles in 2030 (Millions)	T (2030)		322.37
EVs in 2030 (Millions)	T_{EV}		161.185

Table 42: Number of Cars to Meet Goal)

Results

From this, we can calculate that there will be roughly 322 million cars by 2030 in the US. This amount provides a challenge since half of it, 161 million cars, is the projected EV count and leads to the environmental impact of sourcing the materials needed for these batteries and other materials needed for implementation. Lastly, we ended up coming to the consensus that transitioning to EVs at the current moment and the specified timeframe is not practical as there are many areas in the industry that must benefit from innovation to make EVs more accessible not only to individuals but to the nation.

Environmental Impact

As more EVs enter the market, the power grid may need to be adapted due to the increased strain. According to the U.S. Energy Information Foundation, we produce and consume 95.74 quadrillion and 92.94 quadrillion British thermal units (Btu) (MYEV.com, 2019). This nets us enough energy to export some of the produced energy that is leftover.

As previously determined in Table 4, the number of cars needed in circulation to surpass the desired threshold is 161.2 million EVs. We considered the idea of a need for increased energy production to sustain such a large fleet of EVs. To determine, if we need to adapt our power grid, meaning we need to produce more energy to support the fleet, we used the amount of energy produced by the United States, P_p, and the amount of energy consumed by the United States, P_c. The difference between these two values provides the net power available for consumption in the United States, N_p. With N_p, we divided it by 3412 to convert the net energy from Btu to kWh to produce N_k. We found that optimized EVs will expend 1 kWh for every 4 miles driven on the road, r, and that each consumer drives an average of 40 miles a day, D (*How Far Can Electric Cars Go on One Charge? | Enel X*, 2020). By dividing D by r, we get the average number of kWh used by a person each day. Then by multiplying the average kWh needed per day by the desired number of EVs, T_{EV}, we get the energy needed to charge the fleet per day, P_T. Further, multiplying P_T by 365 gets the total energy needed in a year's timeframe to power this new fleet, P_y. The difference between the amount of energy available and the energy needed to maintain the fleet is represented by P_x. P_x reflects the need for energy through a negative number or surplus of energy with a positive outcome.

$$P_p - P_c = N_p$$

$$\frac{N_p}{3412} = N_k$$

$$\frac{D}{r} * T_{EV} = P_T$$

$$P_T * 365 = P_y$$

$$N_k - P_y = P_x$$

This table has the data from the previous calculations listed above.

Electricity Consumption of the US per year		
T_{EV}, Cars	161.185	Millions
P_p, Btu/year	95.74	Quadrillions
P_c, Btu/year	92.94	Quadrillions
N_p, Btu/year	2.8	Quadrillions
N_k, kWh/year	820.63	Billions
P_T, kWh/day	1.61	Billions
P_y, kWh/year	588.32	Billions
P_x, kWh/year	232.31	Billions

Table 53: Electricity Consumption of the US/year

We observed that there is enough energy to go around for the daily commute of vehicles. However, without an increased capacity for the grid, we will use most of our currently exported energy. This will decrease the amount the US receives as profit and could affect foreign relations. The next steps of action would be to increase the size and reliability of the grid.

Although EVs leave a smaller carbon footprint, there is a significant trade-off in terms of damage to the environment in their creation and maintenance of them. The creation and maintenance of lithium batteries are extremely toxic both to the environment and the social standing in the countries where lithium is mined. For example, "… in 2016, the largest mining companies, as measured by CO_2 emissions, were responsible for 211.3 million Metric Tons of carbon emissions in that year alone" (Goldberg & Anderson, 2021). From this, we can discern the high levels of contamination and environmental impact lithium mining has had on the environment. In terms of EVs, the increase in the production of EVs would create a direct need for more lithium, which would increase the negative effects of lithium mining.

Despite the negative effects of mining lithium, the change to EVs does, however, come with some environmental gains. For example, according to the Energy Systems Division, "2020 ranges from 1.3 to 2.3 billion gallons and cumulative CO_2 reductions range from 4.2 to 13.2 million metric tons" (Gohlke & Zhou, 2021). This is a considerable effect on the environment as fewer greenhouse gases would be released into the atmosphere long-term with the adoption of EVs. Therefore, when taking factors like this into account, there are some benefits to the environment of switching vehicles to those in the electric class.

One way of measuring environmental impact is in Metric Tons of emitted CO_2. To determine the environmental impact of mining the materials of batteries, we found a general metric to base the production of emissions as the number of yearly emissions produced by the largest mining company, E_m. From this, we continued to find the amount of time until 2030 in years, t. By assuming the emissions will remain linear, we were able to model the environmental impact of mining in Metric Tons of CO_2, T_B.

$$E_m * t = T_B$$

We took a similar approach to find the environmental benefits of transitioning to EVs. As previously mentioned, we found the range of reduction of emissions responsible for the conversion of EVs, E_s. We again used the time until 2030, t. Then by assuming a linear relationship with these values, we were able to model the emissions saved by converting current ICE to EVs in Metric Tons of CO_2, T_s.

$$E_s * t = T_s$$

Lastly, by doing the difference between the mining impacts and projected impacts of EVs, we can find the net environmental impact of transitioning to a 50% EV fleet.

$$T_B - T_s = T_f$$

This table has the information from the previous calculations.

Greenhouse Emissions in the US per year (Metric Tons of CO_2)			
Emissions Saved		E_s	13.2
Total Emissions saved		T_s	112.2
Emissions from mining	E_m	211.3	
Total mining emissions	T_B	1796.05	
Net Emissions	T_f	1683.85	

Table 64: Greenhouse Emissions in the US

Results

Although there will be a significant reduction in emissions straight from the EVs themselves, the sourcing of lithium and its reusability leads to the conclusion that short-term predictions for EVs would not entirely reduce emissions in the environment. However, in long-term predictions for EVs, we can expect to see the annual emissions reduce eventually. In conclusion, the environmental impacts of changing to 50% EVs, as shown in our model, will net more carbon emissions than save in the short time frame we are operating within.

Careers

Within the investigation of the environmental impacts of EV production and use, we found two experts in the field to help us develop promising solutions. The ideas of recyclability of batteries, or the minerals in them, and the general ideas of pollution and its containment are the most beneficial the environmental impact.

Chris Cox

Cox has worked as a professor at the University of Tennessee (UT) since 1991 while engaging in research studies covering a multitude of topics ranging from wastewater management to bioenergy production (*Chris Cox | Department of Civil and Environmental Engineering*, n.d.). Cox earned his Bachelor of Chemical Engineering and Master of Environmental Engineering in 1983 and 1984, respectively, from the University of Missouri (*Chris Cox | Department of Civil and Environmental Engineering*, n.d.). Then in 1992, Cox earned his P.H.D. in Environmental Engineering from Pennsylvania State University (*Chris Cox | Department of Civil and Environmental Engineering*, n.d.). Considering time constraints, we were unable to fully implement Cox's ideas into our model and if research were to continue, we would reach out for his expertise in the field. Using his help, adapting some of his wastewater ideas to an industrial setting could be applied to the pollution issue caused by batteries.

Considering his research in engineering and teaching experience as a professor at UT, Cox would be considered a post-secondary engineering professor. The mean annual wage for a post-secondary engineering professor is 119,220 (U.S. Bureau of Labor Statistics, 2022a).

Paul Voigt

Voigt has worked as a manager at Glencore Technology for hydrometallurgy and pyrometallurgy processes for the last 10 years as well as in the past at Glencore for 7 years (*About*, n.d.). Before starting his career, Voigt graduated from the University of Newcastle in 2003 with his bachelor's in Chemical Engineering and later returned to school in 2012 to graduate with his Master's in Business Administration earned in 2015 (Voigt, n.d.). After working with Glencore to help develop the processes tied to precious metal extraction, he is now employed at Redwood Materials as VP of Engineering to lead teams working with "new applications such as non-conventional feed materials, environmental control, waste stabilization, and recycling and energy recovery" (*About*, n.d.). These processes would be applied to the manufacturing and recycling of EV batteries. However, with the time allotted, we did not get far enough to fully use Voigt's ideas in our solution. With more time, we would have further used Voigt's expertise to better our analysis of the recycling ability of EV batteries by reaching out to him.

Considering his work as a manager in hydrometallurgy and pyrometallurgy as well as his work in sustainability, energy, and recyclability, Voigt most closely relates to an environmental engineer in management. The mean annual wage of an environmental engineer in management is $126,190 (U.S. Bureau of Labor Statistics, 2022b).

Recommendations

The production of EVs has played a small part in the production of new vehicles in recent years but has begun to steadily rise as shown by PEV sales from 2011 to 2022 (Gohlke & Zhou, 2021). This economic growth implies that the market for electric cars could expand and shift consumer tastes towards electric cars, granted availability increases. However, for electric cars to be more prevalent in the personal vehicle industry there need to be improvements made to function and form so that consumers find them more convenient and available. Regarding technology that is currently improving, this includes an electric motor, and battery improvements, such as those that have been prevalent in newer designs.

Most of the innovations made in EV technology focus on adapting existing technologies to new systems. Which explains why hybrids, which are semi-electric cars, are more popular considering they have a wider selection in terms of technology. For example, a hybrid vehicle can use either fuel, such as gasoline, or electricity stored in a battery which allows for more versatility for the consumer. EVs could learn to follow this trend and adapt technology to further suit consumer needs. Hybrids have a larger battery for this very reason so that the engine can be of a smaller size compensating for the loss in power using the battery (U.S Department of Energy, n.d). Although, in any market, there are bound to be highs and lows.

When concerning these hindrances and advancements in improving EV technology, events that would accelerate our goal were: continued economic growth, no tragedies such as 9/11, and innovations in EVs. Events that would hinder our goal were: tragedy, change in consumer taste, recession/depression, war, innovations to alternative forms of energy, and bad publicity for EVs. Each of these events could affect the global market, consumer opinion, or the US economy. For example, with further innovations to EVs, we could feasibly reach our 10% goal and further goals could be set. However, with any major depression, an EV would likely become too expensive, therefore, prohibiting the progression towards the goal. Although it would be ideal for the economy to be prosperous it is an unrealistic assumption, thus, we cannot assume a rate of change concerning the progression of technology that may cause growth in the industry. We also cannot include government intervention as many government programs fail and contribute to the national debt reaching an all-time high of $30.29 trillion (Duffin, 2022). Therefore, we decided that the market trends should lead the way in the electric automobile industry, so the federal government does not accrue more debt. This market leader was determined by a couple of factors, one by the debt already accrued by the federal government and another by the problems with government intervention in the past. As was the case for Lyndon B. Johnson's Great Society's governmental surge. In this instance, American citizens have ended up paying $22 trillion to combat the war on poverty, and some studies show the poverty rates have not decreased but rather have increased (University, 2017). With wishes to let the electric industry grow, the best result for this is to let market trends lead the way and cover the costs of infrastructure, development, and research without aid from the federal government.

Overview of Timeline

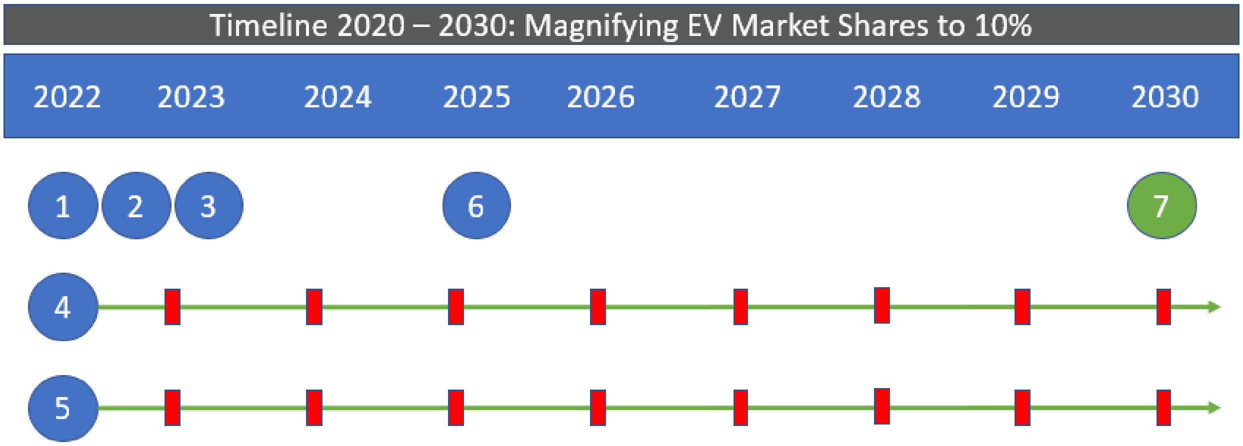

Figure 21: EV Growth Timeline

1. March 2022 - Begin planning for manufacturing increase in the next year
2. Summer 2022 - Reduce prices for better consumer accessibility
3. January 2023 - Start production with new manufacturing plans
4. March 2022 onward - Research and further develop current technology, start annual reports one year from the start date, red squares represent the annual reports
5. March 2022 onward - Develop new technology to increase consumer tastes and decrease the price, start annual reports one year from the start date, red squares represent the annual reports
6. January 2025 - Begin competing against/beating ICE prices to steadily increase market share and consumer approval
7. January 2030 - Meet the goal of having 10% EVs shares in the automobile industry

Currently, what should be done is the formation of a plan concerning production and the improvement of current technology to increase the efficiency of the recent models of EVs available and to ensure that there is enough in stock. Alongside that new technology should also be developed immediately so that the limitations of previous models are taken care of to get rid of challenges that may occur due to ICE vehicles having more features. Following the Summer of 2022 prices should drop so there is enough incentive to buy to obtain a larger customer base. Then after the plans have been constructed production of new EVs should commence in January 2023. Once a solidified customer base is established competitive prices will be established to beat ICE manufacturers during 2025. After which the priority of EV manufacturers would be to meet quotas by 2030.

Model Analysis

Pros

Our model addresses the prompts and provides sensible and realistic expectations for the future of EVs. On the one hand, it considers the quarterly rate at which vehicles are bought which can be modeled more accurately than a yearly trendline. It also is simplistic and easy to understand but complex enough to adequately answer the question.

Cons

Although the model serves its purpose of finding the general degree of emissions, it leaves a lot to be desired. Some things we would have liked to take into consideration were transportation costs, manufacturing, and waste recycling. However, within the time constraints, we were not able to model these factors reliably which led us to utilize a simpler version of our originally desired model. Furthermore, this model assumes constant emissions across years, however, we understand that there are fluctuations year by year and emissions realistically change every calendar year, especially moving forward with greater quantities of production. From this, we also have failed to acknowledge other benefits to EVs outside of emission-free usage.

Improvements Moving Forward

One of the main limitations of our model is that it fails to address the issue of the power grid. While having the available energy, the current United States power distribution infrastructure is incapable of supporting such a power draw as massive as 161.2 million cars in 2030 with no upgrades. Therefore, if allowed more time, we would address our lack of supporting infrastructure in our model and investigate alternative forms of energy such as nuclear, wind, and solar to bring power to the EVs.

Another point we failed to address is the manufacturing processes of EVs. Mainly EV components vary from their ICE alternatives, for example, lithium batteries. Given more time we would better research the environmental emissions that manufacturing has on the environment and included our findings in our environmental impact model as well as what can be done to make EVs more efficient.

It must also be mentioned that we did not account for the potential environmental friendliness there can be through recycling lithium batteries. If we were to consider, that some EVs batteries could be recycled to create new ones this would drastically affect the environmental impact since it is accepted that recycling helps the environment. Therefore, moving forward, we would consider recycling into the environmental impact of our model.

Although we assumed the emissions of power generations not to have an impact on our model, there is still a large amount of power we export in the United States. Furthermore, keeping a healthy margin of power available would help in the eventuality of power plant breakdowns, natural disasters, or even peak usage times. Therefore, we would adapt our model to maintain the ratio of energy produced to the energy consumed in the United States to what it currently is now and develop a way to easily manage the power production in the United States.

Conclusion

Although EVs are recognized as a more environmental option in the automobile industry they are in significantly smaller demand. Whether it be because of the price or underdeveloped technology, EVs maintain a small percentage of the total cars owned in the US. Therefore, for EVs to reach the goal of a 50% share in the automobile industry by 2030, there will need to be a substantial advancement in technology and infrastructure. A major portion of that infrastructure is the expansion of the power grid so that those who are part of the 50% can recharge their cars at home. Required technological advances include increasing the longevity of EVs as with their current battery ranges, not many are willing to invest. Alongside that, the price also needs to go down, regardless of the features offered, because an exorbitant price tag deters customers who are willing to make the transition to EVs. If EV manufacturers cannot follow these market trends, they would be unlikely to notice a huge increase in EV share. After all, in a market-driven economy, the customer's needs to be acknowledged by the producer. The technology also needs to improve as hybrid vehicles, which are partially electric cars, find greater success through improvement in their technology, which EVs could benefit from. Regardless of their current flaws, it would be shocking if electric cars do not continue to improve in the future from a technological and market share standpoint.

References

AAA. (2016). *State Gas Price Averages - AAA Gas Prices*. AAA Gas Prices. https://gasprices.aaa.com/state-gas-price-averages/

About. (n.d.). Redwood Materials. https://www.redwoodmaterials.com/about

Borrelli, L. (2021, July 26). *Car Ownership Statistics*. Bankrate. https://www.bankrate.com/insurance/car/car-ownership-statistics

Bruzek, J. (2022, March 7). *How Much Does It Cost to Charge an Electric Car?* Cars.com; Cars.com. https://www.cars.com/articles/how-much-does-it-cost-to-charge-an-electric-car-447817/

Carlier, M. (2021, December 15). *U.S. - number of vehicles in operation | Statista*. Statista; Statista. https://www.statista.com/statistics/859950/vehicles-in-operation-by-quarter-united-states/

Chris Cox | Department of Civil and Environmental Engineering. (n.d.). Cee.utk.edu. Retrieved April 2, 2022, from https://cee.utk.edu/people/chris-cox/

Duffin, E. (2022, March 14). *Public debt of the U.S. by month 2021-2022*. Statista. https://www.statista.com/statistics/273294/public-debt-of-the-united-states-by-month/#:~:text=In%20February%202022%2C%20the%20public

Edelstein, S. (2022, January 17). *EPA finds median range of EVs dropped in 2021*. Green Car Reports. https://www.greencarreports.com/news/1134758_epa-finds-median-range-of-evs-dropped-in-2021#:~:text=The%20median%20range%20of%20new

Edmunds. (2011, June 21). *Electric Vehicle Tax Credits: What You Need to Know*. Edmunds. https://www.edmunds.com/fuel-economy/the-ins-and-outs-of-electric-vehicle-tax-credits.html

Gohlke, D., & Zhou, Y. (2021). *Assessment of Light-Duty Plug-in Electric Vehicles in the Energy Systems Division* (p. 45). https://publications.anl.gov/anlpubs/2021/06/167626.pdf

Goldberg, S., & Anderson, S. (2021, August 19). *Lithium Mining: Dirty Investment or Sustainable Business?* Investopedia. https://www.investopedia.com/investing/lithium-mining-dirty-investment-or-sustainable-business/#:~:text=its%20applied%20output%3F-

How Far Can Electric Cars Go On One Charge? | Enel X. (2020, September 9). Evcharging.enelx.com. https://evcharging.enelx.com/resources/blog/666-how-far-can-electric-cars-go-on-one-charge#:~:text=An%20electric%20car

How Long Does It Take to Charge an Electric Car? | Pod Point. (2021, November 11). Pod-Point.com. https://pod-point.com/guides/driver/how-long-to-charge-an-electric-car#:~:text=Summary

Kopestinsky, A. (2022, March 5). *Global and US Auto Sales Statistics For 2021 | Policy Advice*. Policyadvice.net. https://policyadvice.net/insurance/insights/us-auto-sales-statistics/#:~:text=How%20many%20cars%20are%20sold

Martynyuk, E. (2021, November 8). *7 Reasons Why Electric Cars Are So Heavy | Motor Hills*. Www.motorhills.com. https://www.motorhills.com/7-reasons-why-electric-cars-are-so-heavy/#:~:text=EV%3A%20Currently%2C%20half%20of%20the

MYEV.com. (2019, October 9). *How Long Should An Electric Car's Battery Last?* MYEV.com; MYEV.com. https://www.myev.com/research/ev-101/how-long-should-an-electric-cars-battery-last

Ryan, C. (2020, April 2). *2019 smart fortwo EQ coupe Values & Cars for Sale | Kelley Blue Book*. KBB. https://www.kbb.com/smart/fortwo-eq-coupe/#:~:text=The%202019%20Smart%20EQ%20Fortwo%20electric%20vehicle%20(EV)%20starts%20as

Sergeev, A. (2021, January 7). *US Average Fuel Economy Fell In 2019, EPA Expects Record Jump For 2020*. Motor1.com. https://www.motor1.com/news/464672/us-average-fuel-economy-2019/#:~:text=According%20to%20the%20United%20States

Should I Buy a New or Used Car? (2021, September 27). Ramsey Solutions. https://www.ramseysolutions.com/insurance/new-car-vs-used-car

Shrider, E. A., Kollar, M., Chen, F., & Semega, J. (2021, September 14). *Income and Poverty in the United States: 2020*. The United States Census Bureau. https://www.census.gov/library/publications/2021/demo/p60-273.html

Tesla. (2019). *Tesla Roadster*. Tesla Roadster. https://www.tesla.com/roadster

Tesla Roadster. (n.d.). EV Database. https://ev-database.org/car/1167/Tesla-Roadster#efficiency

True Cost of Electric Vehicles. (n.d.). Www.aaa.com. https://www.aaa.com/autorepair/articles/true-cost-of-ev

U.S. Bureau of Labor Statistics. (2022a, March 31). *Engineering Teachers, Postsecondary*. Www.bls.gov. https://www.bls.gov/oes/current/oes172081.htm

U.S. Bureau of Labor Statistics. (2022b, March 31). *Environmental Engineers*. Www.bls.gov. https://www.bls.gov/oes/current/oes251032.htm

U.S. Department of Energy. (n.d.). *Alternative Fuels Data Center: How Do Hybrid Electric Cars Work?* Afdc.energy.gov. https://afdc.energy.gov/vehicles/how-do-hybrid-electric-cars-work#:~:text=Hybrid%20electric%20vehicles%20are%20powered

University, H. B. (2017, February 28). *What has the Great Society Wrought Fifty Years Later? Marriage, Family and Poverty | Houston Baptist University*. Hbu.edu. https://hbu.edu/news-and-events/2017/02/28/great-society-wrought-fifty-years-later-marriage-family-poverty/

Voigt, P. (n.d.). *Paul Voigt*. LinkedIn. https://www.linkedin.com/in/paul-voigt-76715b2a

Winters, M. (2021, December 29). *Here's whether it's actually cheaper to switch to an electric vehicle or not—and how the costs break down*. CNBC. https://www.cnbc.com/2021/12/29/electric-vehicles-are-becoming-more-affordable-amid-spiking-gas-prices.html

Witt, J. (n.d.). *Costs of Electric Car Battery Replacement*. Www.recurrentauto.com. Retrieved April 1, 2022, from https://www.recurrentauto.com/research/costs-ev-battery-replacement#:~:text=Replacement%20ranges%20from%20%240%20to