Team 9539, Problem A: Charge!

Summary

As technology becomes more prominent worldwide, public spaces like malls, schools, and airports have begun to combat the increasing need for energy with public charging stations for a variety of devices. These vary from the ever-present smartphone to the newly-reemerging electric car. The task at hand was to identify the ramifications of this increased demand for energy, develop a model for the resulting costs of public energy consumption using these ramifications, and determine how costs could be lessened.

Impacts for increased demand in public energy begin first with accessibility. As demand increases, public energy became more available as more buildings began to provide it. Therefore, public areas have to provide as much accessibility as possible in order to avoid being passed up for the shop, restaurant, or station with more charging areas. It also had to be cost-effective, or else the financial impact of increasing public energy consumption at the given establishment would be detrimental instead of beneficial.

To solve this problem, a simulation was used to find the energy one device uses per one person outside of the house every day via an algorithm implemented in a Python program. The algorithm was written originally for phones exclusively. After this, it was modified to fit in components involving both electric cars and laptops. Next, component to run this program for a certain number of people in order to represent the number of visitors of an establishment charging their devices in that establishment per day was added. Using this data, the program was tweaked again to calculate the amount this would cost the company that owns the charging station. This way, the algorithm becomes more flexible for different areas and establishments and allows for easy access to financial data regarding energy usage by customers.

After this, possible initiatives were investigated to reduce the cost of these charging stations. The main goal was to either reduce the cost of the energy itself or find a means by which the company can profit off of the energy consumption. Two solutions became apparent: implementation of renewable energy and charging fees for charging station use. Both of these solutions address one of the goals and could be enacted either individually or at the same time.

Article

A Look into the Future of Charging Phones and Laptops in Public Places such as Coffee Shops

Over the years, our world has been increasingly connected to the digital world. As our reliance on our electronic devices has risen, so has the amount of power needed to charge them. With technology being more and more widespread, there has also been a surge of power outlets in public places to charge these devices. These power outlets, though seemingly insignificant, give whoever uses them the power to utilise all the benefits of the internet and technology, and thus help better themselves and the world. Public spaces constricted by their geographical location now have the ability to help people collaborate across continents.

However, though the energy that customers can take from the power outlets are free to them, the owners of the building will still have to pay something. Even though the cost of charging a phone for a year is $0.12, if tens of thousands of people come to a building each day, and charge their devices, the electrical cost can add up quickly. In order to ensure that this utility is provided to the people who rely on it for internet access, it would be beneficial for all involved if the energy cost of charging stations could be brought down. This can be done multiple ways, but two main ones come to mind: first, the cost per kWh could be reduced by changing the energy from conventional energy to renewable energy, such as solar panels, or users could pay a small fee in order to access the charging stations.

The first solution, changing the type of energy used, is a complicated process. The cost of installing solar panels is immense, and the return on this investment doesn't break even until a few years after the solar panels are installed. However, over a long period of time, the cost per kWh is much less than the $0.12 per kWh commercially provided.

An infographic detailing the annual cost of energy per year, for the average phone, computer, and car, respectively.

The second one seems unnerving at first. After all, if users have to pay in order to get energy, wouldn't this be restricting the use of the internet for those who would benefit from this the most, the people who can't afford to charge their devices? However, given the extremely low cost of energy in general, it wouldn't need to be a large sum. In fact, a single cent per hour of charging would be more than sufficient; this would actually result in a profit for the building. Additionally, $0.01 is a small enough sum that most everybody can pay for it. It wouldn't bar anybody out of perhaps their only source of energy, and keeps the charging outlet operational for many more years to come.

All the same, the very idea of charging people for the ability to access the internet violates the idea for which these outlets were installed for in the first place. Even if they weren't installed for lofty, idealistic reasons, the very fact that one can plug in their laptop while sipping on a cup of coffee gives people incentive to buy that coffee in the first place. It only takes $0.24 to power a phone for a year[1]. Even if there are a considerably large number of customers coming to the building, this shouldn't deter the owners from providing this utility, as the electrical bill would not be that high, compared to the profit made off of the customers if they were to actually buy something.

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Introduction

In recent years, the increasing popularity of various technologies has also meant a new necessity for energy. Cell phone sales have skyrocketed, with smartphones alone pulling in 1.556 billion sales in 2018[5]. Other devices, like laptops and electric cars, have also become popular. This surge in everyday technology has had significant effects on everyday life: the smartphone alone has encouraged worldwide communication in daily life on top of providing millions of people with an immeasurable number of resources in the palm of their hand. The sudden newfound convenience of education and communication means that technology as we know it has become essential to society, and, in turn, accessibility at all possible times is a must. As a result, many places worldwide have taken the initiative and begun to provide visitors with public charging stations. For the people, this means free charging and more constant accessibility. But what does this mean for the places providing public energy? If a store, school, or gas station has to use up more energy, how does this change the cost for the establishment, and how can the new cost get paid?

To answer these questions, an algorithm was used for the cost of the energy one person uses outside of the house in one day. This was then simulated using a Python program that was able to implement the algorithm for many people at once. Then the program was implemented for a large group of people at once, using the average visitors for a particular area and percentage of people who own a cell phone. This way, the cost of energy for the particular area could be simulated for multiple days. The algorithm was also modified to work for laptops and electric vehicles so that one or multiple of these costs can be calculated at once.

After looking at the costs for each place, the next step was reducing energy bills by either reducing the cost of energy itself with renewable energy or profiting off of the energy use with charge fees. The former solution prevents more fees for visitors, but is more difficult to implement because the transfer to renewable energy is complicated for large buildings and also not cheap. Since no revenue is coming from the stations, that means that the buildings themselves would have to pick up the slack. The latter solution would deter some visitors to other areas that may still have free charging stations, but would create a new source of revenue for the establishment.

Problem Statement

As increase in demand for technology continues, so does increase in demand for energy. As such, public areas have begun to include public charging areas for various devices to help alleviate this demand. This means that public areas have to pay for more energy as visitors plug in their devices throughout the day. The task is to create a model with which the cost of the new usage created by these public chargers can be identified and then to develop ways that this cost could be lessened for the places that provide these charging stations.

Assumptions

Assumption 1: People are out of the house on work days for ten hours, and on off days people are out for up to ten hours.
Reasoning: The average work day for a person who works five days per week is eight hours per day, thus meeting the maximum of forty hours per week before overtime. However, people don't necessarily go straight home after work every day. They still need time to run errands or participate in leisure activities outside the house. On off days, people spend more time on leisure or other important non-work matters, and as such may either stay at home or go out for the day.

Assumption 2: People have two days off per week.
Reasoning: The average work week is eight hours a day for five days, which meets the maximum of forty hours before overtime.

Assumption 3: People do not go home to charge their pones before the allotted time period ends.
Reasoning: Most people will not go out of their way to go home and charge their devices when there is a charging area readily available. While not everyone carries a charger on them, many places offer wires to plug into as well as free energy.

Assumption 4: The person in question leaves the house at 100% charge for whatever device they have (with the exception of electric cars).
Reasoning: Many people will charge their devices overnight so as to avoid dead phones, laptops, and other things in the morning. This means that when they leave the house for work or school, they will end up with extremely close to, if not exactly, 100% charge.

Assumption 5: The person in question charges their phone at 20% or below and charges to 100% (with the exception of electric cars).
Reasoning: Most people will begin to worry about battery life at 20% or less. Many people will also stick around or leave their devices to charge long enough to reach 100% so they don't have to worry about recharging their device again during the day.

Assumption 6: Any person with an electric car does not have a personal charging station.
Reasoning: Installing a charging station efficient enough to charge the car in a reasonable time is expensive. Since some electric car charging stations are free to use, it's possible that the car

owner would not be interested in the installation. This overestimates the cost of charging, which means that more money is expected to be used than will actually be used, but that also means that the place that operates the chargers will be fully equipped to pay more fees than would be expected otherwise.

Assumption 7: The only devices necessary to investigate are phones, laptops, and electric cars.
Reasoning: Cell phones are essential to everyday life as of recent years, and so it would be a catastrophic mistake to exclude them from the model. While laptops are now required to compete with tablets, they are still more common than tablets, and both have similar features. Electric cars are not as common as either of the aforementioned devices, but they are a highly common high-energy devices available to the public and therefore can represent another end of the spectrum from the low-energy cell phones and laptops.

Assumption 8: All people referred to in this model either have full-time jobs or are enrolled in school for five days a week.
Reasoning: Most adults work full-time in order to support themselves. Even if they don't, many are still in college or other alternative schools so that they will later be able to support themselves. If they didn't have a source of income, they would have find someone else to rely on, which isn't often possible.

Assumption 9: All people referred to in this model are adults.
Reasoning: While children are intense users of modern technology, adults are more likely to be working full time as the model requires, and they are more likely to have access to public places without reliance on another adult.

Assumption 10: People unplug their devices immediately after their phone reaches 100%.
Reasoning: Oftentimes, in a public area, the person charging their device will unplug their laptop at a satisfactory charge for various reasons: the ability to sit or stand in a more comfortable position, worry about battery decay, or simply time constraints and a need to leave.

Assumption 11: People driving electric cars only own one electric car.
Reasoning: There are only about 1.2 million electric cars on the road [7], and electric cars are often high in price. Assuming a large amount of people own multiple electric cars would minimally effect the percentage of people owning an electric car, and while that means the percentage given (1.2 million / 327.2 million people in the United States = 0.0037) will be larger than the actual, that means that the company in question will be better equipped for variations in energy consumption from electric cars because even if there is a period of above-average consumption, the money needed to pay off the bill will be more robustly prepared.

Model

1. Discussing Development and Identifying Ramifications

Before a model can be developed, the goals of the model must be identified. This was done by looking at the development of public and electronic energy consumption from phones, laptops, and electric cars over the years.

The oldest of these three, electric cars, were first introduced in the 1830s, but lost popularity until the late 1900s and early 2000 s[14]. Energy consumption by electric cars has gotten more and more efficient since their resurgence, but they still take up much more energy than other commonplace devices; while mobile devices tend to use less than 100 wh (watt hours), newer electric cars like the 2017 Nissan Leaf use 30 kwh (kilowatt hours) per 100 miles, coming out to 0.3 kwh (300 wh) per mile[6]. Nevertheless, the new gains in popularity also mean new charging stations. Such stations can be found at gas stations and in some parking lots.

Next came the laptop, which was first released to the public in 1981[16]. Since then, laptops have also become more efficient, with some coming in at between 50 and 100 wh of battery life. However, unlike cars and phones, which are generally used whenever available, laptops are nowadays mostly used for work, school, and some hobbies like writing and digital art.

The youngest and most prominent of the three devices are cell phones, which were first introduced to the public in 1983. No one can deny the cell phones have become a staple of everyday life around the world; every year brings on a slew of new phones with the latest of technologies to make them faster and more efficient. In recent years, phones have been made to hold around 5.45 watt hours and charge on similarly-powered 5 watt chargers[8][4].

As technology becomes more popular, the demand for constant accessibility also goes up. If opportunities to charge devices aren't available in public, it lessens the appeal of those same places to the public as charging in public becomes inconvenient. Why get a coffee from that shop when you can get one from another around the corner where you can plug in your phone or your laptop while you drink? Nowadays, everything is about convenience, and that means that public charging is a must if places want to stay relevant.

However, the cost of adding used energy to the bills must also even out for the new addition of charging stations to make sense. For some places, this isn't a big deal; with the cost of one kilowatt hour only being an average of twelve cents, it shouldn't have a significant impact on profits. However, in cases like electric cars, a larger amount of energy is used, and therefore something has to even out the new and substantial costs.

2. Process: Model

2.1 Goals of Model

Develop a model which can:

1. Determine the energy usage of one person using a given device (phone, laptop, or electric car);
2. Be easily modified to function from device to device (i.e. minor modifications to phone model for a laptop model);
3. Account for variations in time spent out of the house, time spent on the device, etc.;
4. Determine the costs of a person’s device usage over a given period of time;
5. Do the above for varying numbers of people to represent the different amounts of people that visit different places.

2.2 Parameters

Variables: Cell Phones

P_W	P_E	H_W[11]	H_E	T_{min}[11]
Public Charges Per Person Per Work Day	Public Charges Per Person Per Off Day	Phone Pickups Per Work Day (20 – 40)	Public Phone Pickups Per Off Day (0 – 24)	Minimum Time Spen on Phone Per Pickup Minutes

T_{mid}[11]	T_{max}[11]	B	B_C	T_E
Middle Time Spent on Phone Per Pickup, Minutes	Maximum Time Spent on Phone Per Pickup, Minutes	Battery Life, Hours (3.58 – 4.51)	Battery Used at Charge (0.8 – 1.00)	Time Spent in Public per Off Day, Hours (4 – 10)

Constants: Cell Phones*

S_{min}[11]	S_{med}[11]	S_{max}[11]	H_{Wavg}[11]	W[8]
Percentage of Minimum Time (70)	Percentage of Mid Time (25)	Percentage of Maximum Time (5)	Average Phone Pickups Per Work Day (30)	Watts (5.45)

Variables: Laptops

W[8]
Watts (50 – 100)

Constants: Laptops

T[12]
Average Time Spent Per Day, Hours (2.21)

Variables: Cars

M	K
Miles Driven Per Day (27 – 47)	Kilowatt Hours Per Miles (0.24 – 0.44)

Constants: Cars

C	M_Y
Number of Charging Stations (20, 021)	Average Miles Driven Per Year (13, 476)

Other Variables

V	E_W	E_E	E_T	C
Number of Visitors	Energy Usage Per Work Day For Given Device	Energy Usage Per Off Day For Given Device	Total Energy Usage Per Week For Given Device	Total Cost Per Year For Given Device

K_T	C_D	C_T	Y
Total Kilowatts Used by Devices	Cost Per Day For Given Device	Total Cost Per Person Per Year For Given Device	Years

Other Constants

C_K [10]
Cost Per Kilowatt Hour (0.12)

*NOTE: Since data was found during research pertaining to phone pickups on workdays only, workday pickups is a constant and weekday constant varies based on other calculations.

Laptop Variables

**Variables repeated or shared among devices will be subscripted with the initial letter of the device in future references.

2.3 Model Summary

The task was using a model to estimate the annual cost of energy used to charge electronic devices. The main focus was solely on phones, laptops, and electric cars, since the former two are often in everyday use and the latter is gaining traction and takes up more energy. In order to make this model more precise, it includes several randomized variables, such as the time it takes a person to look at their phone once in a day, or the kWh used by a car per hour. This helps to better simulate real world conditions, because the variables wouldn't be a single perfect number, but rather a number from an array of possible ones. To create more of a variation among data sets, the program randomizes variables based on the ranges given in Section 2.2. Thus, the program can account for multiple devices and days, while accounting for variations from person to person.

After this model was completed, possible initiatives to reduce energy costs were considered. Two solutions became apparent. The first was to switch to renewable energy. Switching to energies like solar power could reduce the cost of energy so that the companies paying for it weren't spending as much without getting anything back. However, the cost of switching itself would be expensive, and since there is no additional revenue, the place that holds the charging station would have to make additional money on top of whatever it already gets in order to keep the same profits and pay off the installation fees. However, once the installation was paid off, the solar panels would only require additional costs for maintenance, and the energy itself doesn't cost anything. The second solution would be charging small fees for visitors to charge their phones. The main issue with this solution is that it would deter customers from using the charging stations, and if there's another place nearby with free chargers, they may go there instead. However, fees as little as $0.01 per hour would make considerable profits for the company with the charging stations .

2.4 Phone Costs

The first part of the model deals with looking at the average cell phone usage, in minutes, over the course of a day. The model was based on the assumption that a work day was 10 hours long, and data that says people pick up their phone approximately 30 times a day on average. Of these 30 times, the average person would use it for less than 2 minutes for 70% of the time, they would use it for less than 10 minutes 25% of the time, and 5 % of the time, they would use it for more than 10 minutes [11]. We made a function that uses Python to model P, the number of times a phone must be charged in public, based on these factors and the average battery life of a phone.

In order to get P, the model uses the total number of minutes that the average person uses a phone per day divided this by the time it takes a phone to decay, around 3.58 to 4.51 hours (CITE!!!!!). P was split into two parts: the five work days and two off days of the average work week. These two sections require minor modifications in order to be accurate.

The number of charges on a work day was dependent on the number and duration of phone pickups during work. The total number of minutes divided by the battery Based on the information given, the equation for charge number per work day P_W is as follows:

$$P_W = \frac{H_w\left(\left(S_{max} * T_{min}\right) + \left(S_{med} * T_{med}\right) + \left(S_{min} * T_{max}\right)\right)}{B * 60};$$

Multiplying P_W by the watts a phone can hold, W, returns E_W, the energy usage per work day. Multiplying this by 5 gives the total energy used per work week.

The number of charges on an off day is slightly different. Instead of using an average for a given time period, the number of average phone pickups can be multiplied by the percentage of the day a person spends out of the house based on T_E. This means that instead of the equation above, P_E is represented by:

$$P_E = \frac{\left(\frac{T_E}{24} * 58\right)\left(\left(S_{max} * T_{min}\right) + \left(S_{med} * T_{med}\right) + \left(S_{min} * T_{max}\right)\right)}{B * 60};$$

Multiplying P_E by W returns E_W. Multiplying this by 2 gives the total energy use per days per week.

Adding P_W and P_E gives the total weekly energy consumption per week, E_T. Multiplying this by C_K gives the value for cost per week of energy consumption for one person, then multiplied by 52 weeks to get cost per year for that same person, C_{TP}. A sample simulated table of values is provided below.

2.5 Laptop Costs

In order to find the total cost of computer usage for the building, we first looked at what the annual cost for charging a computer would be. In order to find this, the model uses the energy used per hour (W), the average number of hours spent on a computer per day (T, 2.21 hours), and the cost of kWh (C_K, \$0.12). This became:

$$C_{TL} = W \cdot \frac{1\text{ kWh}}{1000\text{ Wh}} \cdot T \cdot \frac{7\text{ days}}{1\text{ week}} \cdot C_K;$$

This therefore represents the total cost of powering one laptop for one week. Repeating this process for the number of weeks per year will create an estimate for the total cost of laptop charging for one person per year. A sample table of simulated values is provided below.

2.6 Car Costs

The model for car usage was created much in the same way that the computer usage model was; in order to find the total cost of electrical car charging for the business, first the annual cost for charging an electric car would be must be found. This was done by using the kWh a car uses each mile (K), the miles (M), and the cost of kWh (C_K).

$$C_{TC} = K \cdot M \cdot \frac{7\text{ days}}{1\text{ week}} \cdot C_K;$$

This part of the model was expanded upon in our code, which calculates the average cost per week based on the above equation. A sample simulated table of values is provided below.

2.7 Overall Model

Putting these together for varying locations gets the public energy costs per person per day for the area in question. Costs can simply be added together when multiple devices are commonly used. This also takes into account the different technological habits of different people.

3. Process: Variation

One problem was that the model needed to accommodate different types of places with different numbers of people. To solve this problem, a visitor number (V) was added to the model. For each person, the algorithm is repeated, and costs are added together to get a total yearly cost based upon average visitation and charging station usage. The new addition also takes into account the people who do not own the given device, so that an area where all devices are commonly used looks as follows:

$$C = C_{TPtot} + C_{TLtot} + C_{TCtot};$$

where each total represents multiple run-throughs of each part of the algorithm. The number of run-throughs for each segment is represented by 0.81V, 0.73V, and 0.0037V respectively, where V is the number of visitors and it is multiplied by the percentage of each . The equations for these devices can also be combined so that costs are added together for places where multiple types of devices are commonly charged, like coffee shops or libraries. In this way, changes in visitors can be accounted for, and so can commonly charged device types for the establishment.

3.1 Example A: Airports

The model took various rates of foot traffic for different places into account. Multiple constants were found by calculating the ratio of visitors per week. The ratio for airports was found to be approximately 782.85, given 798,230,000 US passengers in 2015 [13] and 19,536 airports in 2016 [15]. Therefore, for the average airport, V = 783 people.

Typically, airports are not considered to be a location that owns electric car chargers, but many people charge phones and laptops for entertainment or work purposes before getting on the plane. This means that the two primary focuses of an airport algorithm are phones and laptops, and therefore

$$C = C_{TPtot} + C_{TLtot};$$

where each section is repeated 683 times and 572 times respectively.This means that the program will simulate the energy usage of 783 people, including people who do not own phones or laptops, people who own one, or people that own both.

3.2 Example B: Libraries

The ratio of visitors per week for libraries was found to be approximately 3174, given 1.5 billion library visits in 2011[2] and 9,057 public libraries in 2019[10].

Libraries are commonly used as places of study for students and quiet places to work for people with jobs. However, very few, if any, are large enough to necessitate electric car charging stations. Therefore, phones and laptops are the most significant data sets, and the equation is

$$C = C_{TPtot} + C_{TLtot}$$

where each section is repeated 2,571 times and 2,317 times respectively. This conducts the same calculations as Example A with a variation in V.

3.3 Example C: Coffee Shops

The ratio of visitors per week for coffee shops, using data for 60 million customers visiting 18,000 Starbucks stores[3] as a model, was about 3,333.

Coffee shops like Starbucks are commonly used by students as a laid-back study space, which means that, like libraries, they also use phones and laptops. Therefore, it uses the same equation as examples A and B, but V = 3,333 and each section is repeated 2,700 times and 2,433 times respectively.

3.4 Example D: Gas Stations

The visitors per week at a gas station is approximately 7,700 people (CITE).

Gas stations are most prominently used to fill up cars and get back on the road as soon as possible. Most gas stations do not see many people charging their phones or laptops as well, so the gas station algorithm is

$$C = C_{TCtot};$$

where V = 7,700 and the one section is repeated 28 times.

4. Reducing Costs

Another goal presented by the problem was enacting initiatives to reduce costs in areas that include public charging spaces. Based on the model, this goal was split into two variations: either reduce the cost of the energy itself or find a means by which the establishment running the charging stations can make an additional profit to pay off the costs. This ultimately resulted in two different solutions, each of which addresses one of the two versions of the goal.

4.1 Solar Power

One option is to convert to renewable energies like solar power. Having solar power eliminates the cost of energy entirely, since the energy would be generated directly from solar panels. However, there is a new cost that appears instead: installation fees.

In order to gain access to solar energy, the establishment in question would need to install enough solar panels to power the building. That means that they would have to buy several solar panels. The equation for solar installation fees is

$$C_{TS} = 2093\ (K_{TR})$$

where K_{TR} is the total number of kilowatts rounded upward.This equation was found by developing a fit function from research data.

In order to determine the worth of this solution, it must be determined when the savings from the lack of energy fees will pay off the installation fees. If it is within a reasonable amount of time, then it will be worth it; however, if it is a timespan of more than five years, that digs excessively into the profits of the business. To find this, we subtracted the total cost of solar energy from the total cost of regular energy to find the energy saved. The cost of regular energy begins lower than the cost of solar energy because solar panels are sold based on set kilowatt hours, and it is unlikely that a building uses a whole number amount of kilowatts. Because of this, the amount of saved money will start out negative. To find the time it takes a building to break even, the point at which saved money totals to zero must be found, so

$$\left(C_K * K_T * Y * 365 * 24\right) - \left(2093\ (K_T)\right) = 0 \to C_K * K_T * Y * 365 * 24 = 2093\ (K_T) \to Y = \frac{2093}{C_K * 365 * 24}$$

Solving for Y results in a break-even point of 1.99 years, and therefore converting to solar energy would be worth the installation cost.

4.2 Pay-to-Charge

The second option was adding a small fee to the charging stations in order to create a source of profit to pay for the costs of the charging stations. The problem with this solution is that the new addition of cost may deter visitors from using the charging stations and also might encourage them to go to another place if someplace nearby still provides free charging. However, the cost itself can be extremely minimal due to the cost of energy. This solution was designed based upon the fact that some electric car charging stations already charge by time, and therefore the solution does not include electric cars in its equations because that part of the solution has already been enacted and requires higher prices since the electric car takes up significantly more energy.

C_K, the cost of energy per kilowatt hours, is \$0.12. That means that the cost of a watt is $\frac{0.12}{1000}$, or \$0.00012. Consider a cell phone that is being charged so its dead battery reaches 100%. Based on our data, the cost to charge this phone once would be 5.45 watt hours * \$0.00012, or \$0.000654. That is less than one thousandth of a cent. If a non-fast charging phone charger is 5 watts, that means that the charging station is used for 1.09 hours. Charging 5 cents per hour, rounding up for any fractions of time, would mean that an establishment would make 10 cents per full charge, which is \$9.999346 of profits per full charge for one person. An equation can be derived to find the total annual profit, which is represented by

$$C_{TPtot} = (0.00012)\,(B_U * 1.09)\,(2\,P_{Etot} + 5\,P_W) - (0.05)\,(B_U * 1.09)\,(2\,P_E + 5\,P_W), \text{ repeated } 0.81\,V \text{ times;}$$

$$C_{TLtot} = 7\,(0.00012)\,(T) - 7\,(0.05)\,(T), \text{ repeated } 0.73\,V \text{ times;}$$

$$|\,C\,| = C_{TPtot} + C_{TLtot};$$

So, if $P_E = 19$, $P_W = 13$, $W_L = 72.5$, $B_U = 0.9056$, and B = 4.43 ,then C = \$3.20 if one person charges their phone and laptop in the same place every time they must be charged in public for one week. If these numbers were the same for each person, and V = 5,000 people, then C = \$16,001.94. That would be \$832,101.03 per year for 5,000 daily visitors if everyone with a phone and laptop charged both things there. This way, not only does the cost reduce, but it is entirely eradicated; instead, the establishment makes money instead of losing it.

5. Conclusion

The model that was developed divides popular devices into three sections: cell phones, laptops, and electric cars. Using information on power, battery life, and phone usage per person, the model calculates the cost for one device per day, week, or year. Putting these costs together gives the total cost for one person who owns all three devices, or the devices can be paired up in different ways. This is repeated for each person to account for different habits and device health, then the numbers are averaged and plugged into calculations to find the total cost of public energy for one area or establishment. This allows for variation in visitors, phone habits, popular devices to use or charge in a certain area, and the health of the device itself.

Based on the model described, two successful solutions to the increase in energy cost were discovered: solar energy and charging fees. Both of these have their benefits and deterrences: solar energy eliminates the cost of energy, but the installation cost means that profits are lower for two years; charging fees create an extra source of profit for the company, but may put off customers. However, the benefits of a successful implementation of these initiatives outweigh the worries of unsuccessful implementation because for solar power, the cost is eventually paid off, and for charging fees, the company makes a profit regardless.

6. Strengths and Weaknesses

The strengths of the model are that:

1. The model takes into account variations in technological habits and efficiency of the device in question. This means that different habits paired with different efficiencies can be investigated instead of focusing on singular average values.

2. The model is split into sections and programmed so that the populations and popular devices can be accounted for in different types of places. This means that the number of people owning phones does not get taken into account when calculating the cost of public energy at a gas station, and the cost of powering an electric car is not accounted for at coffee shops. However, depending on the place, one, two, or all three types of technology can be included, and so the model becomes individualized for each place. Different visitation numbers are also used, so that the each person visiting a place on an average day is accounted for individually.

3. The model is not overly complicated and takes only a few equations to understand. This means that it is not too complex for others to understand, and it can be simulated through programming.

4. The programs used are split up into sections for each calculation. This means that incorrect values can be easily identified and corrected, and errors can also be pinpointed and isolated easily.

The weaknesses of the model are that:

1. Simulated numbers are extremely similar. While there is a general relationship between all the variables included in the model, it is difficult to mimic the deviation of each data set from the predicted value in real life. This means that simulated values are much closer to predicted values than they should be.

2. This model requires information on battery usage and average phone time for each customer, which may vary among regions or among establishment types. This variation is not included in the model, and so a library sees similar amounts of phone usage per person as an airport, even though some libraries may get more laptop usage on average. This is also different for the companies with the charging stations to account for themselves, because they might not have such data available.

3. The model only takes into account three types of devices. These devices were picked because phones and laptops are popular and electric cars have high energy consumption levels. However, there are other devices that are similar in nature and just as prevalent; for example, tablets are structurally and conceptually similar to laptops, but may not use the same amount of energy due to their generally smaller size. The three device types used are also extremely general. Differences in laptop sizes, for example, are not taken into account, even though larger laptops will take up more energy than smaller ones. Thus, the diversity of technol-

ogy is not efficiently included in the model.

7. Extensions

This model could be modified to address the energy costs of other areas. The four different types of areas that regularly include charging ares are airports, libraries, coffee shops, and gas stations. One of the issues with these examples is that they only show two versions of the algorithm's combinations; the pairings of laptops or phones alone, laptops and electric cars, phones and electric cars, and all three devices are not shown. This was going to be partly remedied by the addition of a simulation for a mall, but a lack of data prevented that example from fully developing. This is one thing that could be added. Such additions would make the costs and other calculations more accurate.

Another option is expanding the types of devices included in the model.This could also include modifying already-included device types to account for structural variations between models, like size, charger wattage, or decay of battery. One example of a new device that could be included is tablets, which were put aside due to both time constraints and similarity in nature to laptops. While laptops and tablets are similar in some respects, there are some major differences that make them stand out, like portability and battery life. Different models of devices, like Androids or iPhones for cell phones, could also be considered. Using other devices would create more variation between the three main device types used as well, creating a more realistic model.

Other types of renewable energy could also be investigated. One option that was considered was piezoelectric power, but ultimately a lack of data resulted in this option being abandoned. This could be further investigated to see if it would be an equal or better solution than solar power. Other renewable energies, like wind or hydroelectric power, could also be considered. Some may be more expensive than others, and therefore an optimal solution could be determined this way.

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Appendices

Appendix 1

main.py

phoneUsage.py