Do You Stay Connected, or Do You Disconnect?

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Abstract *— This Research Project is based on the lack of knowledge in the area of solar energy in Puerto Rico. Yes, a low percentage of residents have invested in solar systems. The current power grid is not reliable and it's constantly failing. This prevents some small businesses to cease operations due to loss of power. The flip side of this is the patients that live in their houses that have medical equipment that requires power constantly to function. This research project shows the benefit of constant and reliable energy to cover all necessities.*

Key Terms *— Fossil Fuel, Renewable Energy, Solar Energy, Solar Panels.*

PROBLEM STATEMENT

As the title states "Do you stay connected, or do you disconnect?". What we are referring is to the energy source that is provided to a household or business. Three main sources of energy exist, nuclear, fossil fuels, and solar. This project will only concentrate on two, solar and fossil fuels. In 2021 fossil fuels provided about 97% of Puerto Rico's electricity. In recent years many clients have moved to a more stable source of energy, solar. The current power grid is not stable due to a lack of maintenance and lack of upgrades. Another issue is the forces of nature. Puerto Rico is constantly experiencing heavy rains or worse, hurricanes. This causes the grid to degrade or fail.

Research Description

The importance of this project is to allow the general population or business owners to select different options when it comes to a stable source of energy. We will look into companies operating in Puerto Rico that provide solar power options and the only fossil fuel company in Puerto Rico, Luma. Also, we are going to compare two households. One of them is a regular home and the other one has a special case where the AC has to be on due to a skin condition.

Research Objectives

Be able to educate the clients strategically so that they can start knowing and contemplating the implementation of the Lean Six Sigma concepts. Starting with developing improvements in the warehouse, eliminating waste, and positively impacting current and future inventory management processes. As well as to understand that proper inventory management is essential to avoid economic losses and obtain better profits.

Research Contributions

Provide the general population or business owners with the needed information in order to select the most beneficial source of energy configuration based on need, efficiency, cost, and productivity. Other major contributions are that solar power is pollution-free, produces renewable clean power, provides a return on investment, creates jobs; and solar panels are virtually maintenance-free and can last up to 30 years.

LITERATURE REVIEW

It is important to know what the origin of renewable energy is. The concept of renewable energy appeared in 200 BC with the waterwheel. Renewable energy is defined as energy that can be renewed, unlike any fossil fuel [1]. Renewable energy can be seen in different technologies: solar energy, wind power, hydropower, bioenergy, geothermal energy, etc. We will be focusing on solar energy. It is important to present Augustin Mouchot, a French inventor. He is the first person to use solar energy to heat up water and create steam in 1860. Let's move on a few years later [2]. Let's define solar energy.

Solar energy can be seen as back in history as the 7th century BC. It was used to make fire and burn ants [3]. In 1839 a French scientist Edmond Becquerel discovers the photovoltaic effect while experimenting with an electrolytic cell made up of two metal electrodes placed in an electricity-conducting solution-electricity-generation increased when exposed to light. Then in 1876 William Grylls Adams and Richard Evans Day discover that selenium produces electricity when exposed to light. Although selenium solar cells failed to convert enough sunlight to power electrical equipment, they proved that a solid material could change light into electricity without heat or moving parts [3]. We will be completing the research with one of the major companies in solar power conversion in Puerto Rico, Power Solar.

Everything leads to evolution and change, from fossil fuels to renewable clean energy. In order to achieve the change, we have to install a system that generates enough energy to charge the batteries and supply them for day-to-day living or operations. We need to explain the crucial components of a solar energy system. The components are a solar array or solar panel, microinverters, electrical panel, battery charge controller and measuring panel, and battery storage.

The first step is conducting an electricity consumption and cost analysis. In this analysis, we find the hourly, daily, weekly, and annual electric consumption and cost. This analysis monitors the following variables: voltage, amps, and power. This is monitored in different locations, solar panels, electrical panels, and battery storage. This is the most important analysis because based on these numbers we will design our solar system. Once we've obtained the hourly, daily, weekly and annual electric consumption, we can concentrate on the design of the solar system. Here is where we have to pay close attention to the company and available products. The product options and availability are what will affect our economic aspect.

How does a Solar system work? Our source of energy is solar, next, we have a solar array or solar panel. The solar array absorbs the rays and converts it to DC electricity. Next in line is the charge controller or gateway, which sends DC electricity to the batteries for storage or to the AC inverter. The DC electricity needs to be converted to AC, which is done using an Inverter. The inverter converts electricity from DC to AC to be used in the house with all the regular household appliances. See Figure 1 for an example of a standalone PV system [4].

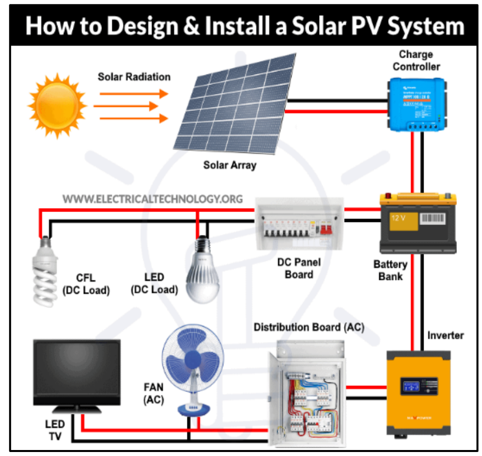


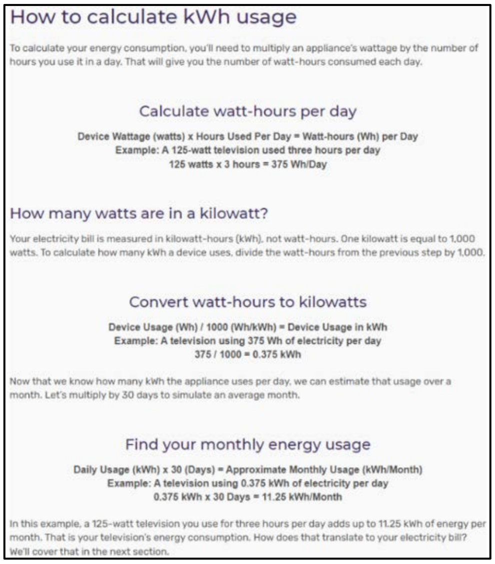
Figure 1
Standalone PV System

Methodology

For this part, we will calculate the energy consumption in the household in order to design the solar system. First, we need to identify the electrical device and pull out the specs in Watts*hour (Wh). Second, with the Wh, we multiply the number of hours used during the day, which gives us the Watts*hour per Day (Wh/day), if we dived it by one thousand, we get kilo*Watt*hour per day (kWh/day). Third, we multiply by the times used during the week and we get kilo*Watt*hour per week (kWh/week). Fourth, we multiply it by 4 and get kilo*Watt*hour per month (kWh/month). See Figure 2 for an example [5].

In Table 1 we calculated the power consumption per electrical device used in a household. The hours per day and day per week, are average use calculated for the first household analyzed.

Next, we have one of the monthly bills with the reading of the use of electricity. The month showed there was a consumption of 755.00 kWh. This gives us an idea of what to design for. We need a system capable of generating this amount or covering the bill. This is the most important part of the project, the analysis of the yearly consumption. We have to use all the values from all months and find the average. With this average, we design our system. This way we cover the yearly consumption. Covering all the low-consumption and high-consumption months.



How to calculate kWh usage

To calculate your energy consumption, you'll need to multiply an appliance's wattage by the number of hours you use it in a day. That will give you the number of watt-hours consumed each day.

Calculate watt-hours per day

Device Wattage (watts) x Hours Used Per Day = Watt-hours (Wh) per Day
Example: A 125-watt television used three hours per day
125 watts x 3 hours = 375 Wh/Day

How many watts are in a kilowatt?

Your electricity bill is measured in kilowatt-hours (kWh), not watt-hours. One kilowatt is equal to 1,000 watts. To calculate how many kWh a device uses, divide the watt-hours from the previous step by 1,000.

Convert watt-hours to kilowatts

Device Usage (Wh) / 1000 (Wh/kWh) = Device Usage in kWh
Example: A television using 375 Wh of electricity per day
375 / 1000 = 0.375 kWh

Now that we know how many kWh the appliance uses per day, we can estimate that usage over a month. Let's multiply by 30 days to simulate an average month.

Find your monthly energy usage

Daily Usage (kWh) x 30 (Days) = Approximate Monthly Usage (kWh/Month)
Example: A television using 0.375 kWh of electricity per day
0.375 kWh x 30 Days = 11.25 kWh/Month

In this example, a 125-watt television you use for three hours per day adds up to 11.25 kWh of energy per month. That is your television's energy consumption. How does that translate to your electricity bill? We'll cover that in the next section.

Figure 2
How to Calculate kWh Usage

Table 1
Average Power Consumption Use of Electrical Devices

	Component	Quantity	Wh	Hours of use per day	kWh/day
1	TV	2.00	75.00	6.00	0.90
2	Lights	12.00	10.00	5.00	0.60
3	Lamps	3.00	15.00	6.00	0.27
4	Ac 1	1.00	1,000.00	6.00	6.00
5	Ac 2	1.00	1,000.00	6.00	6.00
6	Phone Chargers	4.00	40.00	5.00	0.80
7	Computer	1.00	750.00	3.00	2.25
8	Laptops	3.00	60.00	6.00	1.08
9	Microwave	1.00	1,200.00	0.50	0.60
10	Fridge	1.00	275.00	24.00	6.60
11	Stove	1.00	3,000.00	2.00	6.00
				Total	31.10

	Days of use per week	kWh/week	kWh/month	kWh/year
1	4.00	3.60	14.40	172.80
2	7.00	4.20	16.80	201.60
3	7.00	1.89	7.56	90.72
4	7.00	42.00	168.00	2,016.00
5	3.00	18.00	72.00	864.00
6	7.00	5.60	22.40	268.80
7	1.00	2.25	9.00	108.00
8	4.00	4.32	17.28	207.60
9	7.00	4.20	16.80	201.60
10	7.00	46.20	184.80	2,217.60
11	7.00	42.00	164.00	2,016.00
	Total	174.26	693.04	8364.72

Once we have our average, we can design the system accordingly. We need to calculate how many solar panels we need and how many batteries we require. First, we calculate our averages. We add all the monthly consumption and dived it by 12. Also, we will annotate our max and lowest consumption for comparison. Once we have that average, we compare it to all of our monthly consumption and make sure that we cover more than 75% of all readings. A detail new to the analysis is the consumption per house occupant. This is calculated using the yearly average divided by the house occupants.

To calculate the amount solar panels, we need a few details. We require the number of hours daily of sun, we are going to use 5 hours daily of sun. That gives us 1800 hours of sun per year. We need to know the capacity of generating electricity depending on our solar panels. Our design uses a 415 Wh per hour solar panel. With this, we can calculate our number of solar panels (1).

$$\underbrace{16{,}500\left(\frac{kWh}{Yr}\right)}_{(Yearly\ house\ required\ power)} \times \underbrace{1{,}000\left(\frac{W}{kW}\right)}_{(kWtoW\ conversion)} \times \underbrace{\frac{1}{1{,}800}\left(\frac{Yr}{h}\right)}_{(Yearly\ hrs\ of\ Sun\ Power)} \times \underbrace{\frac{1}{415}\left(\frac{h}{Wh}\right)}_{(Solar\ panel\ power\ generation)} = 22\ panels \tag{1}$$

Next, we move to the option of how many batteries we require. We have to be based on how much consumption is needed. One battery is 13 kWh, but the use of the battery is not to power everything in the house, it's only for the essentials during an emergency or local grid outage. In an emergency the only devices used may be tv, fans and lights. A TV only consumes around 75W, a fan consumes around 100W, and lights consume around 10W. From the table "Average power consumption use of electrical devices table" we can calculate how much a battery will last (2).

$$\frac{Battery\ Power\ Capaity}{The\ Sum\ of\ Electrical\ Devices\ Used}$$

$$\frac{1\ Battery}{1\ TV + 3\ Fans + 10\ Lights}$$

$$\frac{13{,}000\ Wh}{75\ W + 300\ W + 100\ W} = \frac{13{,}000\ Wh}{475\ W} = 27\ h\ 20\ min\ on\ one\ battery\ only$$

$$\frac{2\ Battery}{1\ TV + 4\ Fans + 10\ Lights}$$

$$\frac{26{,}000\ Wh}{75\ W + 400\ W + 100\ W} = \frac{26{,}000\ Wh}{575\ W} = 45\ h\ 12\ min\ on\ two\ battery\ only \tag{2}$$

RESULTS AND DISCUSSION

The first house analyzed, see Figure 3, is four occupants' household, three adults and one child. Per the electrical bill, we have an average of 697kWh per month and yearly consumption of 8,368kWh per year. It is clear that the highest consumption will always be in June and July or if a weather pattern presents itself, for example, a heat wave.

Now we can calculate the Max, Average, and Minimum consumption, and most important the average use of electricity per occupant, see Table 2. Using the formula to calculate the number of solar panels is eleven and one battery is required. With that calculated, we can take our information to a company that sells, installs, and maintains solar systems. We got a quote of $200.11 per month.

The quote provides a very important detail, see Figure 4, about how much energy you will consume from both sources, solar and electrical grid. For house 1 we can see that 77% of the energy will be solar power and 23% will be electrical grid.

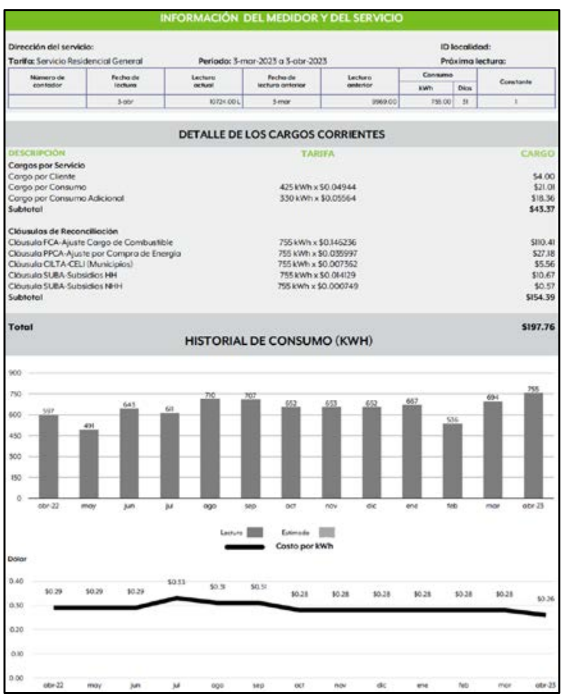


Figure 3
Electrical Bill, Household 1

Table 2
Analysis of Household 1

House 1 analisis (4 ocupants)				
Month	Cosumption History (kWh)	Cost per kWh	Monthly Bill	
Apr-22	597	$ 0.29	$ 173.13	
May-22	491	$ 0.29	$ 142.39	
Jun-22	643	$ 0.29	$ 186.47	
Jul-22	611	$ 0.33	$ 201.63	
Aug-22	710	$ 0.31	$ 220.10	
Sep-22	707	$ 0.31	$ 219.17	
Oct-22	652	$ 0.28	$ 182.56	
Nov-22	653	$ 0.28	$ 182.84	
Dec-22	652	$ 0.28	$ 182.56	
Jan-23	667	$ 0.28	$ 186.76	
Feb-23	536	$ 0.28	$ 150.08	
Mar-23	694	$ 0.28	$ 194.32	
Apr-23	755	$ 0.26	$ 196.30	
	755		$ 220.10	Max
	697	$ 0.29	$ 201.69	Average
	491		$ 142.39	Min
	174	$ 0.29	$ 50.40	Average per occupant
	8368		$ 2,418.31	Total per Year
	11	Number of solar panels needed.		
	1	Tesla Powerwall Plus Battery.		
	1	Gateway.		
	$ 200.11	Monthly Bill of Solar System for 25 years.		
	$ 2,401.32	Annual Bill of Solar System for 25 years.		
9 months out of the 12 are below the Average consumption				

Figure 4
Household 1, Solar System Quote

The second house analyzed, see Figure 5, is 5 occupants' household, three adults and two children. Per the electrical bill, we have an average of 960kWh per month and yearly consumption of 16,500kWh per year. It is clear that the highest consumption will always be in June and July or if a weather pattern presents itself, for example, a heat wave.

Now we can calculate the Max, Average, and Minimum consumption, and most important the average use of electricity per occupant, see Table 3. Using the formula to calculate the number of solar panels is eleven and one battery is required. With that calculated, we can take our information to a company that sells, installs, and maintain solar system. We got a quote of $382.95 per month.

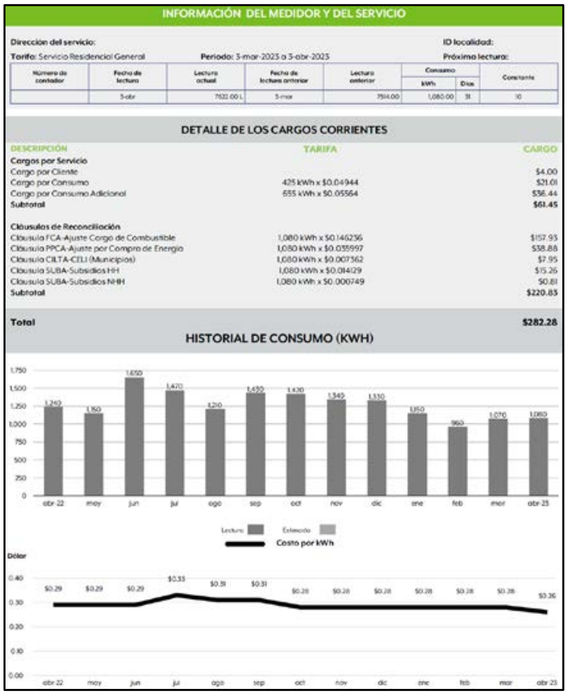


Figure 5
Electrical Bill, Household 1

The quote provides a very important detail, see Figure 6, about how much energy you will consume from both sources, solar and electrical grid. For house 1 we can see that 85% of the energy will be solar power and 15% will be electrical grid.

Table 3
Average Consumption per Occupant

Average consumption per occupant. The second house has a special medical situation. We can find an average between a special case and a regular house.			
Consumption History (kWh)	Cost per (kWh)	Monthly bill	Average per occupant
225	$0.29	$64.95	

Table 4
Analysis of Household 2

House 2 analisis (5 ocupants) Special Case				
Month	Cosumption History (kWh)	Cost per kWh	Monthly Bill	
Apr-22	1240	$ 0.29	$ 359.60	
May-22	1150	$ 0.29	$ 333.50	
Jun-22	1650	$ 0.29	$ 478.50	
Jul-22	1470	$ 0.33	$ 485.10	
Aug-22	1210	$ 0.31	$ 375.10	
Sep-22	1430	$ 0.31	$ 443.30	
Oct-22	1420	$ 0.28	$ 397.60	
Nov-22	1340	$ 0.28	$ 375.20	
Dec-22	1330	$ 0.28	$ 372.40	
Jan-23	1150	$ 0.28	$ 322.00	
Feb-23	960	$ 0.28	$ 268.80	
Mar-23	1070	$ 0.28	$ 299.60	
Apr-23	1080	$ 0.26	$ 280.80	
	1650		$ 485.10	Max
	1375	$ 0.29	$ 397.69	Average
	960		$ 268.80	Min
	275	$ 0.29	$ 79.50	Average per occupant
	16500		$ 4,791.50	Total per Year
	22	Number of solar panels needed.		
	2	Tesla Powerwall Plus Battery.		
	1	Gateway.		
	$ 382.94	Monthly Bill of Solar System for 25 years.		
	$ 4,595.28	Annual Bill of Solar System for 25 years.		
8 months out of the 12 are below the Average consumption				

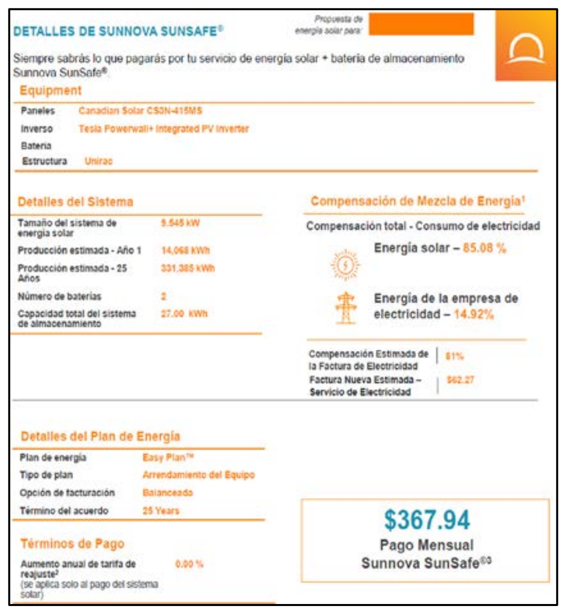


Figure 6
Household 2, Solar System Quote

Conclusions

Per the analysis of both households, we can clearly identify that both solar systems cost less than the average monthly payment. Currently in Puerto Rico the current electric company is Luma. The average cost of electricity in Puerto Rico between

2014 and 2021, is $0.21 per kWh. It is clear that the current average cost between 2022 and 2023 is $0.29. That shows that Luma is charging higher prices than in the last 7 years. Luma continues to announce that there will be a rise in the cost of electricity.

By converting to solar you eliminate all fluctuations of the cost and stop it from getting a higher bill. If we dived our monthly payment for the solar system and our energy consumption, we get an electricity cost of $0.26 proving that it is cheaper to run on solar power. By switching to solar power, we achieve all our objectives.

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