HiMCM 2019: Problem A

Team 9533

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Summary

The aim of the model is to develop a solution to the increasing demand and use of electric chargers. Electric vehicles and power outlets in public spaces have increased in prevalence, and the dependency of people on their electronic devices creates burden and cost on the energy industry as a whole. The method of modeling this problem and providing different possible solution to paying for these new charges is left open.

First, the goal is to learn more about the problem itself, and answer the first problem which asks for the research into the evolution of the industry and possible things affecting its growth. Overall electric vehicles and devices that need charging like cell phones increased significantly in use over the past 50 years, almost to the point of dependency. If these devices are not charged then many humans cannot function normally. Overall energy consumption has stayed in the United States, but in reality, methods of creating energy are becoming more efficient and electric solutions replace fuels like gas or oil, not just add on.Public places now feel obligated to provide charging services for their customers in order to maintain their business which often leads to a decline in profits as they are offered for free.

Problem 2 involves modeling the increases in electric costs and consumption as well as finding where these costs originate from. First, electric vehicles(EV) acted as the newest innovation in recent years and a large consumer of energy. The cost of EVs were tackled through costs of station and home charging, as well as the price of constructing new stations in public places. These were done using the statistics of yearly distance driven, EV efficiency, and prices for electricity in stations or at home. This data displayed significant increases in yearly costs going to the EV industry, and allowed for the fitting of the data to a quadratic. This quadratic could be used to predict future costs assuming no significant changes in the electric vehicle occurs(stability). The final model for the total public energy costs over time was
$\text{Cost}[x] = 5.39533 \times 10^{13} - 2.96104 \times 10^{10}\, x + 7.35679 \times 10^{6}\, x^{2}$, where x represents the year (such as 2020 or 2030). Many of these costs will be attributed to consumers indirectly. Likely, places will not charge directly for a charging station at their parking space, or outlets in their stores, they will need to compensate for their losses. Assuming no government grants or other injections of money, businesses will have to recouping their costs in some method.

Different public spaces require different methods of compensating for their costs. Assuming they all take on the same load(car chargers, outlets..) all the costs become compensated differently. A school may have to increase tuition or cut budgets, shopping malls may have to support trendier stores or bump up rent, while airports would increase parking fees or charge the companies more. All these indirectly burden the customer or student as ultimately their experience is taken away from or they have to pay more.

Different initiatives should be taken to combat these issues. Renewable energy sources enable methods of generating electricity with little long term price after an initial fee. Solar panels could be used to augment free space into providing extra electricity that could reduce prices and the effects of the electrical burden. Furthermore, energy efficiency and reduction would decrease negative effects on business. Simple actions like being conservative or investing in things as simple as LEDs over incandescent lightbulbs could save a fortune over many years, with little detriments to their services or prices. Capping electrical consumption on free available services would have a similar effect.

Therefore, increased free charging creates dependency and obligation over these amenities that serve to detriment businesses. Initiatives can be taken to combat this and must be to preserve the comforts of modern day.

Newspaper Article

Students have completed an independent research project regarding the increase in free charging stations and energy use in public places. Overall, they found that energy usage in the United States as a whole has remained relatively constant over the past few decades, even though the provision of electricity in public places has increased. This includes phone charging stations at malls and airports as well as public EV (electric vehicle) charging stations.

Most of the population has noticed the fairly recent rise in popularity of electric cars, which brought along a new opportunity for business in the form of electric vehicle chargers. Over the past decade, these public chargers have popped up near libraries, retail stores, and even college campuses. As awareness of the negative properties of gas cars spread, the number of electric vehicles is expected to rise in the future, along with the number of public chargers. In addition to car chargers, many malls have added charging stations for people and their devices. Though this will likely increase the energy consumption of current buildings, the mall itself does get a lot of revenue back in return due to the increased shopping time and checked out rate correlating with the time it takes to charge their portable devices.

As previously stated, the increased energy demand in the public sector will make the business foot a bigger bill. However, the owners will probably not directly charge their consumers for the electricity, (to keep their business) but they must find a way to recoup the costs to minimize the loss in profits, which can be done in a multitude of ways.

However, the methods to regain money will vary based on the type of institution. Malls and airports will probably increase the price of their goods to the consumers to make more money, or decrease the price (and quality) they pay for the goods. Airports also may increase parking fees. Public schools might need more funding, increasing the taxes the townspeople pay.

To reduce the overall costs of free public energy, businesses and institutions should explore new options in renewable energy such as solar panels and wind energy. This would help to offset the price they have to pay for the energy, thereby decreasing the amount of energy that has to be produced (which is not necessarily environmentally friendly).

To conclude, energy usage of the United States has mostly remained stagnant over the past decade, even though electric vehicles, EV chargers, and public charging stations have increased. To help balance the higher electricity costs these businesses would have to pay, the students strongly recommend they begin initiatives to use more renewable energy.

Problem Restatement

Public places are expanding the availability of electrical outlets, charging stations, and electric vehicle charging spots. In some areas, there is a fee to use this electricity; however, many areas offer charging for “free.” What is the impact of “plugging in” our electronics at these “free” charging sites in public places such as airports, railway terminals, schools, libraries, shopping malls, coffee shops, and offices? And, who pays for it?

Problem 1

Discuss how has this type of energy consumption has changed over recent years and how it will continue to change. Identify impacts on, and requirements of, public places with these increasing energy (electricity) and charging demands.

Problem 2

Use your identified impacts and requirements to develop a model for the resulting costs of the increased demands and energy usage on public places. Discuss the extent of these costs and how they are paid.

Problem 3

Discuss how your model changes, if at all, for different types of public places (e.g. a school vs. a café/coffee shop vs. an airport vs. a shopping mall, etc.)?

Problem 4

What initiatives should be explored to reduce the cost of this increased energy usage in public places? How would implementation of these initiatives adjust your cost model?

Problem 5

Write a one-page article for your school newspaper describing your findings and recommendations.

Assumptions and Justification

Assumption:

Predictions about future energy consumption and electric vehicle popularity from trustworthy internet sources are accurate.

Justification:

Predictions created by companies such as Bloomberg New Energy Finance are based on large amounts of data from previous years. Predictions about the future are made based on this data, and although they usually do not perfectly represent the future, they are usually close to the true value, so for the purpose of this problem, they can be assumed to be accurate.

Assumption:

Public energy consumption, excluding electric vehicle charging stations, is directly proportional to total energy consumption in the United States

Justification :

An increase in total energy consumption generally means that there is an increase in the demand for electricity. As a result, the demand for energy in public places would also increase, leading to an increase in public energy consumption. While these values would not increase exactly proportionally to each other, it would be close to proportional, so it is fair to assume for the purpose of the question that they would be proportional. Electric vehicle charging stations, however, make up a large portion of the public US energy consumption while making up a small portion of the total US energy consumption, so they do not fit under this assumption.

Assumption :

Total US Energy consumption has been constant in recent years, and will stay that way in future years

Justification :

Appendix B contains a graphic from the US Energy Information Administration, which shows that the total US energy consumption over the last 20 years has remained relatively constant, increasing and decreasing by small amounts between the years. This pattern can be reasonably assumed to be consistent in future years.

Assumption :

Commercial costs listed as ' other ' in a pie chart refer to personal, non – work related energy costs

Justification :

The “other” section of a pie chart is used to represent costs not explicitly listed in other areas. The other areas of the chart focus mainly on work-related costs. While it cannot be fully known whether or not the “other” section includes other work-related costs that weren’t explicitly listed, the public usage is not explicitly cited by any studies, and it can be assumed that public use represents a large portion of this. Because of this, it can be assumed for the purposes of the question that the “other” section represents public energy usage.

Problem 1: How public energy consumption has changed over the years

How public energy consumption has changed over recent years:

Electric vehicles have greatly increased in popularity in recent years. While electric vehicles were first created in the 1800s, they decreased in popularity over the years, and the interest in electric cars was not renewed until 1996, when General Motors released their own electric vehicle, the EV1. The next year, Toyota released the first mass-produced hybrid, the Prius, which further increased the electric vehicle's profile. In 2006, Tesla Motors began production of electric cars, which led other automobile companies to start focusing on electric vehicles. As of now, there are 44 available electric vehicle models (including both battery electric vehicles and plug-in hybrids), from 20 different manufacturers. Estimates are that one in every 250 cars on the road is an electric car, battery electric cars compose 2.1 percent of total global car sales.

Charging stations in public stations such as malls have also increased. For example, ChargeItSpot, a free charging station for customers to charge their phones while they shop, was first installed in 2014 and has received wide scale support as in 2015, with 150 kiosks were installed in 18 states and Canada. During a December test, shoppers used the station 41 times per day and charged for 53.5 minutes each time. In 2015-2016, these charging stations charge approximately 2.5 million phones per year and 6,000 phones per day. As the data from this research ends at 2015, it can be estimated that the charging stations are currently increasing in numbers and charging more and more phones all across the US.

Primary energy consumption has increased from 87,715.94 Terawatt hours of energy consumption in 1990 compared to 141,837.84 tWh in 2016 in the world. Energy consumption has nearly doubled over the course of 26 years, and will only continue to increase. But in the United States consumption went from 21,298.78 tWh to 24,302.67 tWh. The energy consumption in the US has remained rather constant. in comparison to the rest of the world, but the causes need to be explained.

How public energy consumption will continue to change:

There are many different estimates about how popular electric cars will become in the future. Bloomberg New Energy Finance (BNEF) estimates that by 2040, the total number of electric cars in the world will be close to 500 million, approximately 32 percent of the world's passenger vehicles, and that 50 percent of new passenger vehicles sold will be electric. However, other projections, such as those created by ExxonMobil and OPEC, estimate this number to be much lower: around 150 to 300 million. CNN and FOX both accept Bloomberg's estimates, so those estimates will be used in this paper. Many automobile companies have announced their plans for electric vehicle development over the next few years. Ford is spending 11 billion dollars on electric vehicle development over the next 3 years, GM is planning on releasing 20 new EV models over the next 4 years, and Toyota is planning on adding 10 new battery electric vehicles by the early 2020s and electric options for all its vehicles by 2025 (Reuters 2018). This will greatly increase the demand for electric vehicle charging stations, as a much larger percentage of the population will require these stations.

Total power consumption is projected to increase greatly over the next few decades. The United States Energy Information Administration (EIA) estimates that world energy use will increase by nearly 50 percent by 2050. Worldwide renewable energy consumption is projected to increase by 3.1 percent per year until 2050, petroleum is projected to grow at 0.8 percent per year, coal is projected to grow at 0.4 percent, and natural gas is projected to grow by 1.1 percent per year. Overall, in the 31 years leading up to 2050, natural gas consumption is expected to increase by more than 40 percent and liquid fuels consumption are projected to increase by 20 percent.

Impacts on Public Places:

As more charging sites are added in public places, it is possible that these charging sites may in return benefit the places itself. As many as 90 percent of the people use phones to compare and research different products. If phones become out of charge during shopping, it would hinder the shopping of many individuals, which would negatively impact the income of stores. Moreover, research conducted shows that charging sites make people browse and stay in stores for double the time. This would increase the checkout rate by 29 percent and 54 percent of the customers feel positively about the retailer, which might indicate a higher rate of return in the future.

As of the need for increasing electric vehicle charging stations, the EV charging station market is predicted to grow from about 5.3 billion dollars (2018) to about 30.41 billion by 2023, an annual growth rate of 41.8 percent between the two years. Even though states such as California invested a total of 80 million into EV infrastructure, the current rate of addition of EV charging stations are clearly not enough to support the rising amount in electric vehicles. If the rate of addition and advancements regarding charging stations still follows the current rate US has, this will likely negatively impact the market of EV charging stations and possibly even the market of electric vehicles itself.

Requirements of Public Places:

They would need to be more efficient in conserving energy for other processes of the business. Since they are offering more electricity but still charging nothing, the company's profit would be affected. In turn, they might change a few things about their business to offset these costs. Firstly they might increase the price of their product for the consumer. This will allow the company to use that extra money to help pay for the energy. Similar to this, the brand might take a second route of decreasing the quality of the good, so it costs less to produce. This would also improve their margins, helping to recoup the increased energy costs. A more likely approach might include restrictions on free outlets, limiting their access to only paying customers, reducing the amount of people using the outlets.

In terms of electric vehicle charging stations, the companies that provide the service are generally very different. Normal stores and restaurants generally don't provide charge for electric vehicles, since the vehicles take a long time to charge and the customer usually does not stay long enough to gain a significant amount of charge. Instead, charging stations are usually located at large parking lots, parking garages, banks, malls, and streetside parking areas where people tend to stay parked for extended periods of time. Similarly to with the normal power outlets, if the owners of these areas do not charge extra money for people to use electric vehicle chargers, they would be forced to increase their revenue by other means. For example, parking garages could slightly increase the cost for all parking, banks could decrease customers' interest rates and increase the interest rates on bank loans, malls could charge more, and the price of streetside parking for all cars could increase.

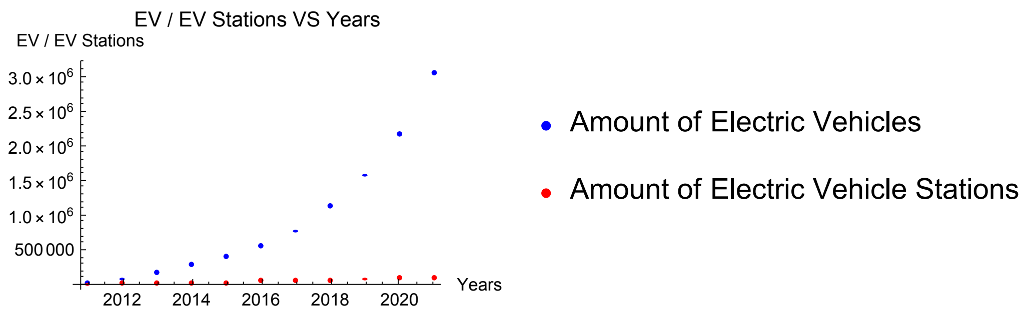
Problem 2: The Model

Approach - Attacking the Electric Vehicle Problem

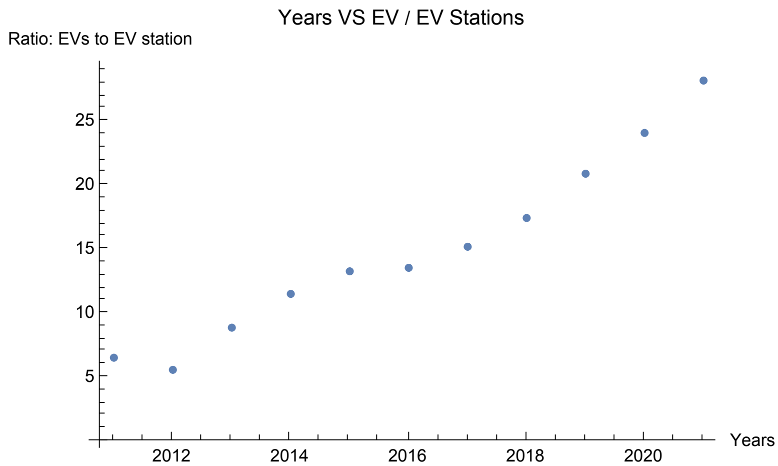
As discussed during the background of the question the prevalence of electric cars could add stress to the electricity providing industry. The increase in popularity of these cars mean more business and burden for electric companies over traditional oil companies. An approach was searched for to quantify the new additional cost electric vehicles would introduce into the question. First, the increase in the amount of vehicles and amount of charging stations had to be found, as well as the cost associated with each. This cost was taken and projected over the next few years in order to see visible increased cost on the electricity providing industry.

Acquiring the Data

According to "EV Charging Statistics," the following data was acquired and graphed. This graph displays two lines, one representing the amount of electric vehicles, and the other the amount of electric vehicle stations per 2011 to 2022. All numbers past 2018 were projected by the source.

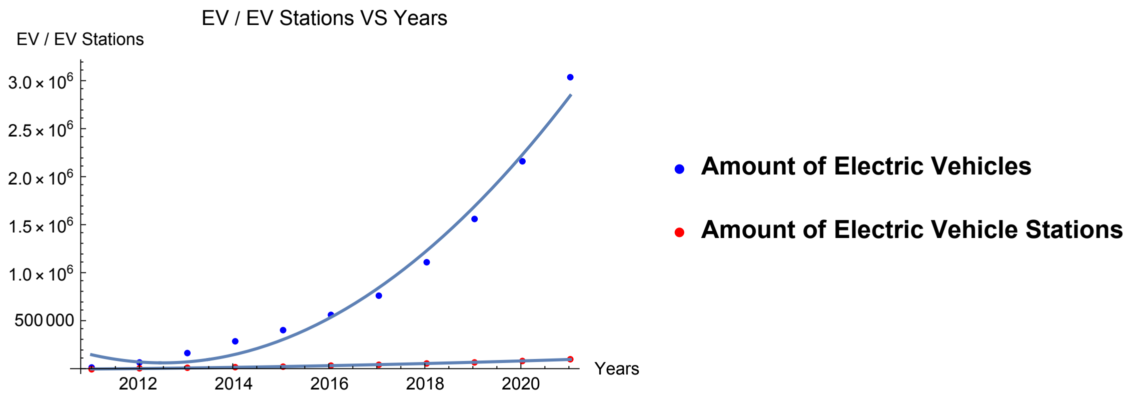


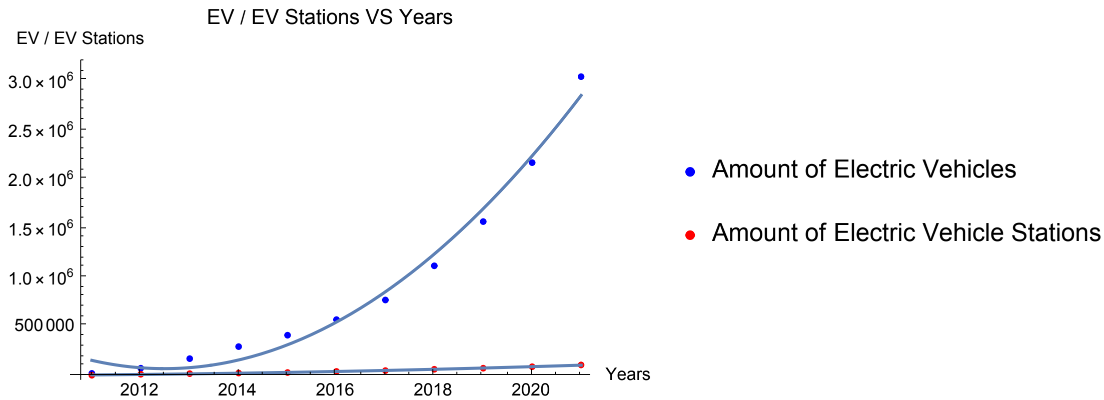
Next, the relationship between electric vehicles and stations was calculated in order to help predict the amount of stations of the future, so only one necessary was necessary to find the other. The graphed data looks linear and directly proportional at a negligible variance as years progress. While not necessarily useful for this section, this graph will help future work with the vehicles.



Fitting the Data

Two lines were fit to the amount of electric vehicles, and the amount of stations so that future years could be predicted assuming similar growth continues in the future. The fits were done in Appendix A. The results shown below.



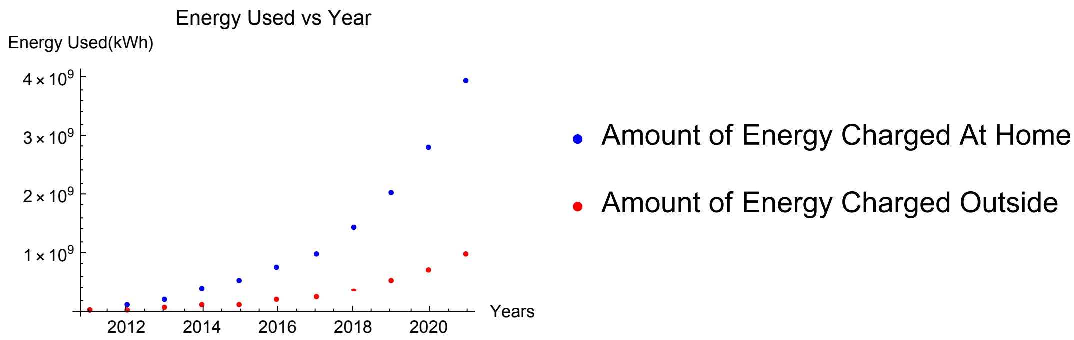


Small Conclusions

Judging by the data, the amount of electric vehicles will continue to grow in a quadratic manner so their costs are worth pursuing as part of our mathematical model. The numbers seem significant enough to pursue the cost of the burden on the industry. Furthermore, demand of electric vehicle stations will need to increase along with vehicles, drawing more resources and money in order to be payed for.

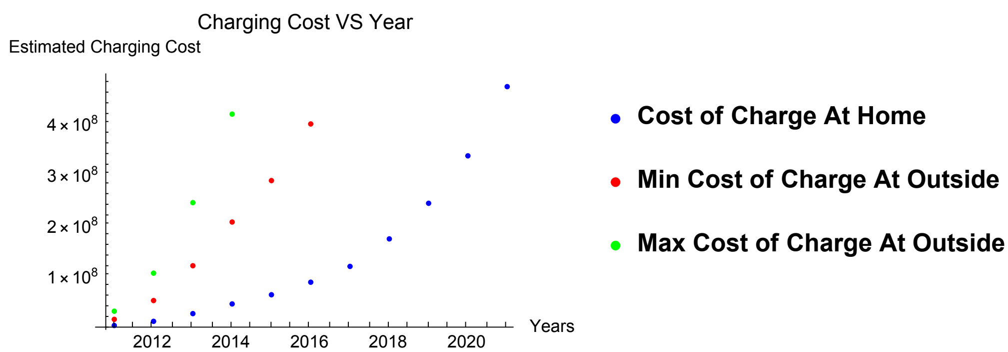
Charging EVs

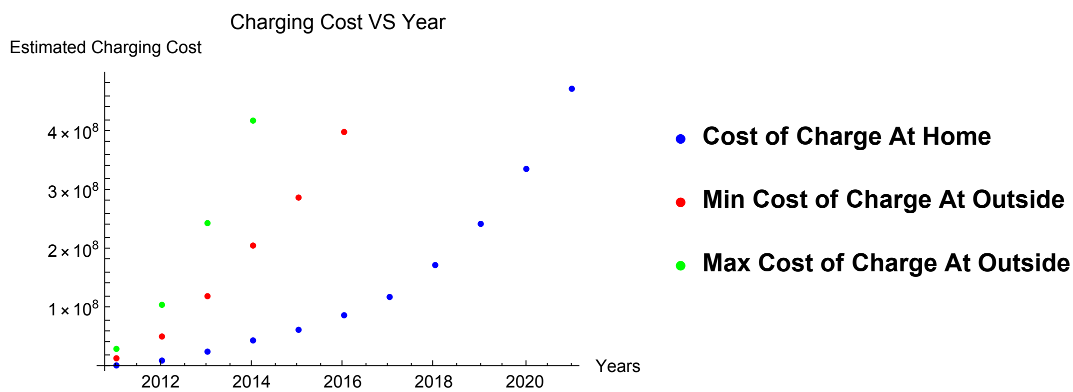
In order to find the amount of energy that users would charge at home rather than from outside sources, based on the amount distance users drive during a year. According to “Energy consumption of full electric vehicles,” people drive 9,000 miles on average during a calendar year. Using this statistic and how an electric vehicle uses 18 kWh every 100 miles, the amount of energy used could be calculated to 1620 kWh per year per electric vehicle. Furthermore, 80% of EV charging is conducted at home, which allows where the price of charging the EV’s goes. This 1620kWh * 80% per vehicle was then multiplied by the amount of vehicles their are and the other 20% was used for the outside amount. The data was plotted below.

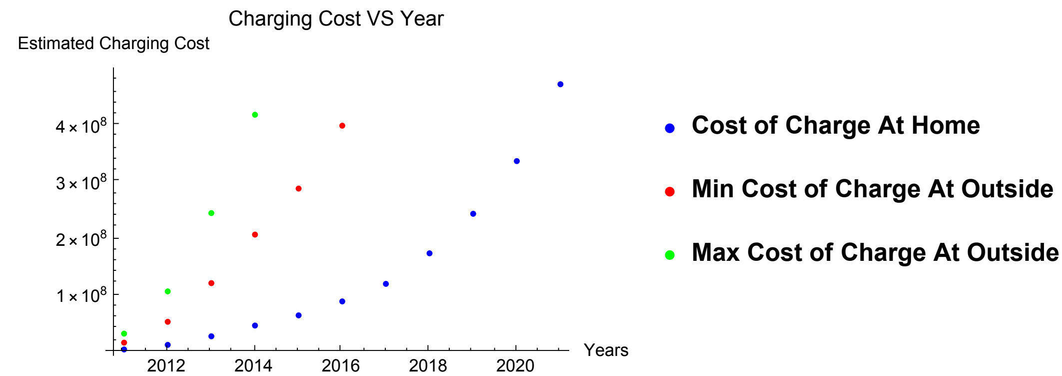


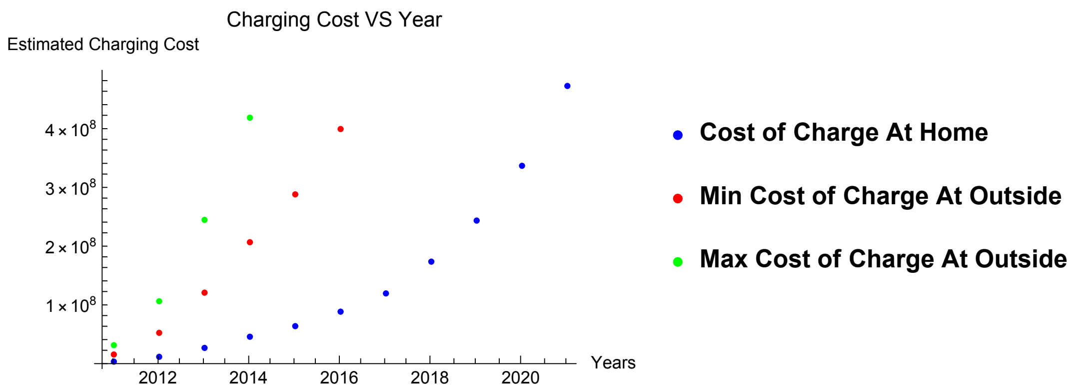
Cost of EVs

According to the same source, the minimum cost of charging at an outside station is $0.39 and the maximum is $0.79. According to “U.S. Energy Information Administration” the cost of electricity per kWh is $0.12 on average across all states. This was then used to compute the costs by multiplying it by the energy used.






Charging Cost VS Year
Estimated Charging Cost
4 × 10^8
3 × 10^8
2 × 10^8
1 × 10^8
2012
2014
2016
2018
2020
Years
Cost of Charge At Home
Min Cost of Charge At Outside
Max Cost of Charge At Outside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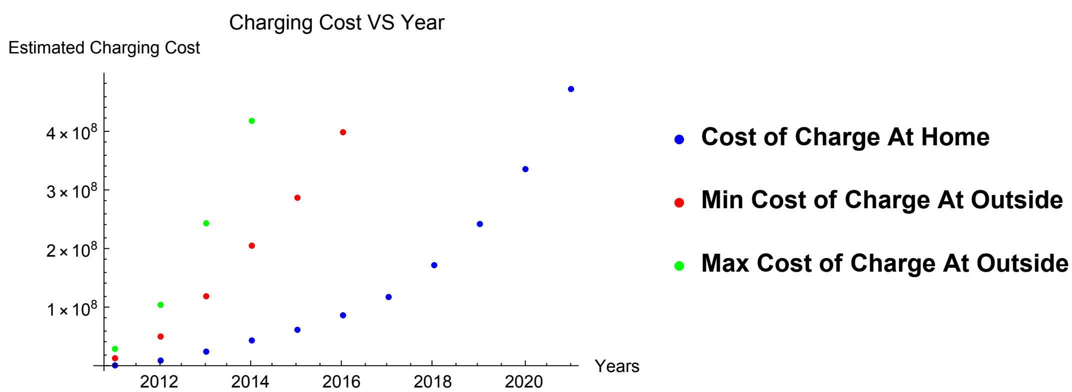
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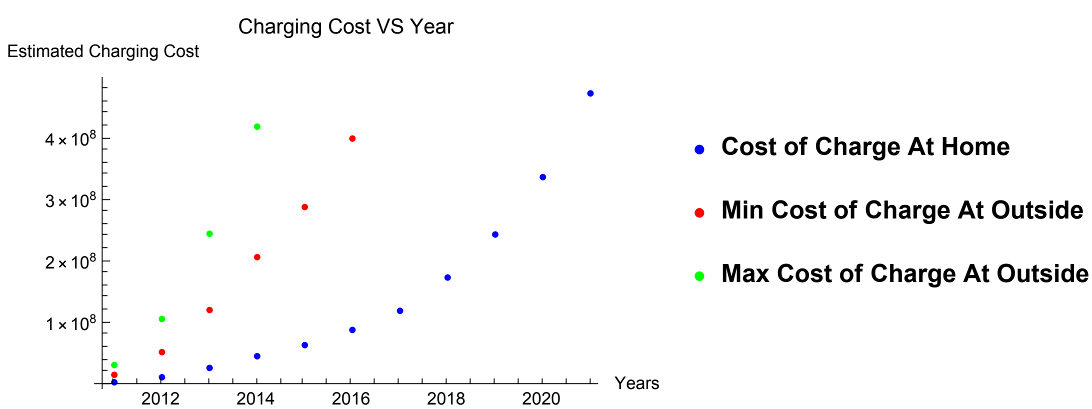
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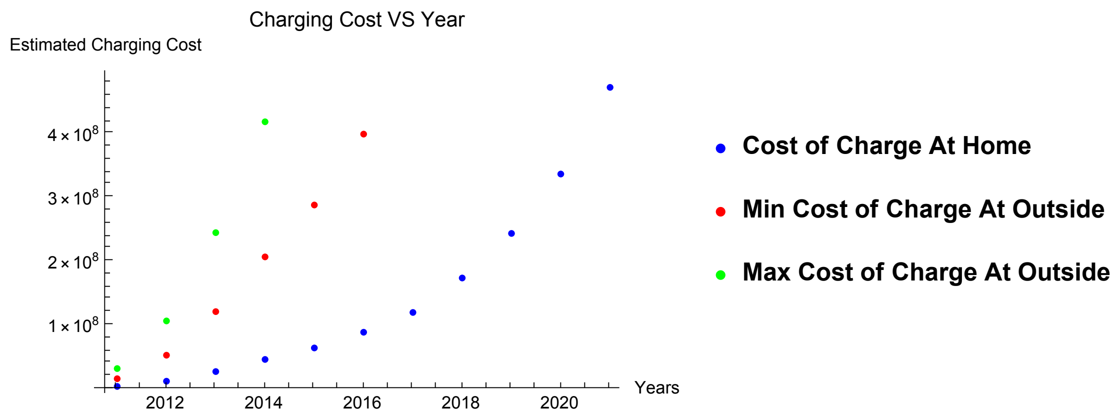
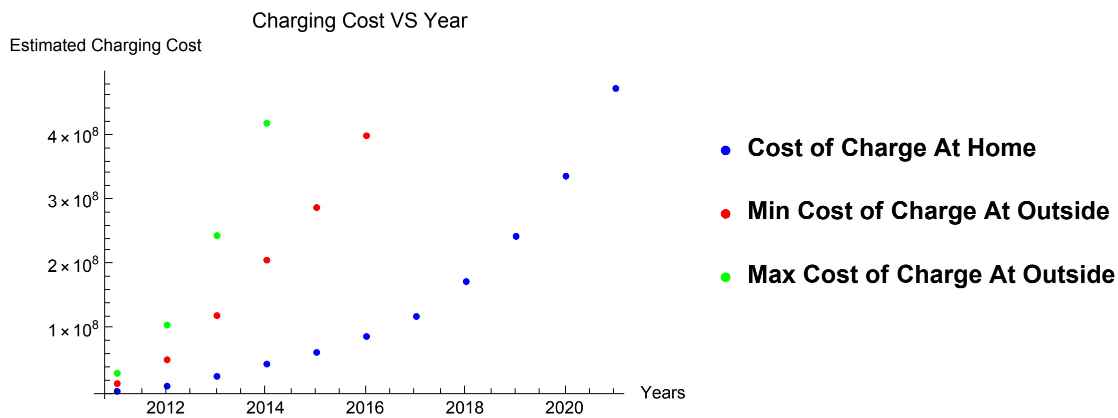
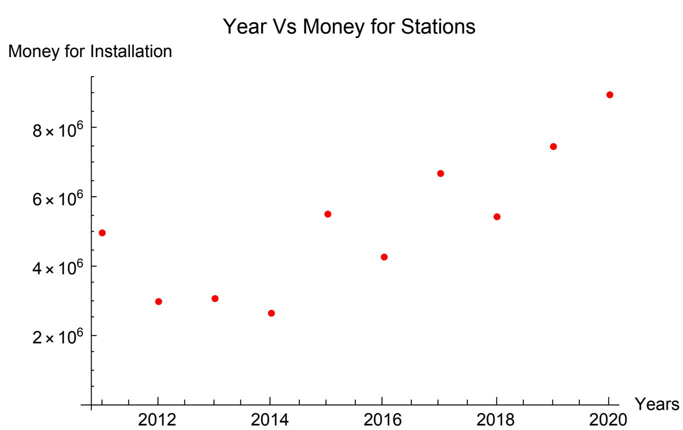




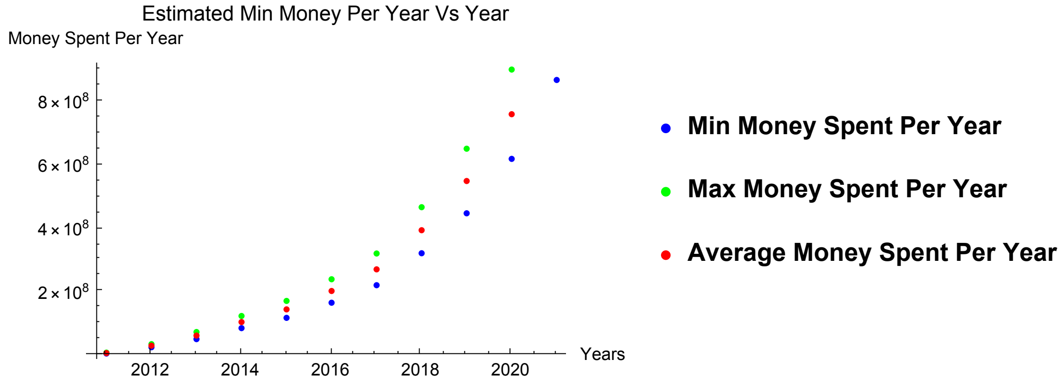
Cost of Station Construction

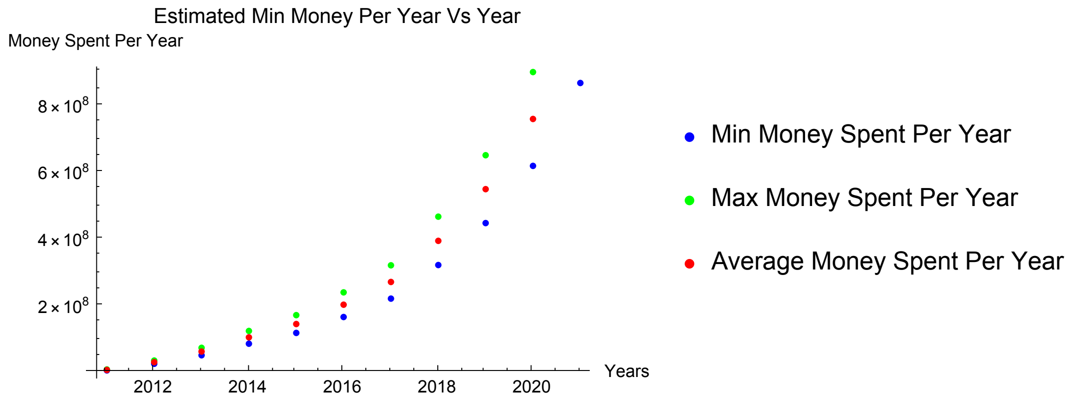
The price of creating a station is around $500, and new the amount of new stations per year was taken by subtracting the amount of stations per year from each other. This cost was then graphed.



Total Costs

Next, the total yearly costs that EVs would cost was created using the above data by adding the at home and averaging the outside costs. Then the cost of new stations was added to it to get the total amount spent a year on improving and maintaining the electric vehicle industry.

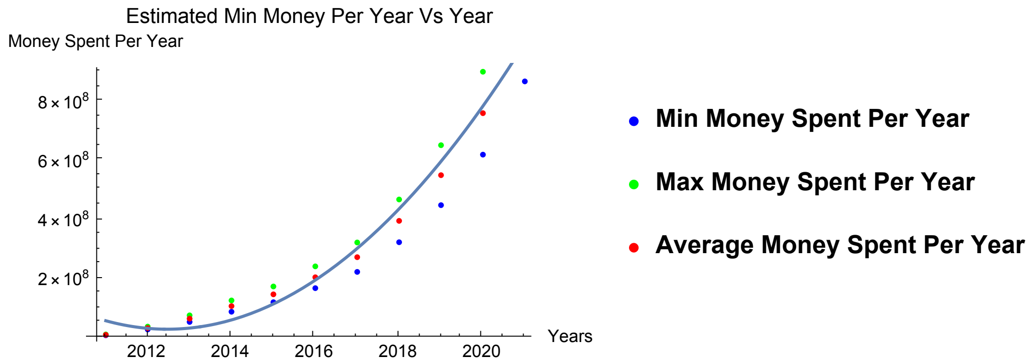


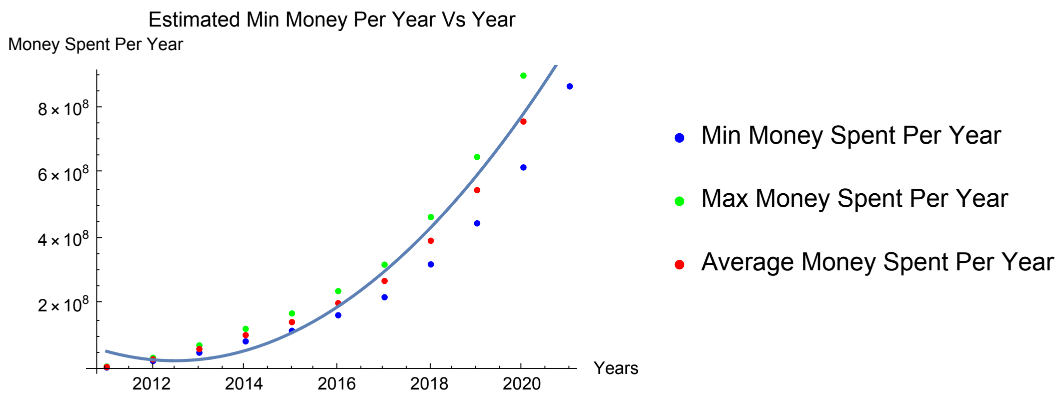


Fitting the Data

The data was then fit to create an equation that could be used to predict the costs of the EV industry in the future(Cost of energy of EV + Station in US), which represents the model. The following equation represents the fit as well

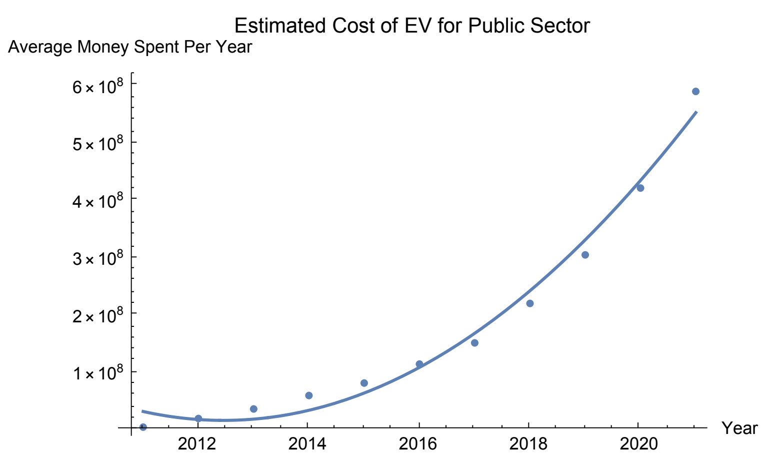
$.33924 \times 10^{13} - 6.30011 \times 10^{10}\, x + 1.5653 \times 10^{7}\, x^{2}$.





Cost of EV for Public Sector Only

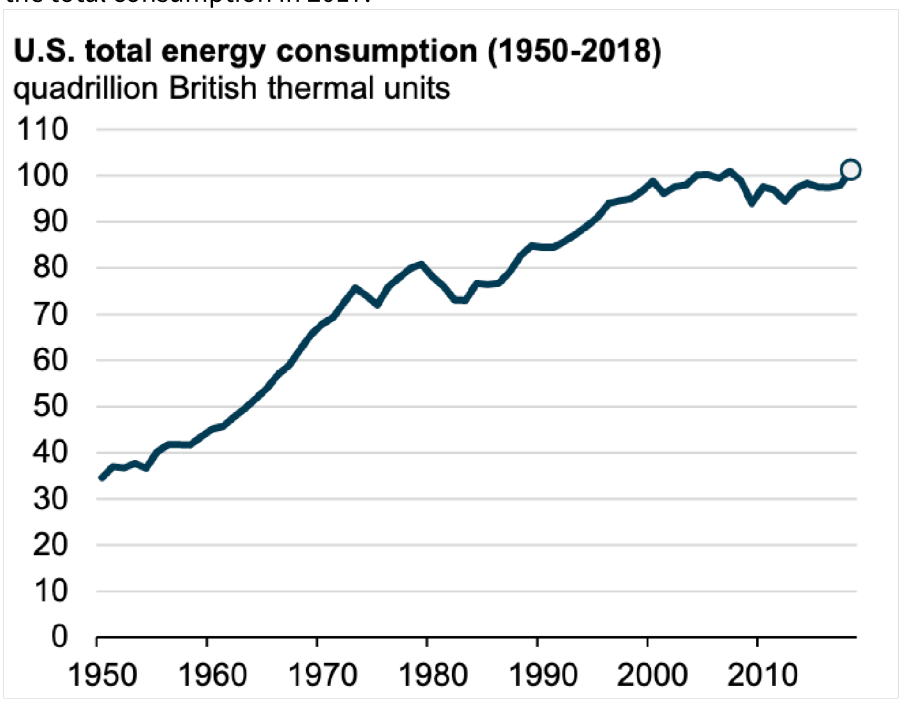
However, since this is mainly about how the public is going to pay for these fees, only the cost of EV for the public sector is calculated, which includes the building of new stations and the cost of charging outside and excludes the cost of charging at home. The graph is based on the average cost spent on EV per year for the public sector.



After fitting the data, the cost of EV for the public sector can be modeled after the equation $2.97948 \times 10^{13} - 2.96104 \times 10^{10}\, x + 7.35679 \times 10^{6}\, x^2$.

Approach: The public electricity consumption problem (excluding electric vehicles)

Information from the United States Energy Information Administration has shown that, within the last decade, public energy consumption has had very little change. Although over the last 50 years, public energy consumption has more than doubled, it has begun to taper off since around 2008. Calculations in Appendix B show that the total energy consumption in 2008 and in 2017 were very similar, and that the total consumption in 2008 was actually higher than the total consumption in 2017.



Graphic from the United States Energy Information Administration.

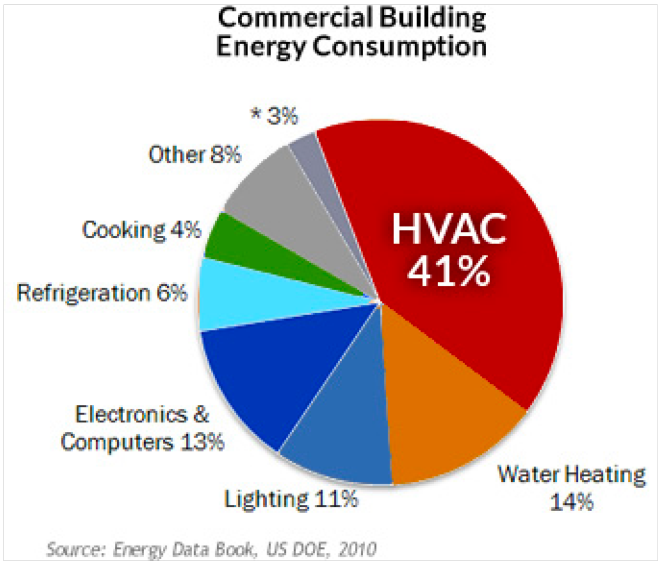
Total US energy consumption per year

Appendix B contains calculations of the total United States energy usage in 2017. The total amount of energy used was about 4090 Terawatt-Hours, and the total cost of this energy was about 413 billion dollars. However, public energy consumption mainly comes from the commercial sector, whose total cost of energy came out to about 149 billion dollars. Based on the assumption that total United States energy usage will remain relatively constant in future years, total US energy spending in future years will be around the same. Thus, the total US energy usage in the commercial sector in future years will be around 149 billion dollars per year.

Note: This does not account for electric vehicle charging stations, which have grown greatly in popularity in recent years. EV charging stations account for a small portion of the total US energy consumption, but make up a much larger proportion of the total public US energy consumption, so they were kept separate from this data.

Total US public energy consumption per year

It can be assumed that total public energy consumption is proportional to total energy consumption, and it can also be assumed that the "other" section on a pie chart containing the breakdown of commercial costs represents the public energy consumption (see assumptions).



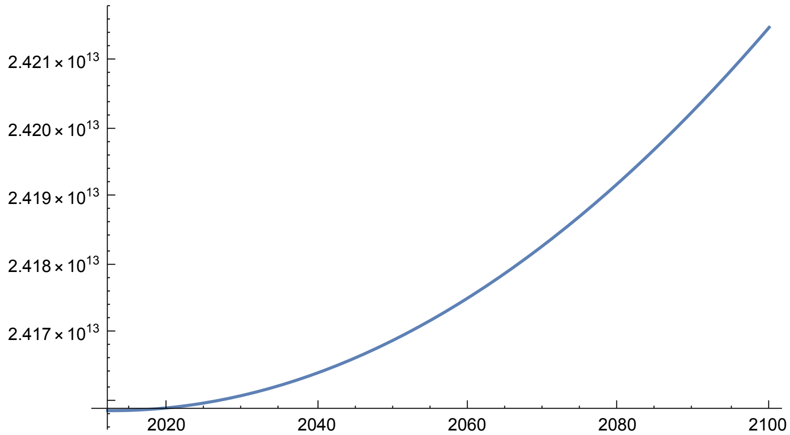
Graphic from Atlantic Westchester

This graphic shows that "other" costs represented 13 percent of total US commercial energy consumption, and this can be assumed to represent public energy consumption. Thus, the total cost of public energy consumption is 8 percent of 149 billion dollars, which is about 11.92 billion dollars.

Putting it all together

To put the entire model together, the data for total US public energy costs (excluding electric vehicle charging station) per year was added to the data for the electric vehicle charging station costs per year. The total annual public energy costs excluding charging stations was 11.92 billion dollars, and the electric vehicle charging station costs could be modeled by the equation $5.39414 \times 10^{13} - 5.36072 \times 10^{10}\ x + 1.33188 \times 10^{7}\ x^2$. Adding these together, the final model for the total public energy costs is $5.39533 \times 10^{13} - 2.96104 \times 10^{10}\ x + 7.35679 \times 10^{6}\ x^2$, where x is the year. While it may

seem that the model only changed by a very insignificant amount when the total public energy cost was added to the electric vehicle costs, the value of the electric vehicle model during years close to 2000 are much smaller than the term 5.39414×10^{13}, so the public energy cost makes a significant difference at values close to 2000 (which are around the current year). For example, without the public energy term added, the total cost in 2000 would be about 2.09 billion dollars. With the public energy consumption value added, the cost jumps to about 14 billion dollars.



Problem 3: Requirements of Public Places

There are a variety of institutions that have a soon will implement more public charging stations, whether they be for phones or even cars. These mainly include office buildings, malls, airports, and even schools.

Office buildings, will most likely charge the tenants (businesses) more to make up for the power costs. This in turn might make the businesses pay their employees less, or in some cases increase the cost of amenities (coffee in lobbies, printing for personal use).

Public schools and libraries are funded by the government and taxes, so to pay for the increase in the cost of electricity, more taxes may be charged upon the residents. The biggest differences will occur in restaurants and shopping malls. The restaurants might increase the price of their goods to make more from the consumer, or decrease the price and quality of the raw ingredients. Another possibility for malls is to increase the amount they charge from stores, causing the individual shops to foot the bill. They can also increase the cost of parking. Another option malls have is to increase the number of independent kiosks in the area.

Airports also have a variety of ways to pay back the costs of offering free energy to customers. Just like shopping malls, they might charge more from the shops and restaurants, and they can also increase the price of parking. Airports also have the option of charging more for car rentals, since that is a big transportation function at these travel hubs. The way airports make most of their money however is by charging the airlines to come use their terminals. These airliners will then have to charge their customers more to pay back the airports.

Overall, since these companies are offering more electricity but still charging nothing, the company's profit would be affected. In turn, they might change a few things about their business to offset these costs. They would likely have to increase the cost of merchandise or lower employee wages to pay for the increase in electricity cost.

In terms of electric vehicle charging stations, the companies that provide this service are generally very different. Normal stores and restaurants generally don't provide charge for electric vehicles, since the vehicles take a long time to charge and the customer usually does not stay long enough to gain a significant amount of charge. Instead, charging stations are usually located at large parking lots, parking garages, and perhaps airports, banks, malls, and streetside parking areas where people tend to stay parked for extended periods of time. If the owners of these areas do not charge extra money for people to use electric vehicle chargers, they would be forced to increase their revenue by other means. For example, parking garages could slightly increase the cost for all parking, banks could decrease customers' interest rates and increase the interest rates on bank loans, malls could charge more for its merchandise, and the price of streetside parking for all cars could increase.

The projected price in the model is the amount of money that institutions such as government agencies and investment companies have to pay off. In order to make sure the cost of the EV industry results in a $0 for the consumers, all the money from the model must be paid off somehow. The mechanism in which it would be paid off will certainly depend on the place as mentioned in the previous paragraphs. This will overall affect the consumers since most companies would be unwilling to sacrifice their profits in exchange for providing free services to the consumer that does not benefit themselves.

Problem 4: Initiatives to Reduce Costs

A method that businesses could use is to get a percentage of their power from renewable energy sources. For example, public areas will be able to place solar panels to collect electricity to use for the free outlets inside. This will allow their overall costs to be less than the projected values if they were simply buying from power station, because the cost of renewable forms of energy has been continuously decreasing over recent years. Since 2000, the cost of electricity from solar power has decreased by 26 percent, bioenergy, geothermal, and wind by 14 percent, and hydropower by 12 percent (Forbes Renewable Energy).

Another way that the cost of this increased energy demand could be reduced is if companies limited the number of available power outlets or the amount of electricity that can be withdrawn. In doing so, they would be able to decrease the total electricity usage through public outlets, which would help them reduce their total electricity costs. They could also reduce the total electricity consumption by decreasing electricity consumption in other areas. For example, some companies leave on lights and machinery after hours, which is usually unnecessary. By ending the unnecessary use of electricity, companies would have more electricity available for public use for the same cost.

One more way that the cost of this increased energy usage could be reduced through an increase in energy efficiency in public buildings. By increasing the energy efficiency, the total energy costs of the company would decrease, while the company would not have to decrease its energy usage. This could happen one of two ways: either the company could decide to increase its energy efficiency on its own, or the government could increase its energy standards and require public buildings to meet a certain standard of efficiency.

The implementation of these initiatives would adjust the cost model by decreasing the total cost of electricity in public spaces over time. Some of these initiatives decrease the cost by decreasing the total electricity used. Other initiatives decrease the cost of electricity, while maintaining the same total amount of electricity used. In the end, all of these initiatives decrease the total cost of electricity used, which causes the actual amount of electricity used to be less than the prediction made by the model.

Strengths and Weaknesses of the Model

Strengths of the model

The model is based on previous data about US energy consumption from reliable sources including the United States government. Because of this, the model is likely accurate in predicting future total energy consumption. The model also accounts for the increased presence of electric vehicle charging stations, which make up a large portion of public energy usage, while making up a very small portion of total US energy usage. By accounting for EV charging stations separately from other forms of energy consumption, the model makes a more accurate prediction about total US energy usage.

Weaknesses of the model

The model also has a few weaknesses. The data used in making a prediction of the total US energy usage over time was only based on the last two decades, and ignores data from previous years which show energy consumption increasing. While recent data is generally more accurate in predicting future data, the model would likely be more accurate if it also incorporated some of the older data as well.

The model is based on many assumptions, some of which cannot be guaranteed to be true. For example, it cannot be said for certain that the total US public energy usage is directly proportional to the total energy usage. While there is likely a relationship between these two values, they cannot be guaranteed to be directly proportional to each other.

The model also makes the assumption that the “other” section of the commercial energy consumption represents “free” public energy usage. While public energy use likely represents a large portion of this section, there are most likely other costs in this section, so public consumption is likely less than the estimated value of 8 percent of total commercial energy usage.

Appendix

Appendix A (in the Wolfram Mathematica Language)

Calculation of the cost per tera-watt hours in the United States.

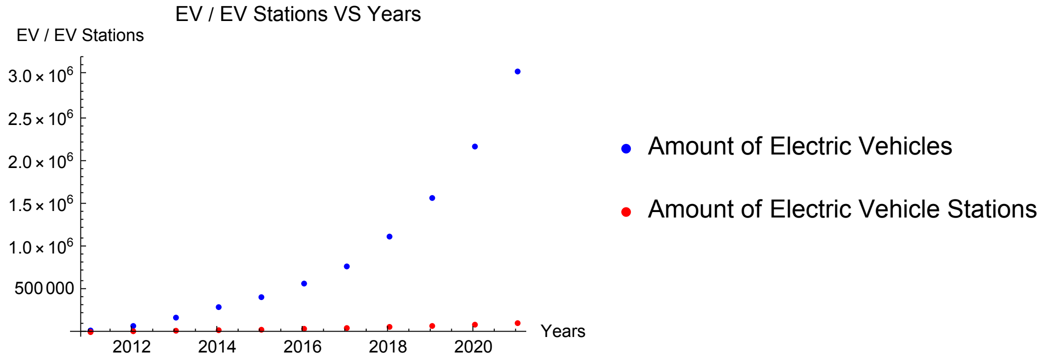
According to NPR, the cost per kilo-watt hour of electricity in the U.S on average is 12 cents. The cost of electricity at charging stations is between $0.39 and $0.79 per kWh. The average resident charges 80% of their electric cars at their houses, and an average electric car drives approximately 9000 miles a year.

Here is the graph of the number of electric cars and number of EV charging stations from 2011 to 2017 and the projected number from 2018 to 2021 according to EVAdoption:

```
In[11]:= years =
  List[2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021];

In[12]:= ev = List[22 161, 74 768, 172 275, 294 713, 410 812,
    569 426, 769 244, 1 117 244, 1 567 244, 2 167 244, 3 042 244];

In[13]:= evstations = List[3394, 13 392, 19 410, 25 602,
    30 945, 42 029, 50 627, 64 067, 75 000, 90 000, 108 000 ];

In[14]:= evvsyrs = Transpose[{years, ev}];

In[15]:= evstationvsyrs = Transpose[{years, evstations}];

In[16]:= plot1i = ListPlot[evvsyrs,
    AxesLabel → {"Years", "EV / EV Stations"}, ImageSize → Large,
    PlotStyle → Blue, PlotLabel → "EV / EV Stations VS Years",
    PlotLegends → {"Amount of Electric Vehicles", "None"}];

In[17]:= plot2i = ListPlot[evstationvsyrs,
    AxesLabel → {"Years", "EV / EV Stations"}, ImageSize → Large,
    PlotStyle → Red, PlotLabel → "EV / EV Stations VS Years",
    PlotLegends → {"Amount of Electric Vehicle Stations", "None"}];
```

```
In[18]:= Show[plot1i, plot2i]
```

Out[18]=




```
In[19]:=

In[20]:= evcurve = Fit[evvsyrs, {2011, x, x^2}, x]
```

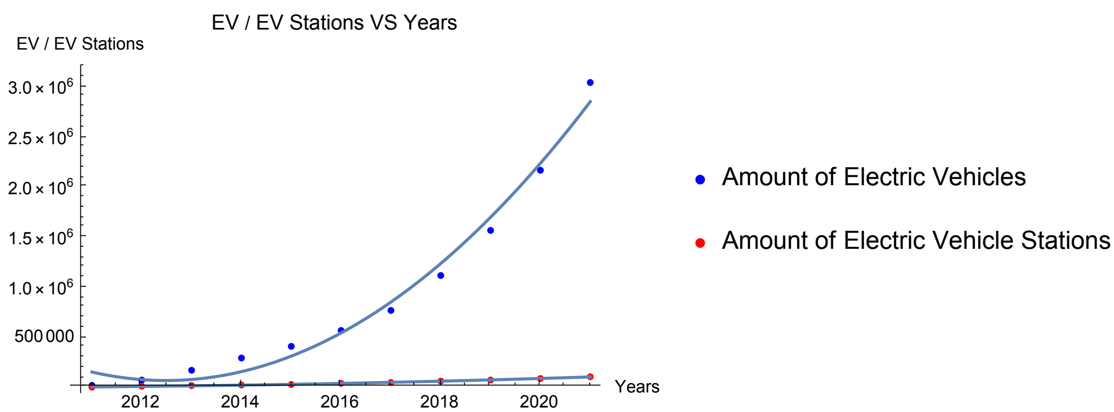
Out[20]= $1.55264 \times 10^{11} - 1.543 \times 10^{8}\, x + 38\,335.8\, x^{2}$

```
In[21]:= f1[x_] = .55264 × 10^11 - 1.543003471790804`*^8 x + 38335.80652439484` x^2 ;

In[22]:= evplot = Plot[evcurve, {x, 2011, 2021}];

In[23]:= evstationcurve = Fit[evstationvsyrs, {1, x, x^2}, x]
```

Out[23]= $2.3693 \times 10^{9} - 2.36039 \times 10^{6}\, x + 587.879\, x^{2}$

```
In[24]:= f2[x_] =
           2.369302658837313`*^9 - 2.3603923271174524`*^6 x + 587.8787878403032` x^2;

In[25]:= evstationplot = Plot[evstationcurve, {x, 2011, 2021}] ;

In[26]:= Show[plot1i, plot2i, evplot, evstationplot]
```

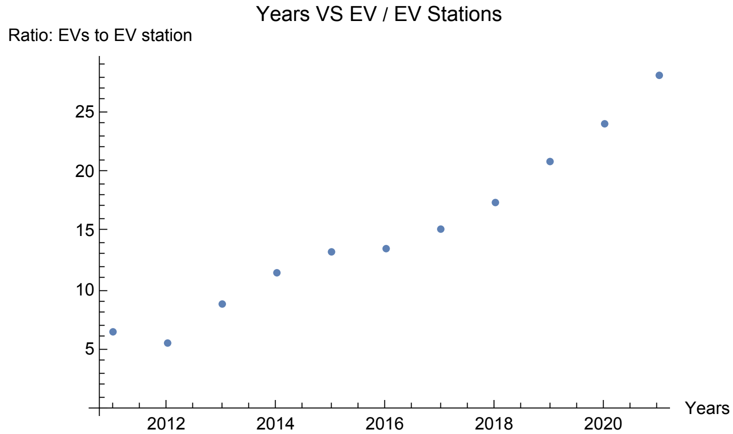
Out[26]=




```
In[27]:= ratio = ev / evstations;

In[28]:= ratiovsyrs = Transpose[{years, ratio}];
```

```
In[29]:= ListPlot[ratiovsyrs, AxesLabel → {"Years", "Ratio: EVs to EV station"},
          ImageSize → Large, PlotLabel → "Years VS EV / EV Stations"]
```

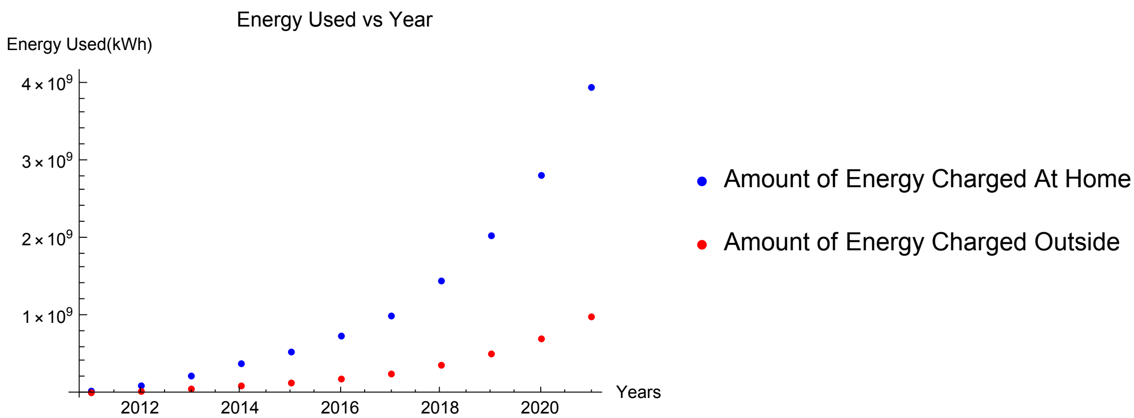
Out[29]=




```
In[30]:= avgmile = 9000 (*Average Mile an electric car drives in a year*);

In[31]:= avgcost = 18 / 100 (*Average kWh per 100 miles*);

In[32]:= costhome = 0.12 (*Charging cost at home*);

In[33]:= mincostoutside = 0.39 (*Minimum charging cost outside*);

In[34]:= maxcostoutside = 0.79 (*Maximum charging cost outside*);

In[35]:= avgcostoutside = (0.39 + 0.79) / 2;

In[36]:= yrsvscosthome = Transpose[{years, ev * avgmile * avgcost * costhome * 0.8}];

In[37]:= yrsminmoney = Transpose[{years, ev * avgmile * mincostoutside * 0.2}];

In[38]:= yrsmaxmoney = Transpose[{years, ev * avgmile * maxcostoutside * 0.2}];

In[39]:= plot3 =
           ListPlot[yrsvscosthome, AxesLabel → {"Years", "Estimated Charging Cost"},
            ImageSize → Large, PlotStyle → Blue, PlotLabel → "Charging Cost VS Year",
            PlotLegends → {"Cost of Charge At Home", "None"}];

In[40]:= plot4 = ListPlot[yrsminmoney, ImageSize → Large,
            PlotLabel → "Min Charging Cost Outside VS Year", PlotStyle → Red,
            PlotLegends → {"Min Cost of Charge At Outside", "None"}];

In[41]:= plot5 = ListPlot[yrsmaxmoney, ImageSize → Large,
            PlotLabel → "Max Charging Cost Outside VS Year", PlotStyle → Green,
            PlotLegends → {"Max Cost of Charge At Outside", "None"}];

In[42]:= energyvscosthome = Transpose[{years, ev * avgmile * avgcost * 0.8}];

In[43]:= energycostoutside = Transpose[{years, ev * avgmile * avgcost * 0.2}];
```

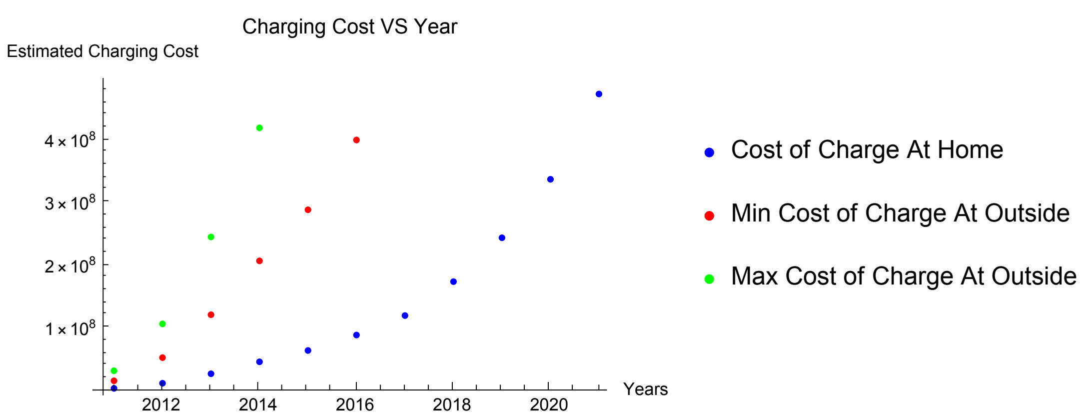
```
In[44]:= plot6 =
  ListPlot[energyvscosthome, AxesLabel → {"Years", "Energy Used(kWh)"},
   ImageSize → Large, PlotStyle → Blue, PlotLabel → "Energy Used vs Year",
   PlotLegends → {"Amount of Energy Charged At Home", "None"}];

In[45]:= plot7 =
  ListPlot[energycostoutside, AxesLabel → {"Years", "Energy Used(kWh)"},
   ImageSize → Large, PlotStyle → Red, PlotLabel → "Energy Used vs Year",
   PlotLegends → {"Amount of Energy Charged Outside", "None"}];

In[46]:= Show[plot6, plot7]
```

Out[46]=




```
In[47]:= Show[plot3, plot4, plot5]
```

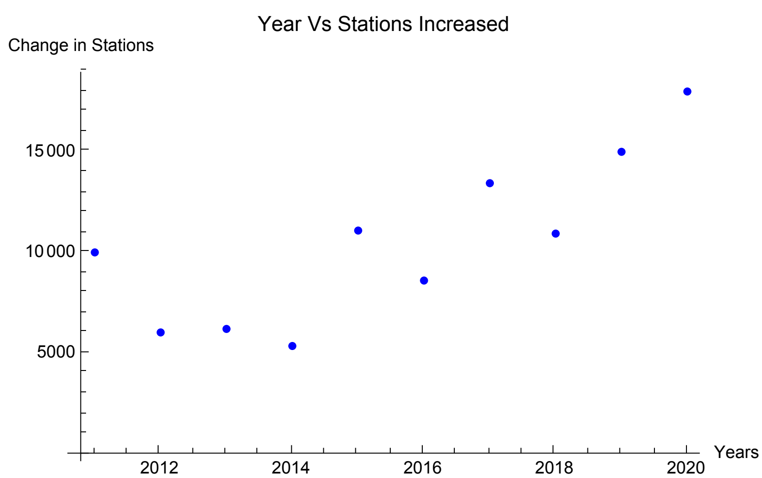
Out[47]=



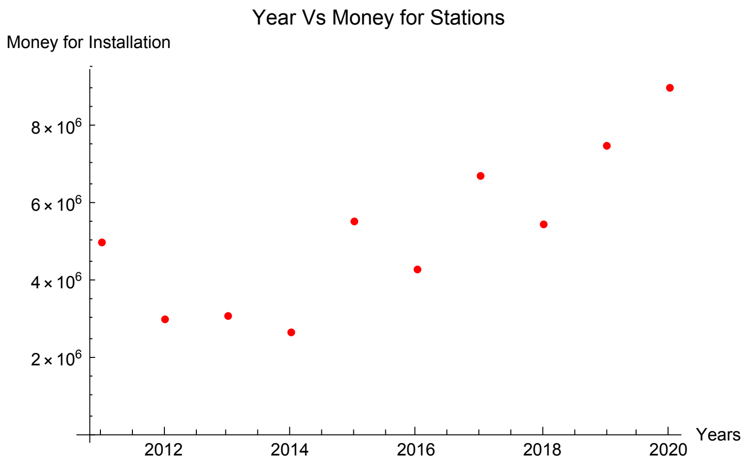

```
In[48]:= list2 = evstations[[2 ;; Length[evstations]]]
Out[48]= {13 392, 19 410, 25 602, 30 945, 42 029, 50 627, 64 067, 75 000, 90 000, 108 000}

In[49]:= list2 = Append[list2, placeholder]
Out[49]= {13 392, 19 410, 25 602, 30 945, 42 029,
  50 627, 64 067, 75 000, 90 000, 108 000, placeholder}

In[50]:= list3 = list2 - evstations;
```

```
In[51]:= list3 = list3[[1 ;; Length[list3] - 1]]
Out[51]= {9998, 6018, 6192, 5343, 11 084, 8598, 13 440, 10 933, 15 000, 18 000}

In[52]:= list4 = years[[1 ;; Length[years] - 1]]
Out[52]= {2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020}

In[53]:= increasestations = Transpose[{list4, list3}]
Out[53]= {{2011, 9998}, {2012, 6018}, {2013, 6192}, {2014, 5343}, {2015, 11 084},
          {2016, 8598}, {2017, 13 440}, {2018, 10 933}, {2019, 15 000}, {2020, 18 000}}

In[54]:= increasestationmoney = Transpose[{list4, list3 * 500}]
Out[54]= {{2011, 4 999 000}, {2012, 3 009 000}, {2013, 3 096 000},
          {2014, 2 671 500}, {2015, 5 542 000}, {2016, 4 299 000},
          {2017, 6 720 000}, {2018, 5 466 500}, {2019, 7 500 000}, {2020, 9 000 000}}

In[55]:= plot8 = ListPlot[increasestations,
           AxesLabel → {"Years", "Change in Stations"}, ImageSize → Large,
           PlotStyle → Blue, PlotLabel → "Year Vs Stations Increased"];

In[56]:= plot9 = ListPlot[increasestationmoney,
           AxesLabel → {"Years", "Money for Installation"}, ImageSize → Large,
           PlotStyle → Red, PlotLabel → "Year Vs Money for Stations"];

In[57]:= Show[plot8]
```

Out[57]=



In[58]:= Show[plot9]

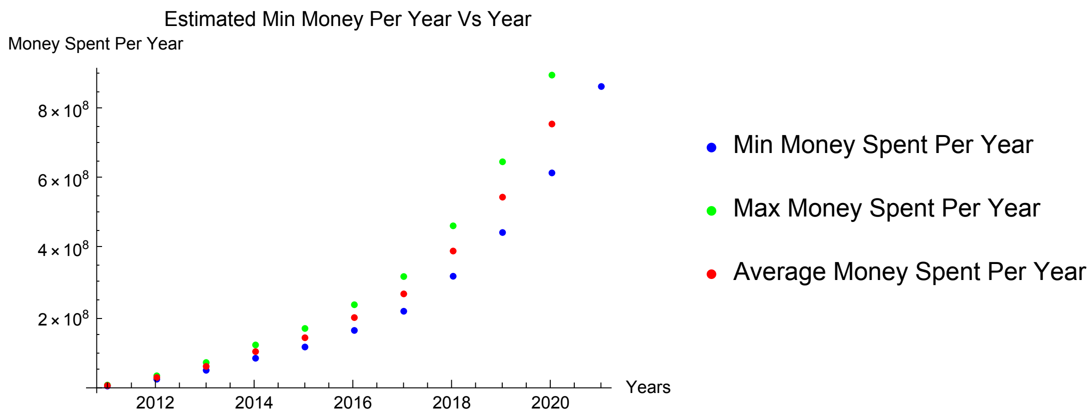
Out[58]=


Therefore, total amount of money for every year (cost of installations of new stations and cost of fuel for all cars in USA) will be as follows

```
In[59]:= list5 = ev[[2 ;; Length[ev]]];

In[60]:= list6 =
   list5 * avgmile * avgcost * (costhome * 0.8 + mincostoutside * 0.2) + list3 * 500;

In[61]:= moneywithmin = Insert[list6,
    22161 * avgmile * avgcost * (costhome * 0.8 + mincostoutside * 0.2), 1];

In[62]:= yrsvsmoneywithmin = Transpose[{years, moneywithmin}];

In[63]:= list7 =
   list5 * avgmile * avgcost * (costhome * 0.8 + maxcostoutside * 0.2) + list3 * 500;

In[64]:= moneywithmax = Insert[list7,
    22161 * avgmile * avgcost * (costhome * 0.8 + maxcostoutside * 0.2), 1];

In[65]:= yrsvsmoneywithmax = Transpose[{years, moneywithmax}];

In[66]:= list8 =
   list5 * avgmile * avgcost * (costhome * 0.8 + avgcostoutside * 0.2) + list3 * 500;

In[67]:= moneywithavg = Insert[list8,
    22161 * avgmile * avgcost * (costhome * 0.8 + avgcostoutside * 0.2), 1];

In[68]:= yravgmoneywithavg = Transpose[{years, moneywithavg}];

In[69]:= plot10 = ListPlot[yrsvsmoneywithmin,
    AxesLabel → {"Years", "Money Spent Per Year"}, ImageSize → Large,
    PlotStyle → Blue, PlotLabel → "Estimated Min Money Per Year Vs Year",
    PlotLegends → {"Min Money Spent Per Year", "None"}];
```

```
In[70]:= plot11 = ListPlot[yrsvsmoneywithmax,
    AxesLabel → {"Years", "Max Money Spent Per Year"}, ImageSize → Large,
    PlotStyle → Green, PlotLabel → "Estimated Max Money Per Year Vs Year",
    PlotLegends → {"Max Money Spent Per Year", "None"}];

In[71]:= plot12 = ListPlot[yravgmoneywithavg,
    AxesLabel → {"Years", "Average Money Spent Per Year"},
    ImageSize → Large, PlotStyle → Red,
    PlotLabel → "Estimated Average Money Per Year Vs Year",
    PlotLegends → {"Average Money Spent Per Year", "None"}];

In[72]:= Show[plot10, plot11, plot12]
```

Out[72]=




```
In[73]:= yravgmoneywithavg
```

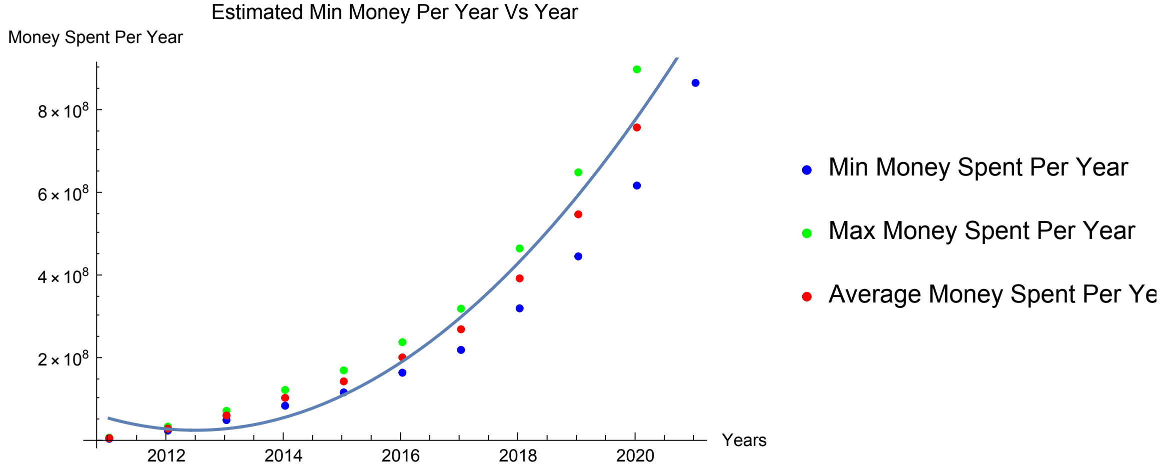
Out[73]= $\{\{2011, 7.68278 \times 10^6\}, \{2012, 3.09196 \times 10^7\}, \{2013, 6.27333 \times 10^7\}, \{2014, 1.05267 \times 10^8\}, \{2015, 1.45092 \times 10^8\}, \{2016, 2.02951 \times 10^8\}, \{2017, 2.70981 \times 10^8\}, \{2018, 3.94046 \times 10^8\}, \{2019, 5.48799 \times 10^8\}, \{2020, 7.5884 \times 10^8\}, \{2021, 1.06369 \times 10^9\}\}$

```
In[74]:= yrsvsmoneywithmaxeq = Fit[yravgmoneywithavg, {1, x, x^2}, x]
```

Out[74]= $5.39414 \times 10^{13} - 5.36072 \times 10^{10}\, x + 1.33188 \times 10^7\, x^2$

```
In[75]:=

In[76]:= plotf = Plot[yrsvsmoneywithmaxeq, {x, 2011, 2021}];
```

In[77]:=
```
Show[plot10, plot11, plot12, plotf]
```

Out[77]=


In[78]:=
```
list9 = list5 * avgmile * avgcost * avgcostoutside * 0.2 + list3 * 500;
```

In[79]:=
```
moneywithavg2 =
  Insert[list9, 22 161 * avgmile * avgcost * avgcostoutside * 0.2, 1];
```

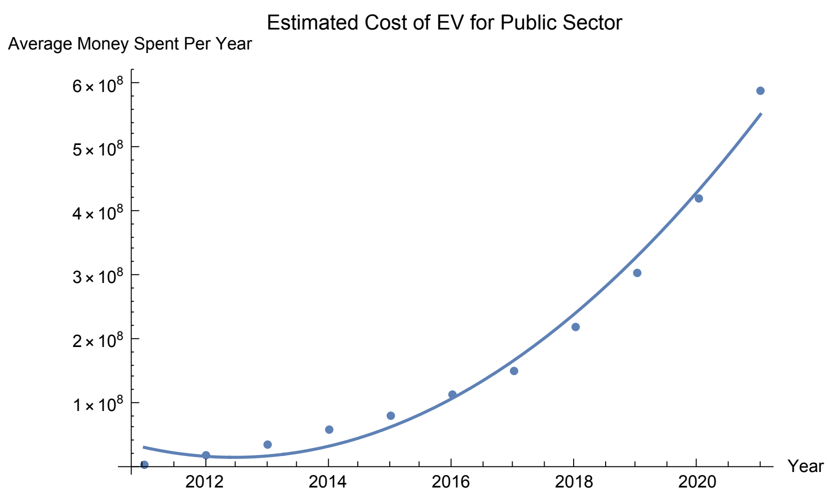
In[80]:=
```
yrvsmoneywithaverage2 = Transpose[{years, moneywithavg2}];
```

In[81]:=
```
moneywithavg2plot = ListPlot[yrvsmoneywithaverage2,
   AxesLabel → {"Year", "Average Money Spent Per Year"}, ImageSize → Large,
   PlotLabel → "Estimated Cost of EV for Public Sector"];
```

In[82]:=
```
yrsvsmoneywithmaxeq2 = Fit[yrvsmoneywithaverage2, {1, x, x^2}, x];
```

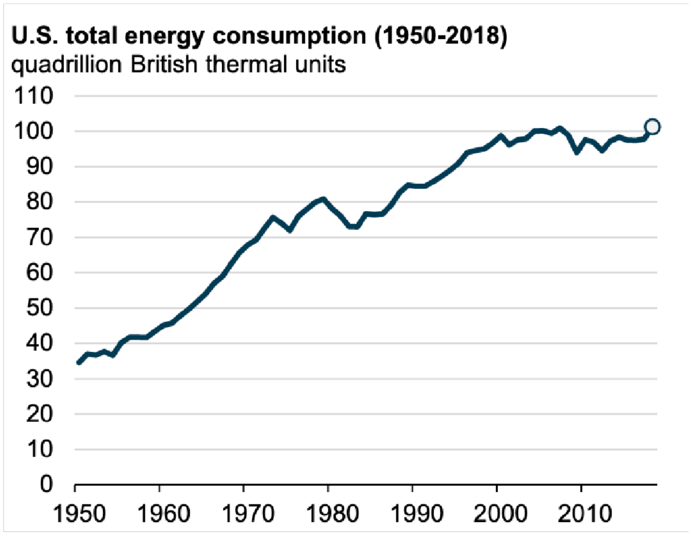
In[83]:=
```
plotf2 = Plot[yrsvsmoneywithmaxeq2, {x, 2011, 2021}];
```

In[84]:=
```
Show[moneywithavg2plot, plotf2]
```

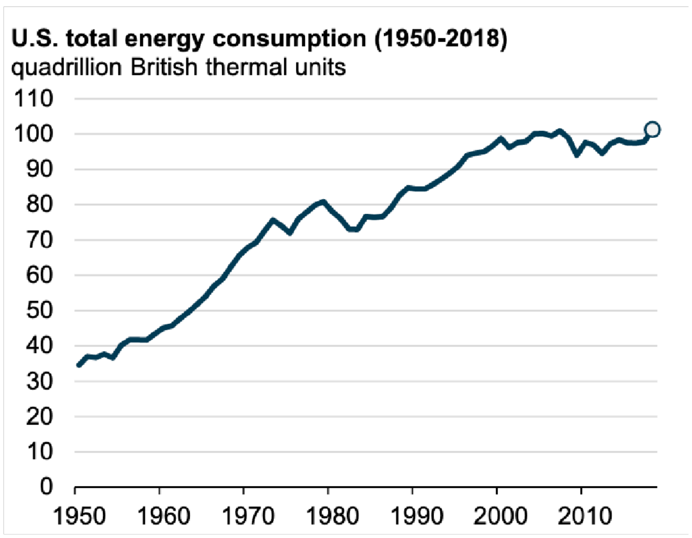
Out[84]=


Appendix B: Total Energy Usage (in the Wolfram Mathematica Language)

In[85]:=



Out[85]=



In[86]:=

Graphic from the U.S. Energy Information Administration

Total energy consumption in the US in 2017:

In[87]:=
```
ResConsumption = 1378.6;
(*Terawatt hours used by residential consumers in 2017*)
```

In[88]:=
```
ComConsumption = 1352.9 ;
(*Terawatt hours used by commercial consumers in 2017*)
```

```
In[89]:= IndConsumption = 984.3;
         (*Terawatt hours used by industrial consumers in 2017*)

In[90]:= TransConsumption = 7.52;
         (*Terawatt hours used by transportation consumers in 2017*)

In[91]:= totalLoss = 367.2; (*Total terawatt hours of electricity lost*)

In[92]:= totalEnergy = ResConsumption + ComConsumption +
           IndConsumption + TransConsumption + totalLoss

Out[92]= 4090.52

In[93]:= ResCost = 0.133;
         (*Cost of one kilowatt-hour of electricity for residential consumers*)

In[94]:= ComCost = 0.11;
         (*Cost of one kilowatt-hour of electricity for commercial consumers*)

In[95]:= IndCost = 0.0744;
         (*Cost of one kilowatt-hour of electricity for industrial consumers*)

In[96]:= TransCost = 0.975;
         (*Cost of one kilowatt-hour of electricity for transportation consumers*)

In[97]:= ResSpending = ResConsumption * ResCost *
           10^9 (*Total amount of money spent by residential consumers in 2017
             (Consumption * cost * conversion factor from terawatt-
               hours to kilowatt-hours) *)

Out[97]= 1.83354 × 10^11

In[98]:= ComSpending = ComConsumption * ComCost *
           10^9 (*Total amount of money spent by commercial consumers in 2017
             (Consumption * cost * conversion factor from terawatt-
               hours to kilowatt-hours) *)

Out[98]= 1.48819 × 10^11

In[99]:= IndSpending = IndConsumption * IndCost *
           10^9 (*Total amount of money spent by industrial consumers in 2017
             (Consumption * cost * conversion factor from terawatt-
               hours to kilowatt-hours) *)

Out[99]= 7.32319 × 10^10

In[100]:= TransSpending = TransConsumption * TransCost *
            10^9 (*Total amount of money spent by transportation consumers in 2017
              (Consumption * cost * conversion factor from terawatt-
                hours to kilowatt-hours) *)

Out[100]= 7.332 × 10^9
```

```
In[101]:= TotalSpending = ResSpending + ComSpending + IndSpending + TransSpending
Out[101]= 4.12737 × 10^11
```

Total Energy Consumption in the US in 2008:

```
In[102]:= Generation2008 = 4119.388
           (*Total energy generated in 2008 (in terawatt hours) *)
Out[102]= 4119.39

In[103]:= NetExports2008 = N[(24 083 - 57 021) / 1000 (*terawatt hours*)]
Out[103]= -32.938

In[104]:= Total2008 = (Generation2008 - NetExports2008) (*includes consumer,
           transportation, industrial, commercial, and lost energy*)
Out[104]= 4152.33

In[105]:= (* This value is very similar to the total energy consumed in 2017,
          and is actually a bit higher than that value,
          which supports the observation that US energy consumption
           has had very negligible change over recent years *)
```

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