HiMCM 2019 - Charging Off the Grid

An Analysis of the Miscellaneous Electric Loads of the 21st Century

Abstract

The costs of free charging are both economic and environmental. Offering free charging to customers is becoming increasingly expensive to businesses as customers' needs for energy grow. Moreover, significant carbon dioxide emissions are created as a byproduct of energy generation. This model considers the various costs of portable device charging at power outlets and vehicle charging at electric car charging stations. For charging outlets, the energy consumption for computers and cell phones are taken into account separately. The amount of energy used on a daily basis is based on statistics and measurements at local facilities of number of charging outlets and vehicle charging stations, along with projected values for their usage. Different facilities, such as airports, universities, shopping malls, and restaurants, are considered. The model finds that in locations where free EV chargers are present, they produce a greater impact than charging at power outlets. The model then uses the total amount of energy used per day (kW) to quantify the monetary cost of importing energy ($) and social costs of producing such a large quantity of carbon dioxide as a byproduct of energy.

This model aims to change the current situation by focusing on using renewable energy sources as an alternative to electricity from the national power grid which is mainly fueled by natural gas. Two forms are considered: wind energy and solar energy. The costs for set up and maintenance for both forms are incorporated into the model. Certain limitations, such as the need for sunlight when using solar panels, are also accounted for. This model can be used to predict the amount of money saved by using alternative energy sources and sourcing energy locally. The model predicts that, in the long run, using solar and wind energy instead of natural gas will reduce the monetary and environmental cost of providing free charging in public spaces.

The best way to implement clean energy is on a microgrid, which, in short, is local energy. This is ideal due to its low impact on the users, as there is no need to change their electricity consumption habits, and due to the fact that it eliminates transmission power losses. This second fact results in less energy needing to be created, thus lowering both the monetary costs to the business purchasing it and the ecological cost due to the fact that less carbon dioxide is being produced.

Problem Restatement

The electricity made available for charging in public places seems free to users. However, there are unseen costs both to the businesses that provide the energy as well as to the environment. A model must be created to determine the energy demand of various electrical devices on "free" charging systems, how these costs can be projected to change over time, and how the costs of these demands can be reduced.

Model - Exposition

Variables

Variable	Description
p	Percent of people who charge laptops (as opposed to phones) in a given facility
h	The expected time to charge a single device at an outlet
c	The number of charging outlets in a given facility
t	Hours of operaction of a given facility
d	The expected energy use per device
x	A proportionality variable whihch accounts for the size of a given facility (number of annual passangers / customers / students, sqft, etc.)
a	% of energy in a microgrid produced by from solar panels
b	% of energy in a microgrid produced by from wind turbines

Assumptions

1. **Electric vehicle chargers are in use 40% of the time.**
   - Currently, gas vehicles still outnumber electric vehicles. However, the short supply of electric vehicle chargers means that those chargers are still occupied fairly often.
2. **Estimates on outlet number and usage:**
   - The following are estimates based on a combination of measurements from local buildings and from various online sources:

   2.1. In universities, there is one power outlet per 3 meters of wall space.

   2.2. Fast food restaurants have 20 charging outlets, regardless of size.

   2.2.1. 90% of the time, the outlet is used to charge cell phones.
   - Fewer people use fast food restaurants as a place to work or study, than those who come for a quick meal.

   2.2.2. The remaining 10% of the time, the outlet is used to charge laptops.

   2.3. There are 45 charging outlets available for free-use in a mall average size.

   2.3.1. The average size for a mall is 173,000 sq. m

2.3.2. **Outlets are always used to charge phones.**

- Malls are places to shop, so customers are unlikely to take computers there often.

2.4. **The number of power outlets and electric vehicle chargers in an airport is proportional to the number of annual passengers.**

2.5. **The number of power outlets and electric vehicle chargers in a university is proportional to the number of students.**

2.6. **The number of power outlets and electric vehicle chargers in a mall is proportional to the floor space.**

2.7. **Outlets are used consistently throughout the operating hours of the facility.**

3. **Estimates on microgrid construction:**

3.1. **The amount of energy lost in transmission on a microgrid is negligible.**

- The distances over which energy must be transported from a microgrid is significantly less than the distance of transport from a power plant.

3.2. **Solar panels and windmills are active during all operating hours of the facility, but are only active during those hours.**

3.3. **Natural gas is an accurate model for all fossil fuels.**

- Natural gas is the fossil fuel which is most used for electricity production.

3.4. **Nuclear energy can't be used on a microgrid.**

- It would be unreasonable due to safety concerns.

Introduction and Problem Analysis

"Free" charging in public spaces can be formally considered as a partial component of the Miscellaneous Electric Loads of the electricity used by the commercial sector. Presently, about 35% of the total electricity produced by the United States goes into powering the commercial sector, which includes the buildings required for education, healthcare, office work, food sales, etc. According to the Energy Analysis and Environmental Impacts Division of the Lawrence Berkeley National Laboratory, the total electricity used by the commercial sector has consistently been increasing each year, albeit at a declining rate. It is projected to continue to grow at least until 2040 at an average of approximately 0.07% per year.

Energy consumption within the commercial sector can be further broken down depending on its use. Common divisions include lighting, heating (space and water), cooling (ventilation and refrigeration), office equipment, including company affiliated computers, and miscellaneous electricity loads (MELs). Despite the fact that the overall amount of electricity used by the commercial sector is increasing, the same is not true for all of the subcategories. In the past, the category which demanded the most electricity is lighting, but with the implementation of more energy-efficient technology and more awareness towards conservation efforts, it has already dropped from demanding around 45% in 1995 to only making up 17% of the total electricity in the commercial sector in 2012. It is proposed that it could decrease by as much as 13% from its 2013 level by 2030 despite the fact that overall electricity used by this sector is on the rise. This means that in order to preserve the general increasing trend, the remainder of the categories must be growing at a rate higher than these are decreasing. Most of this increased energy demand stems from the miscellaneous energy loads category which by 2012 was already up to 125% of its level in 1995, and is still showing a generally increasing trend. This supports the theory that an increase in the popularity of portable electronics, ranging from cell phones to computers, and of electric vehicles, is causing an increase in the amount of energy which companies must allocate to “free energy” for consumers to use to charge these devices. In other words, increased demand for free charging has increased public spaces’ energy requirement. The increased energy requirement has in turn impacted those public places by causing their utility cost to rise. Whether it be an airport, university, or shopping mall, commercial entities must pay a pricier electricity bill to offer charging to their customers “free of charge”.

When electricity usage increases, increased electricity production must come in conjunction with it. In the United States, electricity is generally produced using a generator-and-turbine method, which, put simply, a moving fluid spins a turbine attached to a generator, and this generator works to convert the mechanical energy of the turbine into an electrical energy which can be sent to various locations for use. The fluid that is used can take on many forms but two of the most commonly used are combustion gasses and steam. Both of these are created by burning a variety of fuel sources which include but are not limited to oil, coal, and natural gas; in the case of steam, the fuels are burnt in order to heat the water, changing it to steam, so that it rises and pushes the blades of the turbine, and in the case of combustion gasses, the rising gasses are created directly by burning these fuels. Both of these cases require the burning of fuels, frequently fossil fuels, which means that carbon dioxide effluents are released in the process. Using a national average for the amount of carbon dioxide released when creating a certain amount of electrical energy (measured in kWh), a direct correlation can be drawn between the amount of energy and the amount of carbon dioxide produced.

In recent years, portable electronics have become increasingly available. For example, from 2010 to 2019, smartphone usage in the US increased from 62.9 million users, approximately 20% of the population, to 257.3 million, 78% of the population. The increase in the use of smartphones and other portable electronics may have contributed to an increased demand for free-to-use outlets to charge them. This helps to explain the widespread installation of charging ports in public spaces such as airports, shopping malls, and universities over the past 10 years, which may have contributed to the continuous rise in electricity consumption. That said, growth in smartphone usage has begun plateauing, and is expected to continue slowing over the next 5 years. Another uprising requirement in public spaces is free electric vehicle chargers. In 2010, 1,190 electric vehicles (EVs) were sold in the US, whereas in 2018, that number skyrocketed to 361,320. In contrast to smartphone growth, which is slowing down, electric vehicle sales are increasing at a faster rate than ever before. Moreover, though EV sales per year have increased more than 30,000% since 2010, electric vehicles still make up a mere 2.45% of the US auto market; in other words, there is ample room for growth in the future. Additionally, the number of publicly available EV chargers in the US increased from 374 in 2010 to 54,500 in 2018, and this rate of growth is also increasing. Not all of these chargers are free, but many public spaces, such as the Phoenix Sky Harbor International and the Natick Mall, have installed free EV charging stations to increase convenience for visitors, much in the same way that they have installed free power outlets for visitors' portable devices.

Math modelling is required to better understand the effect of portable electronics and electric vehicles on "free" electricity consumption in public spaces, and in turn their effects on cost, which is based on energy which needs to be purchased, and on the environment based on the amount of carbon dioxide created in producing this electricity.

Model

Costs of Increased Energy Usage

Model Parameters

For reasons described above, this model focuses solely on the amount of energy consumed from two sources: that which is consumed from public charging ports and outlets used for computers and phones and that which is consumed to charge electric cars.

Model of Charging Ports and Outlets

Explanation:

To calculate cost from charging ports and outlets, the model considered the number of charging ports, the number of USB cables in a location, and the ratio of people who charge laptops to those who charge phones. It is assumed that all chargers would be in use for all hours of operation of the location, and the only devices that would be charged are cell phones and laptops. To calculate the number of charging ports and USB cables, a ratio is created which relates the number of charging ports and USB cables to another metric, such as area or population. This ratio is assumed to be representative across all locations. By multiplying the ratio by the specific metric which is decided upon for each location, the number of charging ports and USB ports can be calculated. It was assumed that the average person would charge a laptop for two hours and a cell phone for one hour. The average cell phone requires 0.005 kWh to charge for an hour, and the average laptop requires 0.275 kWh. Thus, if p% of the devices charged were laptops, then (100-p)% of the devices charged would be cell phones. Since laptops and phones are charged for two hours and one hour respectively, laptops are charged for 0.02p of the total time every day, and cell phones are charged for 1-0.01p of the total time every day.

Calculations:

Let h be the expected time that a single outlet spends...?:

```
In[ ]:= h = 0.02 p + (1 - 0.01 * p)
Out[ ]= 1.75
```

The expected electricity used by computers is:

```
In[ ]:= electricityComputers = 0.02 p × 0.275
Out[ ]= 0.0055 p
```

The expected electricity used by phones is:

```
In[ ]:= electricityPhones = (1 - 0.01 p) × 0.005
Out[ ]= 0.005 (1 - 0.01 p)
```

Thus, the total amount of expected electricity by both types of devices is:

```
In[ ]:= d = electricityComputers + electricityPhones
Out[ ]= 0.005 (1 - 0.01 p) + 0.0055 p
```

The expected energy used per outlet can be modeled by dividing the total hours of operation of a facility by the amount of time for each type of device and then multiplying that by the number of each type of device (defined as variable d),. This can be modeled by the equation (t/h)×d. The next step is to multiply this value by number of outlets in a facility, defined as c, thus changing the equation to (t/h)×d×c. Finally, since energy costs on average \$0.12 per kWh, the cost per day is c×(t/h)×d×0.12.

```
In[ ]:= electricityCostOutlets = c * (t / h) * d * 0.12
Out[ ]= 3.63154 x
```

It should be noted that p (the percent of people charging computers over phones), t (the total operating time of the facility), and c (the number of outlets available at a facility) need to be defined for each separate facility. This means that the model can be used either to find the amount of electricity required to power the charging of phones and computers at a specific facility by inputting the specific values for each of these variables, or it can be used to find the average across a certain type of facility by inputting assumed average values. The later of these two processes will be demonstrated later in this paper.

Charging Electric Vehicles Model

Explanation:

The model for charging electric vehicles assumed that each time that a car was plugged in, it would be filled with enough electricity to drive 100 miles as this is a common amount to drive before refilling a car. Instead of addressing the number of cars which arrived at the charging station each day, it was estimated that any given electric vehicle charger would be active 40% of the total time. These pieces of information were used to calculate an average daily cost per charging station, which was done by multiplying the calculated cost per charging station by an estimate of the amount of charging stations at a location.

Calculations:

To provide an electric vehicle with enough charge to go 100 miles, it takes approximately 35 minutes and costs about $8.59. Thus, in dollars per minute, the charger requires:

```
In[ ]:= dollarsPerMinEV = 8.59 / 35
Out[ ]= 0.245429
```

If the charger is run continuously for all time (T, in hours), total cost would be multiplied by 60 in order to convert from price per minute to price per hour, and then by T to convert from price per hour to price per day:

```
In[ ]:= dollarsPerTotalDayEV = dollarsPerMinEV * 60 * t
Out[ ]= 14.7257 t
```

However, due to the fact that it was assumed that the chargers would only be used 40% of the time, so this expression must be multiplied by 0.4, so the total cost would be:

```
In[ ]:= dollarsPerDayEV = dollarsPerTotalDayEV * .4
Out[ ]= 5.89029 t
```

Finally, if c is the number of chargers, the total cost would be:

```
In[ ]:= dollarsPerFacilityEV = dollarsPerDayEV * c
Out[ ]= 5.89029 c t
```

Location Based Variations

Multiple cases are considered with modifications made for the models of charging cars and charging ports and outlets based on the location. The four locations are an airport (with Phoenix Sky Harbor International and Boston Logan as examples), universities (with MIT as an example), malls (with various mall samples), and fast food restaurants. Estimates were made on statistics for which data could not be easily accessible. Namely, the number of charging outlets were estimated by assuming one charging outlet per every 3 meters of wall space, which is reasonable since it approximates the distribution of charging outlets measured at a public space in a university.

Airport

Charging Outlets:

The number of charging outlets was calculated by looking at the number of charging outlets and USB ports, 240 and 204 respectively, that are available at Phoenix Sky Harbor International Airport. Since it was assumed that the ratio of annual passengers to outlets and/or USB ports at Phoenix Sky Harbor International Airport would be representative of any airport, a ratio of passengers to outlets/ports was made based on this data, and it could be scaled up and down by multiplying this ratio by x, which was defined, in this case, as the number of passengers that pass through any given airport in millions. The number of passengers per year in Phoenix Sky Airport is 45 million.

The ratio of charging outlets to millions of passengers multiplied by the scaling factor “x” gives the number of outlets in an airport in terms of millions of annual passangers, which is:

```
In[ ]:= c = N[240 / 45] * x
Out[ ]= 5.33333 x
```

The ratio of USB ports to millions of passengers multiplied by the scaling factor “x” gives the number of USB ports in an airport in terms of millions of annual passengers, which is:

```
In[ ]:= numUSBPorts = N[204 / 45] * x
Out[ ]= 4.53333 x
```

Since a laptop cannot be plugged into a USB, each USB will have an energy output of 0.005kWH. Thus, the total cost for powering these USB ports can be modeled by the power output times the hours that it is operational times the number of ports times the cost of electricity per kWh, or:

```
In[ ]:= electricityCostAirportUSB = 0.005 * 24 * numUSBPorts * 0.12
Out[ ]= 0.06528 x
```

It was assumed that at outlets, 75% of people would be charging their laptop and 25% of people would be charging their phone. Thus, p=75. Since airports operate all 24 hours, T=24.

```
In[ ]:= p = 75
Out[ ]= 75

In[ ]:= h
Out[ ]= 1.75
```

```
In[ ]:= t = 24
Out[ ]= 24

In[ ]:= d
Out[ ]= 0.41375
```

The total cost of outlet energy used in airports could be used by plugging these values into the previously defined function for this purpose:

```
In[ ]:= electricityCostOutlets
Out[ ]= 3.63154 x
```

The total cost can be found by summing the cost from outlets and USBs:

```
In[ ]:= electricityCostAirportUSB + electricityCostOutlets
Out[ ]= 3.69682 x

In[ ]:= Clear[p, h, d, electricityCostOutlets]
```

Airport - Electric Vehicles

To calculate the total cost of charging for electric vehicles, the ratio of electric vehicle chargers to total passengers at Boston Logan Airport was assumed to be representative of any given airport. In total, there are 26 electric vehicle chargers at the airport, and 43.2 million passengers pass through the airport every year. Thus, the number of electric vehicle chargers at any given airport can be found by taking the ratio of electric vehicle chargers to millions of passengers, and multiplying it by “x”, or the number of annual passengers at a given airport in millions of people. This is:

```
In[ ]:= airportEVRatio = 26 / 43.2 * x
Out[ ]= 0.601852 x
```

The cost of operating all of the Electrical Vehicle chargers in an airport could be modeled by:

```
In[ ]:= costEVAirport = 0.4 * 8.59 * 60 * t * airportEVRatio / 35
Out[ ]= 85.0819 x
```

Finally, the cost can be divided by the cost of electricity to get the electricity output:

```
In[ ]:= costEVAirport / 0.12
Out[ ]= 709.016 x
```

University

University - Charging outlets

The number of charging outlets was calculated by looking at the number of charging outlets only, since USB ports are found very rarely in universities. Because no data was found for the number of outlets, the number of outlets in a common room with a perimeter of 58 meters in a university was determined to be 18, and the ratio of outlets to the perimeter of the wall, which was approximately ⅓, was considered to be representative of the ratio of charging outlets to perimeter. Using this measurement, it was approximated that a general common room would have a perimeter 225 meters, so there would be 75 outlets in a room. Assuming that there was one common area per building, the number of buildings in MIT, 190, was considered to be representative of the average number of buildings on a college campus. Thus, the model suggests there are 75×190=14250 outlets at MIT. Since the student population of MIT is 11574, the ratio of outlets to students is 14250/11574=1.2312. Thus, letting the population of a university be x, there are c=1.2312x outlets. It was assumed that students would only use public charging between the hours of 6 am and 12 am, so t=18. Since 73% of college students use their laptop to learn and 42% of college students use their smartphones to learn, p=73/(73+42)×100=63.48. Substituting, h=1+0.01×63.48=1.6348. Substituting into the equation for d =0.02(63.48)×0.275 +(1-0.01(63.48))×0.005 =0.35100. Substituting c, t, h, and d into the equation for energy output, c×(t/h)×(d)= (1.2312x)(18/1.6348)(0.351)=4.75821x. Multiplying the energy output by 0.12 gives 4.74821x×0.12=0.5698x.

University - Electric Vehicles

The number of electric vehicle chargers at MIT, 14, was divided by the student population of MIT, 11754, to obtain the ratio of chargers to population as 0.001191. Let x be the population of another university. Thus, the number of chargers in a university is 0.001191x. Since it is assumed that MIT students will only charge their cars between the hours of 6 am and 12 am, T=18. Substituting into the equation, EV cost is (0.4)(0.001191x)(8.59)(60)(18)/35=0.126276x. Dividing by the cost, energy output is 0.126276x/0.12=1.0523x kWH.

Restaurant

Restaurant - Charging Outlets

The number of charging outlets was calculated by looking at the number of charging outlets only, since USB ports are found very rarely in restaurants. Because no data was found for the number of outlets, the number of outlets in a fast food restaurant was estimated to be c=20 for every fast food restaurant. This is reasonable since fast food restaurants are generally the same size and do not vary based on a factor such as population. It was estimated that 10% of customers will be charging laptops, while 90% of customers will be charging cell phones. Thus, p=10. Substituting, h=1+0.01(10)=1.1. t=18 based on local fast food restaurants. d=0.02(10)×0.275+(1-0.01(10))×0.005=0.0595. Substituting into the equation for total energy output, energy= (20)(18/1.1)(0.0595)=19.473. To find the total cost, the energy is multiplied by 0.12 to get (19.473)(0.12)=2.34.

Restaurant - Electric Vehicles

Generally, fast food restaurants don't have electric vehicle chargers, so there would be no cost associated with running the electric vehicle chargers for a day at a restaurant.

Shopping Malls

Shopping malls - Charging Outlets

For malls, a local mall of 173,000 square meters of floor space was estimated a total of 45 charging outlets. The model uses a proportionality between outlets and floor space. The average amount of charging outlets per thousand square meters is 45/173=0.26012. If x is the area in thousands of square meters, c=0.26012x. The hours of operation of a mall was taken to be t=11 hours. Since most people go to a mall for the purpose of shopping, computers were assumed to not be charged at malls, making p=0. Hence h=1, and d=0.005. Substituting, energy = c×(t/h)×d= 0.26012x×11×0.005=0.14307x. Finding the cost by multiplying the energy output by 0.12, it was found that (0.14307x)(0.12)=0.017168x.

Shopping malls - Electric Vehicles

To determine the number of outlets per one thousand square feet, data from three different malls was used. Auburn Mall has 19 EV charging outlets for 54.4 thousand square feet, Cape Cod Mall has 3 charging stations for 67.7 thousand square feet, and Grapevine Mall has 25 outlets for 150 thousand square feet. There were a total of 47 EV charging stations for 272.1 thousand square feet, or an average of 0.17273 EV charging stations per one thousand square feet. Let x be the number of thousands of square feet in a mall. There are c=0.17273x charging stations. As above, t=11. Thus, EVcostmall= (0.4)(c)(8.59)(60)(t)/35= (0.4)(0.17273x)(8.59)(60)(11)/35=11.2559x. To determine the total energy output, this value was divided by 0.12 to obtain 93.799x.

Strengths and Weaknesses

The strengths of this model is that it accounts for the main sources of free energy consumption in public spaces: electric cars and charging outlets. It also accounts for multiple factors for each facility were also taken into account to scale the energy production, and different factors were used for different facilities, such as passengers for airports and students for universities. Some weaknesses are that most of the assumptions on usage of power outlets and charging stations were based on robust estimates rather than researched data. It should also be noted that this is a generous estimate, as the value used as the average cost of energy is actually closer to being a maximum, as well as the fact that the assumption was made that all outlets would be used all the time. One way to strengthen the model would be to sample many buildings of a certain facility to count the amount of charging stations and outlets, and monitor the energy consumption of both over a period of multiple days.

Data Summary Tables

Facility	Proportionality Variable	Outlet Energy (kWh)	EV Energy (kWh)	Total Energy (kWh)	Total Cost ($)
Airport	x = annual passengers in millions	30.243x	709.08x	739.323x	88.72x
University	x = student population	4.748x	1.052x	5.800x	0.70x
Restaurant	N/A	19.473	0	19.473	2.34
Mall	x = floor space in thousands of square meters	0.14307x	93.799x	93.942x	11.27x

Facility	Proportionality Variable	CO_2 emissions (tons)	Social Cost ($)
Airport	x = annual passengers in millions	0.365x	80.37x
University	x = student population	0.0029x	0.63x
Restaurant	N/A	0.0092	2.18
Mall	x = floor space in thousands of square meters	0.046x	10.213x

Initiatives for the Future

There are many options for different initiatives that could be implemented to reduce the costs associated with increasing energy usage, including that which is associated with increased "free" charging. One such initiative is the idea of changing personal habits, for example limiting the amount of energy which any person can utilize by setting time or voltage limits on outlets, It was determined that on its own, this would not be a viable option, as there is no clear way to regulate it, which opens the possibility that these rules will be disregarded, and thus the perceived benefits will not actually come to fruition. One potential solution for this would be locking outlets so that a fine could be charged for exceeding limits, but this majorly decreases convenience which is one of the major draws of "free" energy. For this reason, one aspect which was considered important when choosing what initiative ought to be focused on for implementation was minimizing the negative impact that it would have on people. To do this, it is more logical to look at changes that can be made to the production of power rather than to the amount which is consumed. For this reason, it was decided that looking forward it is best to attempt to apply these technologies to foster the growth of microgrids.

Microgrids are a way for a certain area, which can be as small as a single building or as large as an entire city, to become entirely self sufficient in regard to electricity. In order to create an effective microgrid, some form of power production is needed on site of the grid. This electricity can come from any source, but in the case of most microgrids, it is desirable for it to be a resource that is local to the area in order to reduce the costs associated with transportation costs. From this place of production, it is moved to the surrounding area much in the same way it would be on a traditional power grid, but with more connections, which is made possible by the smaller total size. By using a microgrid, costs can be reduced in a variety of ways. Most directly monetary costs are reduced due to a reduction in transmission losses. "Transmission losses" is the collective term which refers to the difference between the amount of electricity produced and the amount of this that can be used once it arrives at the site at which it is being used. While transmission losses vary across locations depending on the material that the wire is made of and the distance the energy needs to travel, the United States averages approximately 6.7% of energy created lost due to transmission. In addition, the expenses which are associated power outages, such as purchasing back up generators and lost productivity time which reduces profits, are also reduced through the use of microgrids. This is due to the fact that within a microgrid, there can be more electricity connections and therefore if damage is done to one part of the grid, not all connected parts are going to lose power as well. In other words, microgrids work to improve resilience and in turn reliability. Finally, the environmental cost has the potential to be reduced. Not only is less energy in total being produced, thus reducing the emissions which are associated with that process, as mentioned above, microgrids can be powered by any form of electricity production. This means that in some cases, there are microgrids which are powered partially or entirely by green energy, further reducing the costs which are associated with electricity production.

While the potential exists to create microgrids which power entire cities, if the specific goal is to reduce the expenses which are related to "free charging", it makes more sense that these microgrids only affect the specific commercial sector buildings, specifically those which were outlined in the above models: airports, universities, and restaurants. Currently, there exist some facilities which utilize this process, one of the biggest examples in the United States being the University of Texas at Austin. There, they have implemented a 100% microgrid which depends on a mix of renewable energy sources and natural gas in order to provide electricity to their entire 20 million square foot campus with over 150 buildings. Other college campuses with smaller scale microgrids (ones that only apply to a portion of their buildings, not all of them) have succeeded getting higher and higher percentages of the energy utilized by their microgrids to come from renewable energy sources. One extra benefit to many of these early microgrids existing on college campuses is that there, they can be used for research on how to improve renewable energy sources in relation to microgrids. Improvements found by this research can then be implemented to continuously make the microgrids of tomorrow better than the microgrids of today, and thus 100% microgrids are powered completely by renewable fuel source can be projected.

Using the microgrids that already exist on college campuses as a real world indication of what is possible, the following assumptions were made about microgrids which could hypothetically be implemented right now: First, all microgrids constructed will be 100% microgrids. Second, the term “x% green microgrid” specifically refers to a 100% microgrid where x% of the energy is derived from typical renewable energy sources, such as solar and wind power. To begin, we took 93.3% of the energy total energy which was required to run each type of commercial building or group of buildings which was found from our previous model. This is because microgrids reduce the amount of electricity lost to transmission to negligible amounts, meaning that when a microgrid is used, it is only necessary to pay for the energy which is actually used, as none is wasted.

As time goes on and green technology improves, they will be used on a larger and larger scale. For this reason, it is necessary to assess which of these green technologies are most feasible and most efficient for use. Two reasonable alternatives to natural gas were considered: wind energy and solar power. First, a model was created for replacing natural gas with solar power. Solar panels function for 5-6 hours a day, so a value of 5.5 hours was used. Solar energy cost \$0.08/kWH [5] as opposed to \$0.12/kWH like electricity from natural gas. Let a be the percentage of energy that is being replaced with solar energy. The total amount of energy for the whole day was divided by functioning time to determine how much energy would have to be produced per hour. This energy was multiplied by $0.01\times a$ to determine how much energy would have to be produced by the solar panel every hour. This provided the number of kWH that solar panels would need to produce. This was multiplied by the cost per kilowatt to find the total cost of a functioning solar panel. Thus, $s=(0.01)(a)(\text{totalenergy}/5.5)(0.08)$ per hour.

Next, a model was created for replacing natural gas with wind power. To do this, it was assumed that windmills also functioned for all hours of operation. Wind energy cost \$0.05/kWh [5]. Let b be the percentage of energy that is replaced by wind energy. The total amount of energy for the whole day was divided by the operating hours to determine how much energy would have to be produced per hour. This energy was multiplied by $0.01\times b$ to determine how much energy would have to be produced per hour. This provided the number of kWH that windmills would need to produce. This value was multiplied by the cost per kilowatt to find the total cost of a functioning windmill. Thus, costwind =(0.01)(b)(totalenergy/T)(0.05) per hour.

The rest of the energy was accounted for by natural gas. The percentage of energy that was natural gas was 100-a-b. Thus, the cost of energy accounted for by natural gas is the total cost for that location multiplied by (100-a-b) and divided by 100. Since the total energy is the sum of solar energy, wind energy, and energy from natural gas, totalmoney= (0.01)(a)(totalenergy/5.5)(0.08)+(0.01)(b)(totalenergy/T)(0.05)+(totalcost)×(100-a-b)/100.

While this equation only accounts for monetary cost, the social cost of CO_2 emissions can be factored in to account for environmental impact. To do this, the social cost previously calculated can be multiplied by the percentage of energy still accounted for by natural gas. This is (100-a-b)/100. Thus, the social cost would be (totalsocialcost)*(100-a-b)/100. This modified can be added to social cost can be added to the total monetary cost to find a number accounting for monetary cost and environmental cost. Thus, totalcost= (0.01)(a)(totalenergy/5.5)(0.08)+(0.01)(b)(totalenergy/T)(0.05)+(totalcost)×(100-a-b)/100+(totalsocialcost)*(100-a-b)/100.

Using this, it is possible to model a scenario where an airport with 45 million passengers every year uses solar panels to provide ⅓ of its enegry, windmills to provide ⅓ of its energy, and natural gas to provide ⅓ of its energy. The total energy of an airport is 739.323x kWH. Substituting x=45, the total energy is 739.323(45)=33269.5. In this case, a=33.3, b=33.3, and 100-a-b=33.3. In an airport, T=24 because the airport is in operation for 24 hours. The total cost of an airport is 88.72x, so for an airport with x=45, the total cost is 88.72(45)=3992.4. The social cost of an airport is 80.37x. Substituting x=45, the total social cost is 3616.65. Substituting values into the equation, totalcost=(0.01)(a)(totalenergy/5.5)(0.08) +(0.01)(b)(totalenergy/T)(0.05)+(totalcost)×(100-a-b)/100+(totalsocialcost)*(100-a-b)/100= (0.01)(33.3)(33269.5/5.5)(0.08)+(0.01)(33.3)(33269/24)(0.05) +(3992.4)×(100-33.3-33.3)/100+(3616.65)*(100-33.3-33.3)/100=2725.65. This is lower than the total cost of using only natural gas, 3992.40. Using renewable energy sources can save thousands of dollars spent on free charging on a daily basis without reducing convenience.

Next, the model was used to simulate the scenario where a% of energy was replaced by solar energy. Thus, totalcost=(totalenergy/5.5)(0.08)(a)(0.01) per hour. However, this was multiplied by 5.5 to find the total cost per day. Thus, the total cost per day is equal to (totalenergy)(0.08)(a)(0.01). Thus, the money saved from solar panels each day is (totalcost-totalenergy×0.08(a)(0.01)). Since totalcost=0.12×totalenergy from the previous model, (totalcost-totalenergy×0.08×a×0.01)=(0.12-0.008a)×totalenergy. The solar panel costs $2990 per kiloWatt [17] to install. The energy per hour was calculated by finding total energy and dividing by the number of hours. This value was then multiplied by the cost of installation per kilowatt to find the total cost of installation: costofinstallation=(totalenergy/T)×2990. In addition to installation costs, there are other one-time costs such as the cost of land needed to build solar panels and windmills. Each square foot of a solar panel can produce an average of 15 watts. From above, the number of kilowatt hours produced by solar panels was

(0.01)(a)(totalenergy/5.5), where a is the percentage of total energy accounted for by solar panels. Since there are 15 watts, or 0.015 kW produced per one square foot of solar panel, the number of square feet of solar panel needed is (0.01)(a)(totalenergy/5.5)/0.015. Undeveloped land costs $6500/acre, and since there are 43560 square feet in an acre, undeveloped land costs $0.14922/square foot. Multiplying this by the number of square feet of solar panel needed, the total cost of land needed for solar panels becomes (0.01)(a)(totalenergy/5.5)/0.015*0.14922. The net amount of money saved will be the installation costs and cost of land subtracted from amount of money saved due to the lower cost of energy. Thus, moneysaved=0.04×totalenergy×-days-(totalenergy×2990/T) -(0.01)(a)(totalenergy/5.5)/0.015*0.14922.

Similarly, the model was used to simulate the scenario where b% of energy was replaced by wind energy. Thus, totalcost=(totalenergy/T)(b)(0.01)(0.05) per hour. However, this was multiplied by T to find the total cost per day. Thus, the total cost per day is equal to (totalenergy)(0.05)(b)(0.01). Thus, the money saved from solar panels each day is (totalcost-totalenergy×0.05). Since totalcost=0.12×totalenergy from the previous model, (totalcost-totalenergy×0.05)=(0.12-0.01*0.05*a)×totalenergy. The windmill costs $800 per kiloWatt [17] to install. The energy per hour was calculated by finding total energy and dividing by the number of hours. This value was then multiplied by the cost of installation per kilowatt to find the total cost of installation. costofinstallation=(totalenergy/T)×800. A similar method can be used to determine the cost of land needed for windmills. A windmill producing 2000 kiloWats requires 1.5 acres, or (43560)(1.5)=65340 square feet of land. Thus, there is an energy output of 1333.33 kiloWatts/acre. As determined above, there are (0.01)(b)(totalenergy/T) kiloWatts produced by windmills. This can be divided by the energy output per land area to determine the number of acres needed. Multiplying the numebr of acres of land by the cost per acre, $6500, gives the cost of land needed to build the windmills. Thus, the cost of land is (0.01)(b)(totalenergy/T)/(1333.33)*6500.

The net amount of money saved will be the installation costs and cost of land subtracted from amount of money saved due to the lower cost of energy. Thus, moneysaved=(totalenergy×800/T)-0.07×totalenergy×days-(0.01)(b)(totalenergy/T)/(1333.33)*6500.

Using this model, it can be shown that in the long run, renewable energy will be much more cost effective than using natural gas. For example, consider a parking lot at MIT with 14 electric vehicle charging ports after 20 years. Since MIT is in a large city, it would be difficult to implement windmills. However, it would be possible to implement solar panels. The short term costs of implementing renewable energy are high. The total energy expenditure by the parking lot in one day is 5.800(11754)=68173.2 kWH. The operating time for a university is considered to be T=18. Substituting, moneysaved=0.04×totalenergy×days-(totalenergy×2990/T) -(0.01)(a)(totalenergy/5.5)/0.015*0.14922= 0.04×68173.2×365×20 -(68173.2×2990/18)-(0.01)(100)(68173.2/5.5)/0.015*0.14922=8458940. After 20 years of using renewable energy instead of natural gas, the university will save over 8 million dollars.

Further in the future, it is probable that the efficiency of renewable energy technology will improve enough that the amount of electricity collected on these 100% green microgrids will exceed the amount of energy which is required by the building or buildings that the grid is responsible for powering. If this is to happen it is important to decide how the excess energy produced ought to be divided. One thought is to evenly divide this between the energy draws which need it most. One group from Queensland University defined these as maintenance costs of green energy technology, “free” energy for charging, and excess energy which gets sold back to the main power grid for profit. According to the proposed model ⅓ of excess energy will get allocated to each of these divisions. While this model may not perfectly cover all of the required expenses, for example it is not probable that every year the electricity demand for maintenance will be exactly ⅓ of the excess energy created, it does provide a way to pay for increasing electricity demands for “free” charging, assuming that geen technology follows the current trend of becoming more and more efficient.

While there are many benefits of using a microgrid with renewable energy, there are several drawbacks. In certain areas, the cost of land is very high, and thus, the average cost of undeveloped land may not provide an accurate model of money saved from using renewable energy instead of natural gas. In this case, renewable energy may be too expensive to be feasible. Other areas may not receive sufficient sunlight or wind for renewable energy to be a reasonable option. While this model addresses many factors, it may not accurately reflect locations that have higher than average land prices or other variables. In addition, there are many short term costs associated with renewable energy, of which a few were addressed in the model. While renewable energy is much cheaper in the long run, these short term costs may be burdensome for some institutions and result in massive loans. In this case, an institution may not be able to implement a microgrid powered by renewable energy due to start up costs.

Newspaper Article

Charging off the Grid

Have you ever forgotten to charge your device before school? Like many students, you’ve probably plugged it into one of the many power outlets available throughout the building. Charging at school is convenient, and there are plenty of days when we can’t do without it. That said, there’s no such thing as charging “free of charge”. On average, the electricity which we use to charge for free costs the school 70 cents per student each day. This may seem insignificant, but over the course of a school year, it adds up to $126 of added expense per student.

The recent rise of portable electronics over the past 10 years has led to an increase in demand for free charging in public places like our school. That said, nowadays, most students already have a laptop and cell phone, so the device charging expense for schools isn’t likely to increase much more. However, portable devices aren’t the only electronics that require charging. Free charging stations for electric vehicles have begun sprouting up in airports, shopping malls, restaurants, and schools across the nation. Their true cost can’t be paid in dollars. The carbon dioxide emissions created during electricity production may seem far removed from plugging your laptop into a classroom wall outlet, but the net increase in “free charging” across America is also costing the environment.

Fortunately, there are steps we can take to reduce both the environmental and monetary costs. One possible solution is to generate energy onsite at the building or complex where it is to be used. One benefit of microgrids, as they are known, is that no energy is lost in transmission from a far-off production facility to the place of electricity use itself. On average, implementing a microgrid reduces electricity requirements by about 6.7%. While in the short term implementing a microgrid can be a costly affair, in the long run it definitely saves money. But wait, there’s more! Green microgrids which are fueled by clean energy sources can provide electricity to our devices without hanging the guilt of environmental destruction over our conscience. Our need to charge devices is stabilizing, but electric vehicles are only growing more and more popular. Powering public places like our school via green microgrids is the pathway to a cost-effective energy-efficient future

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