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Case Studies in Math Modeling
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Solar Panels Project Report

Introduction:

The city of Easton developed a CAP in 2016 that aimed for at least a 30% reduction in 2016-level emissions by 2030 and an 80% reduction by 2050, with a more ambitious goal of reducing emissions by 60% by 2030. One of the main targets to accomplish this goal was for 100% of Easton's electricity to come from renewable energy sources by 2030. Our project focused on how this energy could be generated solely from using solar panels while keeping in mind the cost and practicality limitations that solar panels might have. Our purpose was to find a solution that was both financially feasible and environmentally friendly to help the city of Easton achieve its goals efficiently and effectively.

Data:

We used production data that we found on the Solar Edge website from a house in Allentown, shown in Fig 1 [1]. We used daily data for every month of 2021 to come up with a mean and standard deviation for each month. This mean and standard deviation was then used to come up with a normal distribution for each specific month.

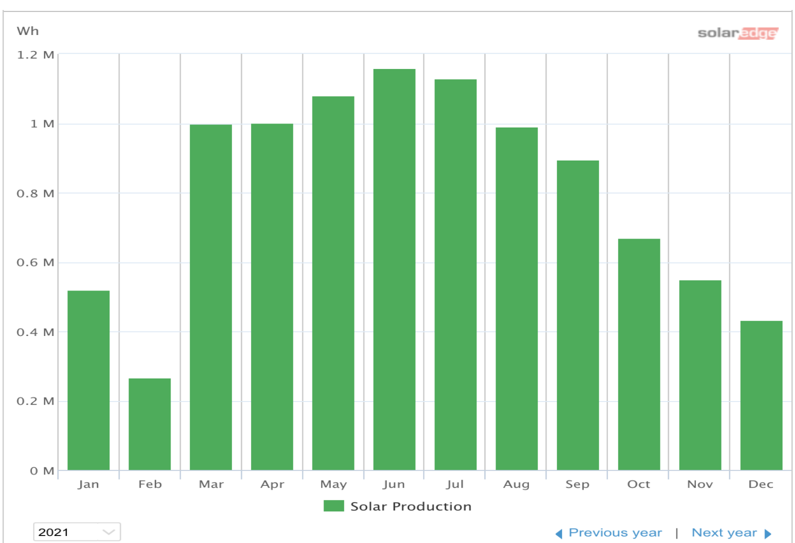

Fig 1. Production data for 2021

For our consumption data, we also used another house in Allentown that we found on the Solar Edge website [2]. We similarly used daily data for every month of 2018 to come up with a mean and standard deviation for each month which was then used to generate a normal distribution for each month. The graph for consumption in July 2018 is shown below in Fig 2.

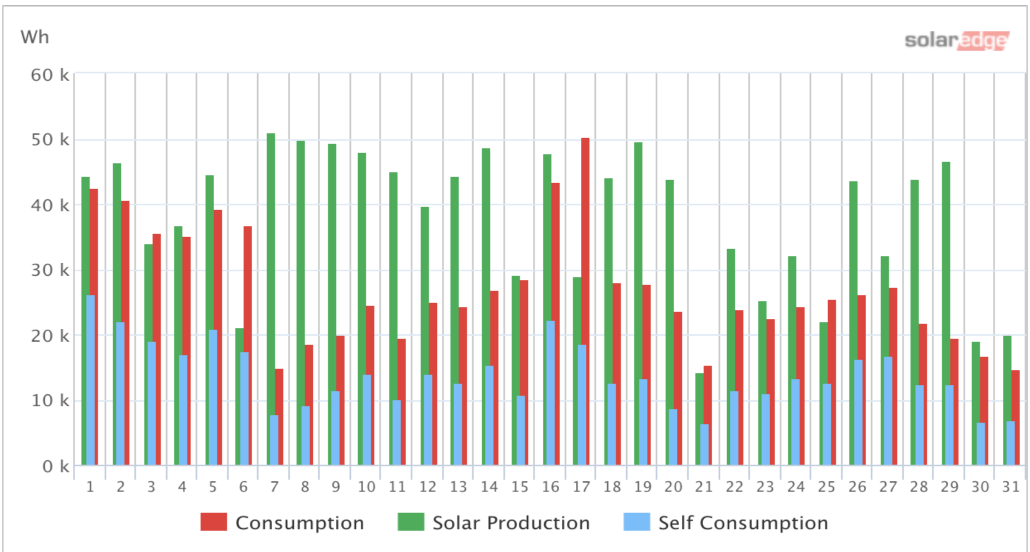

Fig 2. Consumption data for July 2018

Assumptions:

We found data on the Project Sunroof website about Easton which we used to come up with a modifier for scaling our production estimates from a single house to all houses in Easton. As solar systems are designed to be based on a house's consumption [3], we assumed that we could use the same modifier to scale consumption estimates from a single house to all houses in Easton. This assumption made sense as the larger the size of the home, the more solar energy it would require to carry out its daily operations. We also assumed that for the scope of this project we were only looking at houses in Easton that had the potential to generate solar energy according to Google Project Sunlight [4]. This was important later on because it would help us ensure that we only looked at the efficiency of solar systems and did not focus on buildings that used alternative sources of energy. We also incorporated a battery into our solar system and assumed that the energy stored in the battery would get utilized in the house's consumption before any new solar energy produced by the solar system could be used. This allowed us to ensure that the battery was being utilized to the fullest and making the system most efficient.

We used two different Allentown houses for our production and consumption data to come up with a distribution and assumed that they were representative of the production and consumption of a house in Easton. We were able to make this assumption because Allentown is close enough geographically for it to have almost the same weather and climate on a given day. Furthermore, it also has the same latitude as Easton which means it enjoys almost the same levels of sunlight. We also assumed that the data we got for production [1] and consumption [2] had already accounted for different weather conditions and optimal positioning of solar panels.

We also found that the cost of buying energy from the grid was currently 14 cents/kWh [5]. Moreover, we found that the solar renewable energy credits were currently at $42/MWh [6] and the federal government was offering a tax credit of 30% on installation of solar panels [7]. Additionally, we found that the cost of installation of a solar battery system was $800/kWh [8]. Lastly, it was found that the cost of installation of a solar system per watt decreased as the size of the solar system increased starting at $2.35/watt [3].

Simulation Description:

Our code consisted of four main loops which allowed us to simulate our solar system from a single home in Easton to all houses in Easton with solar potential. The innermost loop looked at consumption and production data from our Allentown houses and generated a normal monthly distribution based on each month’s respective mean and standard deviation which was then used to generate a random number for daily consumption and production. A battery variable was also initialized and stored the excess energy if daily production exceeded daily consumption. However, each battery was only capable of storing energy less than or equal to its peak amount (which we varied in the code to account for different battery sizes). Thus, if there was still any energy left over after battery storage had been exceeded it was sold back to the grid. Our loop also accounted for and stored the number of days when energy production was less than energy consumption and energy had to be bought from the grid.

Our next outer loop basically followed the same process mentioned above but extended the simulation to an entire year for this single Easton house. Each month had its own production and consumption distribution which was referenced by calling the mean and standard deviation for each specific month using an array that had stored these values earlier. The number of days of each month had also been stored in an earlier array which was also utilized in this loop to make sure that each month had the data for the correct number of days. Outside the loop, we also stored important values such as total energy consumption, total energy production, total days energy was needed from the grid, total amount of energy needed from the grid, total excess energy generated etc.

The next outer loop extended our code from a single house in Easton to all homes in Easton with solar potential. The modifier was created by looking at production data found on Google Project Sunroof [4] which had a distribution of solar capacity of the houses in Easton. We used that distribution to come up with a modifier that was generated randomly but accounted for the randomness in the sizes and solar potential generation of the different houses in Easton. This loop also included the installation costs of the solar system which was scaled depending on the size of the system using a modifier. It also incorporated the 30% tax credit that the federal government offers on solar systems[7]. At the end of the loop we stored mean values of energy consumption, energy production, days energy was needed from the grid, amount of energy needed from the grid, excess energy generated for every specific house in Easton instead of saving them as total values for all houses in Easton.

Our final(outermost) loop extended our entire simulation to look at how different sized solar batteries would affect the efficiency of our solar systems. We looked at 10 different battery sizes from 0-45 kWh in increments of 5 kWh. We also had arrays to store our mean values for all of our aforementioned variables for each battery size. These arrays were then used to generate the subsequent graphs for our results.

Simulation Analysis:

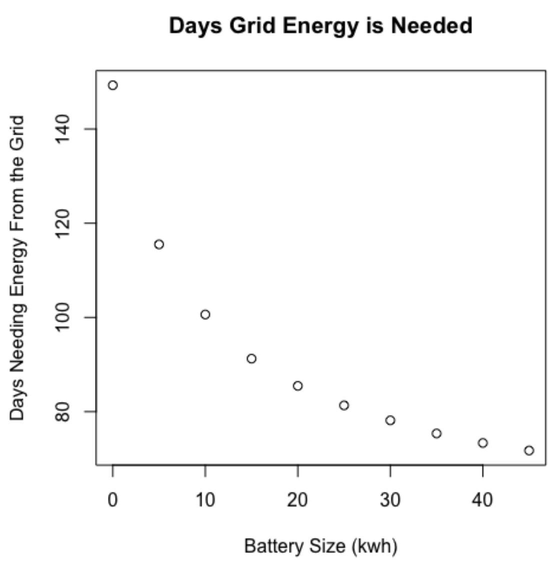

Fig 1. Days grid energy is needed

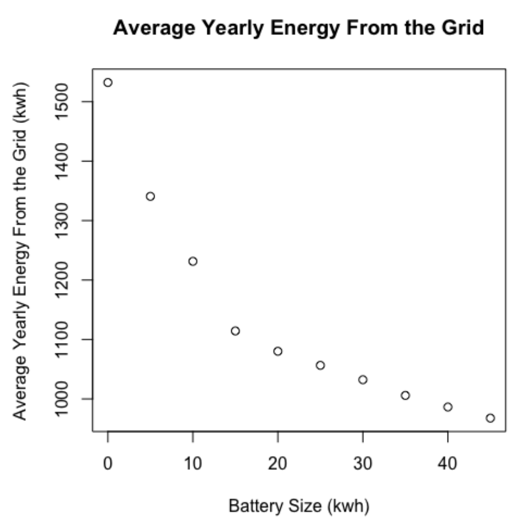

Fig 2. Avg Yearly energy needed from grid

As can be seen in Fig 1 and 2, the days grid energy is needed dramatically goes down even if a 5kWh battery is installed as the battery is able to store excess energy and utilize it the next day which eliminates the need for a lot of energy to be bought from the grid. Similarly, the amount of average yearly energy needed from the grid also decreases significantly as a battery is installed. However, the rate at which this amount goes down decreases as the battery size increases which means that there is decreasing marginal utility of using the battery.

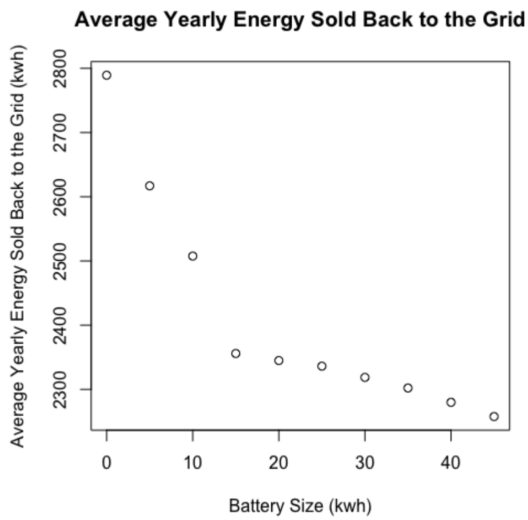

Fig 3. Avg Yearly Energy sold back

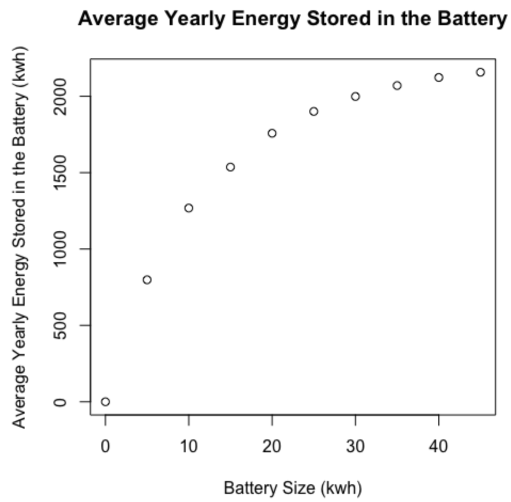

Fig 4. Avg Yearly energy stored in battery

Average yearly energy sold back to the grid is initially very high when there is no battery but instantly shows a huge decrease as soon as a battery is installed as that energy is the excess energy is now being stored in the battery. This ties in with Fig 4 which shows the average yearly energy stored in the battery increasing as battery size increases.

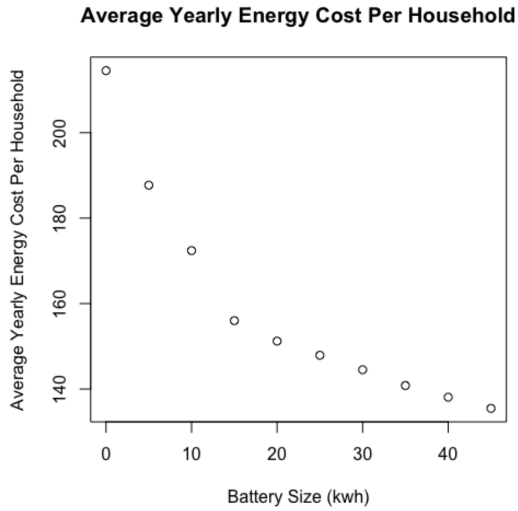

Fig 5. Avg Yearly energy cost/household

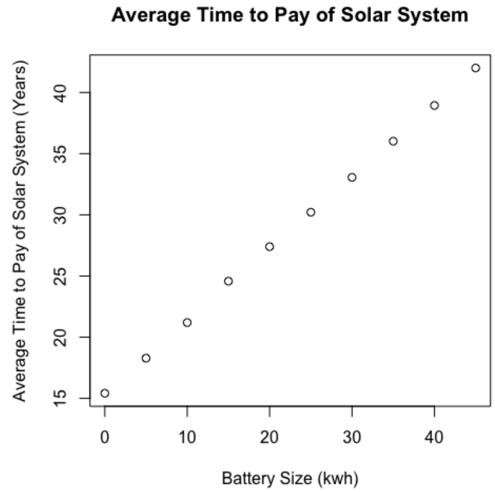

Fig 6. Avg time to pay off solar system

The average yearly energy cost/ household shown in Fig 5 decreases as the battery size increases as the battery is now storing the energy inside it. The average time to pay off the solar system does show a linear trend as the cost of installation increases linearly.

References

[1] "NPSCPurpleHouseSolar." *Solaredge*, https://monitoringpublic.solaredge.com/solaredge-web/p/site/public?name=NPSCPurpleHouseSolar#/dashboard.

[2] "GSE-ALLENTOWN-21." *Solaredge*, https://monitoringpublic.solaredge.com/solaredge-web/p/site/public?name=GSE-ALLENTOWN-21&locale=en_US#/dashboard.

[3] Savino, James. "Solar Panel Cost Guide in Easton." *EcoWatch*, Oct. 2022, https://www.ecowatch.com/solar/panel-cost/pa/easton.

[4] "Project Sunroof - Data Explorer | Easton." *Google*, Google, https://sunroof.withgoogle.com/data-explorer/place/ChIJX1hwGIJrxIkRK8iPdCcyIDc/

[5] "Cost of Electricity in Easton, PA." *EnergySage*, 23 Oct. 2022, https://www.energysage.com/local-data/electricity-cost/pa/northampton-county/easton/#:~:text=The%20average%20residential%20electricity%20rate,rate%20of%2018%20%C2%A2%2FkWh.

[6] Thoubboron, K. (2022, August 31). *SRECs: Solar Renewable Energy Credits explained: Energysage*. EnergySage Blog. Retrieved October 30, 2022, from https://news.energysage.com/srecs-complete-overview/

[7] "Homeowner's Guide to the Federal Tax Credit for Solar Photovoltaics." *Energy.gov*, https://www.energy.gov/eere/solar/homeowners-guide-federal-tax-credit-solar-photovoltaics

[8] *How Much Does Home Solar Battery Cost per Kwh?* https://www.bsl-battery.com/how-much-does-home-solar-battery-cost-per-kwh.html.