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An Experimental Approach towards Energy Sustainability in University Communities

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Abstract

Ever rising demand for energy has crossed the parameters and has reached to an irrepressible level where human activities couldn't go any further unless they address this perilous situation. Most communities and institutions have recently realized that they've been very much un-sustainable in their day-to-day operations. Now their prime concern is not to compete among themselves but to become self-sustainable which they realize as the key to successful business. This paper aims to demonstrate how an institutional community can become self-sustainable in meeting their energy requirements. Our study targets efficient deployment of solar panels in large campus communities to effectively meet the energy sustainability. Sustainability is achieved through the deployment of 1.7 million solar panels in the campus community together generating 13,369 megawatt hours per year. On the consumption side, smart control panels help to limit usage to 4,338 megawatt hours per year, allowing 9,031 megawatt hours to be pushed back to the grid, generating an annual revenue of $0.6 million. This level of surplus helps to defray the initial investment in eleven years' time, which is about half the lifespan of solar panels, thereby proving the economic viability of the deployment. The methodology is repeatable and replicable in any community aspiring to achieve self-sustainability.

Keywords: Energy, Solar, Sustainability

INTRODUCTION

Energy has become a superior concern over the last few decades for policy makers around the world due to increasing prices, demand and diminishing fossil fuel resources(Reddy, et al., 2014)(REN21, 2012)(IEA, 2011)(GEA, 2012). They are many alternatives like nuclear, wind, solar, hydro, biomass, tidal, geothermal etc. to solve this issue of paramount importance(REN21, 2012)(IPCC, 2007). However, *solar energy* is the most abundant and green choice available across the world(Freeman, et al., 2012)(IEC, 2008). According to estimates(IMD, 2009), the solar energy sensed by the planet earth is greater than the world's commercial energy utilization by 15,000 times and also 100 times more than the world's ever known coal, gas and oil reserves. Solar energy was initially used mainly to provide electricity to satellites, but now solar technologies have improved enough to supply energy not only to remote areas but also to add-on the national grid power at multi-megawatt levels(Pipattanasomporn, 2004).

Evidence from the literature advocates that, university communities and campuses are ideally suited for field trials of trying out sustainability of energy, mainly because of:

- Reduced emphasis on immediate profit expectation
- Keen desire to try out new technologies, with their associated risk, without being afraid of temporary failed steps along the way
- Motivation to bring down the costs
- Requirement to provide uninterrupted power to students, faculty, research laboratories and teaching class rooms.

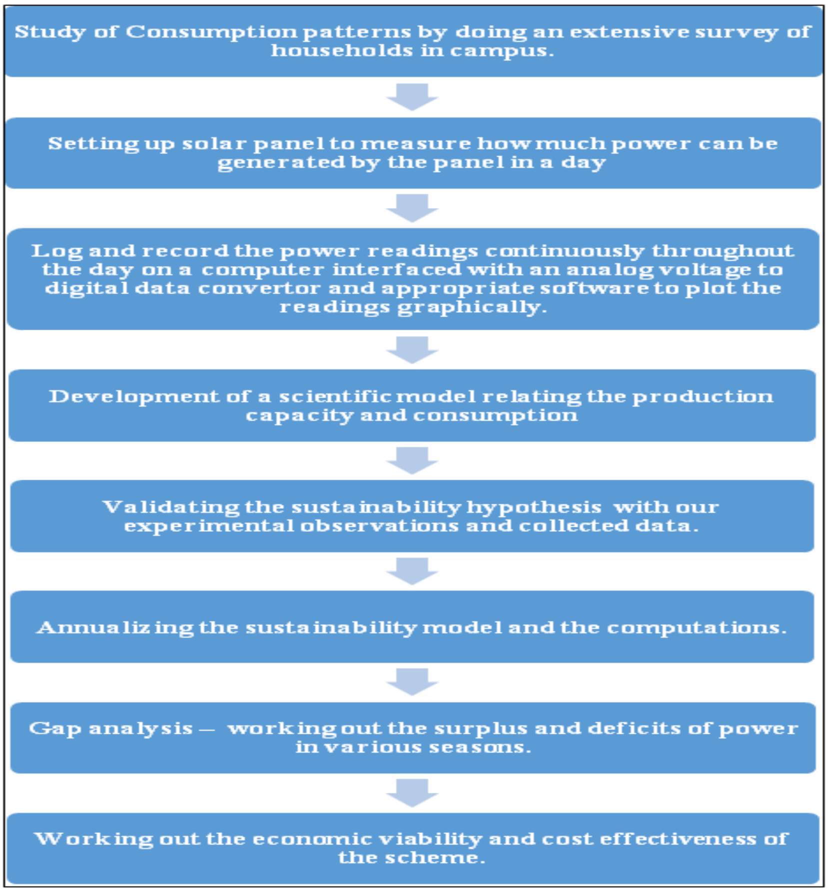
As the primary motive of universities is to excel in academic and research activities, there is less emphasis on immediate break-even or profit. When the vision is to achieve long-term sustainability, revenue generation becomes an ancillary objective to the university. As universities are the power houses of invention and innovation, there is always an intense desire to try out new and cutting edge technologies regardless of the risk that may arise and temporary failures. Universities possess the knowledge and technical knowhow to handle and operate with the sophisticated technologies, while at the same time, they are less worried about the minor failures and hurdles that come in the way. University campuses place substantial demand on power generation as they consume energy on a large scale and they always incur a tremendous expenditure on energy. Thinking from the ethical side, energy consumption rates of universities are always beyond the acceptable range. So, there is a motivation to bring down the costs by becoming sustainable and above all it is an obligation of universities to embrace the concept of *social responsibility.* Further, universities need to provide un-interrupted power to all its students, faculty and laboratories throughout the day, they need to find a cost-efficient way to meet its energy needs. Universities are the centres where research is extensively done for the betterment of mankind, but, it should not be so that the required resources are sourced and consumed un-sustainably. So, sustainability is not an optional concept for them but it's a must.

In this experimental engineering research, we chose the campus community of Amrita University, recently best ranked private university of India, for a sustainability study, deployment, and evaluation of solar energy. The headquarters of Amrita University, located on a sprawling foothills spanning across 400-acres has a student population of over 12,000 and faculty strength of nearly 1500. The campus is ideal for the deployment of solar panels due to many reasons:

- Geographical location of the campus is very much ideal that it recieves adequate sunshine throughout the year. India lies in a perfect geographical location in the equatorial region and has an annual average temperture ranging from 25°C to 27.5°C

- To install the solar panels, it requires a lot of area and the physical space available in the campus is abundant enough to set up the whole system. Rooftops and vacant spaces are plentiful in the campus which can be strategically utilized.
- The campus is managed by Sri Mata Amritanandamayi Math, a world renowned humanitarian organization, which gives so much importance for environment conservation, resource management, and long term sustainability.
- Faculty, students and staff of the campus are very much supportive in bringing changes and they have a profound attitude for welcoming innovative and sustainable ideas.

In many countries, governments (MNRE, 2016) are actively launching numerous promotional schemes such as *'solar cities'* to actively encourage communities to embrace solar power. However, most communities are either ignorant of how and where to start, or exhibit hesitation regarding prospects of economic viability in the face of significant initial investments. In this paper, we present a definite methodology and derive its sustainability and economic viability. The methodology is replicable in any community aspiring for energy self-sustainability.



REVIEW OF RELATED PREVIOUS LITERATURE

Finlay & Massey(2012) state that universities and colleges are chief places of transformation as centres of discourse and vehicles of social change, and they further point out that sustainability is one concern that has become a fundamental focus of teaching and research in universities. Wright (2002) and Clarke & Kouri(2009) argue that, as the teachers of the majority of society's leaders, colleges and universities have a great responsibility to enhance the awareness, technologies, and tools necessary for a sustainable future. The trend of university campuses taking up the initiative of trying out the sustainability of energy has been showing a positive hike which reflects their passion to show concern towards the planet regardless of the possible risk associated with it.Uhl & Anderson (2001) point out that universities have the obligation to guide society towards environmentally sustainable policies and practices as they have access to the most up-to-date knowledge of both environmental issues and practical solutions. There are several other reasons why university campuses are ideally suited for field trials for trying out sustainability of energy. As they give more importance to the innovation and research aspects, they are less concerned about immediate break-even. Uhl & Anderson (2001) have also mentioned that the purchasing power of universities has already been used as a tool for the diffusion of environmentally beneficial innovations. According to Finlay & Massey(2012), universities are important sites to implement sustainable development as the autonomy of the governance structure and local politics are less complex than they are at the scale of the city. Above all, they need to provide incessant power to students, faculty, research laboratories and class rooms for which they need to source energy from sustainable sources such as deployment of solar panels on a large scale.

University at Buffalo, New York has deployed one of the biggest ground-mounted solar arrays in New York State, and the *Solar Strand* consists of 3200 photovoltaic panels which has the capability to generate 750,000 watts of energy (University at Buffalo, 2016). They expect that the solar strand will produce as much carbon-free energy to power hundreds of student houses at UB. They also mention that their intention is to get people thinking about the prospects for renewable energy by allowing them to see it in action up close. Arizona State University argues that their solar portfolio is the biggest of any University in the U.S., and possibly the world (Arizona State University, 2016). ASU has more than 24-MWdc photovoltaic, concentrated photovoltaic and solar thermal solar systems at 89 sites on all four of its campuses including their research park. They argue that, they are able to avoid 23,267 metric tons of carbon dioxide equivalent emissions per year, approximately the same as the annual discharges of 4804 passenger vehicles. Their estimated yearly generation of 42,826 MWHs is equal to the energy required to power 3366 homes for one year. At the University of California, Davis, they have constructed a 16.3 MW (AC) solar power plant on a 62-acre land which is estimated to produce 14% of the electricity the campus needs and is expected to minimize the campus's carbon footprint by 9% or 14,000 metric tons. University of California, Davis, Chancellor Linda P.B. Katehi, has said that "By taking steps to aggressively reduce our carbon emissions, we can set an example to the nation and the world of what can be achieved when we combine political will with science and innovation"(Fell, 2015).

Many campuses aspired to deploy solar panels but due to numerous riddles they're unable to move forward. Shriberg (2002) states that the most common weakness of universities & colleges is that they don't have a coordinated method that can precisely evaluate campus initiatives and provide well-grounded strategies for success to overcome institutional barricades. Nicolaides(2006) and Thomas(2004) point out that inflexible conventional standpoints of faculty and administration and the lack of expertise and tradition can encumber change. Finlay & Massey(2012) declare that in order to overcome these hurdles, the primary step should be to make sustainability explicit in the universities' academic and policies of research, organizational mission, and planning.

GOALS OF OUR RESEARCH

We started the experimental engineering deployment of solar panels with the following scientific and engineering goals in mind:

- To quantify the sustainability of communities through the use of solar energy.
- To develop a deployment model that can be conveniently adopted by other institutional communities in order to embrace the concept of sustainability
- To provide a scientific basis for the model, so that it receives universal acceptability & validity.
- To analytically formulate the economic viability and prove that there is a net savings, and quantify the benefit to the environment by way of reducing the carbon footprint.
- To demonstrate that communities and campuses around the world can boldly transform themselves into net zero carbon communities, and to provide them with a provably correct roadmap for the achieving the same.
- To contribute towards the realization of the vision of 2015 United Nations Climate Change Conference at Paris, (COP21).

As a significant outcome, our efforts have motivated numerous students and faculty researchers of our campus to engage themselves in energy sustainability for benefiting the humanity and Nature.

METHODOLOGY

The whole process can be divided into eight steps as summarised in the ***Figure 1.***The first step of study involved an exploratory investigation to find out the consumption and demand trends of electricity in the 400 acre campus of 5000+ residents. Data gathering drive was conducted to ascertain the amount of electricity consumed by different households. The next step was to identify the power production of a solar panel in a day so as to determine the number of solar panels required. This is a crucial step as this determines whether the area available in the campus is enough for the deployment of solar panels. To avoid the errors occurring due to different weather conditions, the experiment was done at the campus on sunny, cloudy and rainy day and the results were extended to annual projections. The next step involved developing a mathematical model relating the production capacity and consumption which represents a framework for sustainability. The model is validated by plugging in the observations from the experiments. Finally the economic viability is worked out and the gap relating the production capacity and the consumption is calculated. From the results, it was concluded that solar power can become the main pillar of sustainable energy source for the campus.

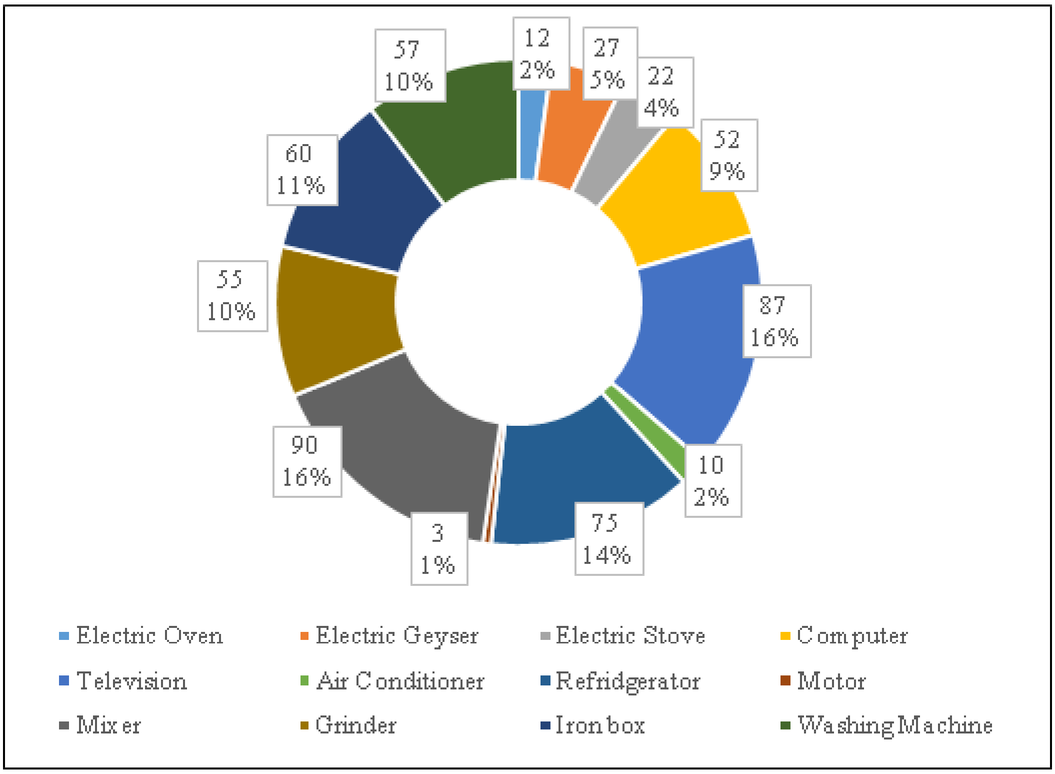


Figure 1: Percentage & number of houses using electrical appliances

HOUSEHOLD ENERGY CONSUMPTION PATTERN

In order to assess the household energy consumption patterns of the campus and to know whether the residents are aware of solar energy and smart grids, a total of 100 residential houses were surveyed. From the data acquired of the survey, average electricity consumption of each household was calculated.

It was understood that the monthly energy consumption illustrates a wide variation from a minimum of 4kWh to a high of 537kWh per household.**Figure 2** presents the percentage & number of houses using different types of electrical appliances. The aggregate energy consumption of all residents amounted to 1, 09,392 kWh in a year. **Figure 3** shows the wattage consumed by various electrical appliances.

These measurements are used in the scientific sustainability model developed in the later sections.

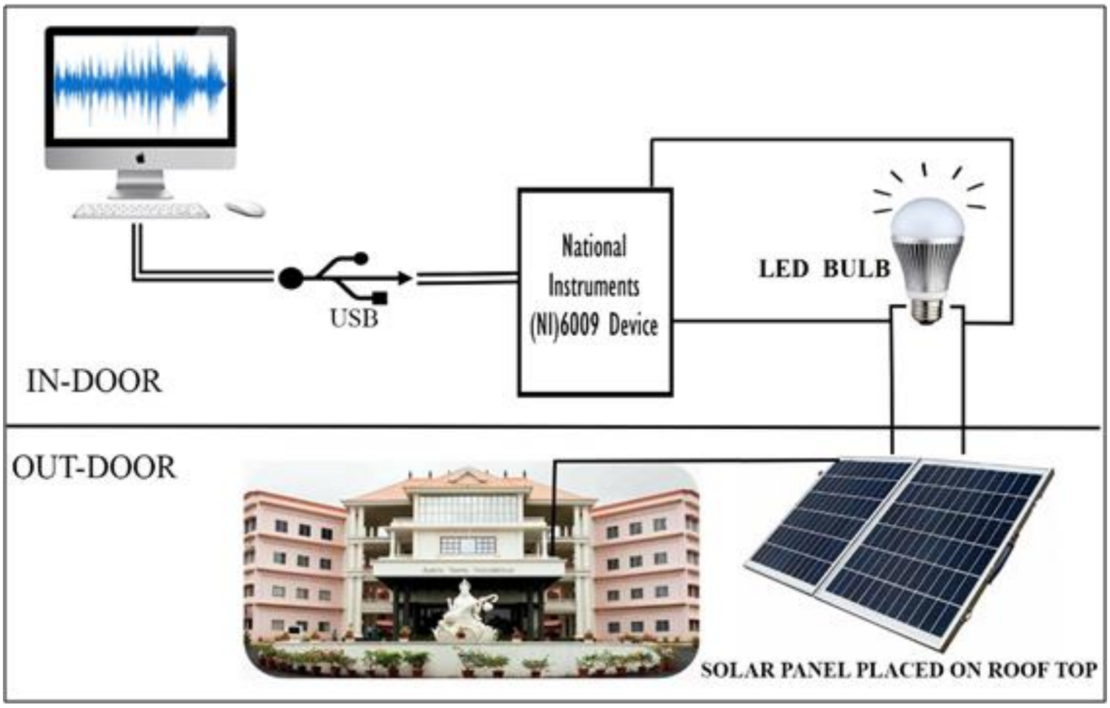


Figure 2: Wattage Consumption of various electric appliances

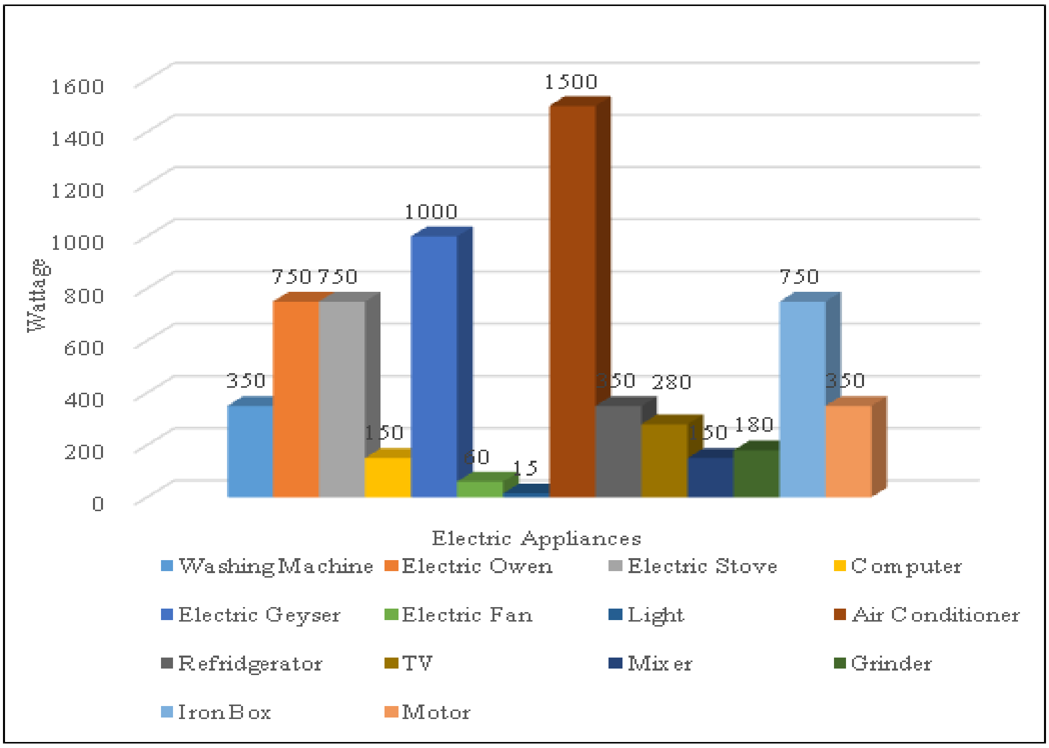


Figure 3: System Architecture for Continuous Monitoring of Solar Power Generated

SOLAR PANEL EXPERIMENTAL SETUP

Moving on to the heart of the project, we set out to design a system which can measure and record the amount of electricity that can be produced by a solar panel in a day at our campus. The particular geographic location of our campus experiences diverse climate than other cities of Tamil Nadu. So, it is necessary to measure the power generation by a solar panel on different days having different climate conditions (Sunny, Rainy & Cloudy).

Figure 4 portrays the system architecture for continuous monitoring of solar power generated. A solar panel having an area of $0.0462m^2$ was selected for the experimental setup. It is made of polycrystalline material with an efficiency of 13-16%. The solar panel is kept on a rooftop receiving direct sunlight. Two wires having positive and negative terminals are connected to the panel and the other ends of the wires are connected to a circuit consisting of a light bulb as its load and simultaneously the voltage is transmitted across the load to National Instruments 6009 device. The NI 6009 is capable of simultaneously converting the analogue signals into digital signals. The NI 6009 is connected via USB to the computer where the digital signals can also be monitored as a graph while they're being logged. The voltage analogue input from the solar panel is sent as a digital output to the PC and is logged. The NI 6009 can receive a maximum of 6 volts and the voltage coming from the panel may be as high as 10-11 volts. So, a midway tap is made onto the load and the voltage built up to the midpoint tap is drawn and supplied to the NI 6009 device for measurement. Then the measured voltage is scaled to a certain value in the computer in proportion to the drop to obtain the actual value.

The NI 6009 can be controlled on the computer using software called Labview. Thus the time interval between which the data must be logged can be controlled. Labview collects the digital data and logs it into a spreadsheet. The digital data (voltage) which is being logged into the computer can be monitored using the Labview software as it is being logged.

We measure the highest voltage generated by the solar panel. Then we calculate the corresponding peak power generated, and extend it to other voltage values during non-peak hours of sunlight. Thus, we come to know the total and average power generated in a day.

We carried out many initial experiments with various kinds of loads like LED bulbs, etc. This load turned out to be perfect for the solar panel because the impedance requirement of the solar panel will be matched. So there will be no wastage of power efficiency of the panel. The voltage across the bulb is measured. This voltage will feed a proportional current into the bulb and the bulb will glow with full brightness during peak hours of sunlight. So the power produced will be completely consumed for illumination of bulb. So the power corresponding to other measured voltages are proportionately calculated.

The first day of the experiment is performed on a sunny day. The second day of the experiment is performed on a rainy day. The third day of the experiment is conducted on a cloudy day. The voltage and corresponding power readings for all 3 days at different instances of the day are tabulated. The peak voltages and corresponding power values on all 3 days are also compared.

On the fourth day an experiment to measure the power generation in a day by a solar panel placed on the wall of a building is performed. This experiment is performed to find out whether solar panels if installed on walls would generated an equivalent amount of electricity as generated by solar cells installed on the roof top area. The observations are tabulated and the spreadsheet is attached. The peak voltage and corresponding power is also calculated.

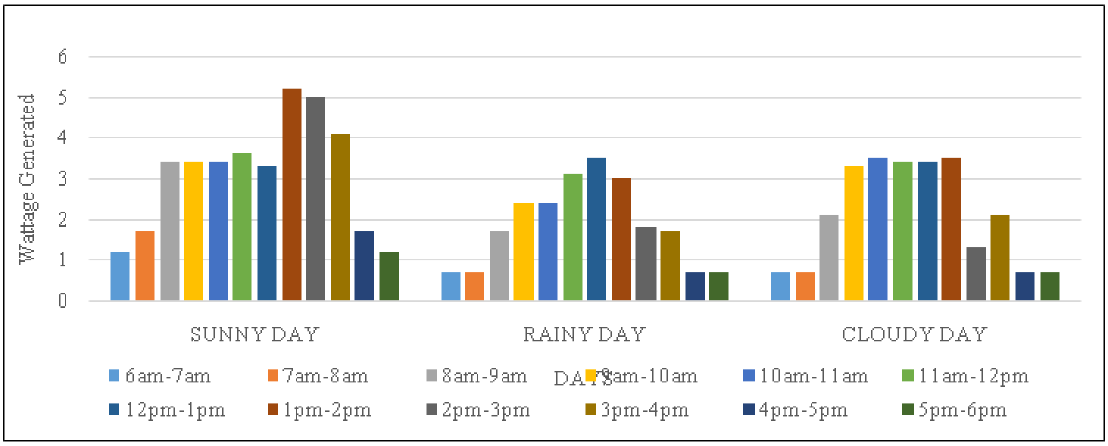


Figure 4: Average Power generated by a Solar Panel on Sunny, Rainy & Cloudy days

OBSERVATIONS

Day 1-Weather: Sunny day

The peak voltage generated was 10.42 volts between the interval of 1pm to 2pm and corresponding power generated was 5.2 watts. The total power generated during the day long experiment was 37.2 watt-hours. The values shown in the graph represent the average values of power generated by the solar panel during various intervals of time during the day.

Day 2-Weather: Rainy day

The peak voltage generated was 7.84 volts during the time interval of 12pm-1pm and the corresponding power generated was 3.89 watts. The aggregate power generated on the whole day was 22.4 watt-hours.

Day 3-Weather: Cloudy day

The peak voltage generated was 7.85 volts during the time interval of 10am-11am and corresponding power generated was 3.9 watts. The total power generated during the day long experiment was 25.4 watt-hours. The values given in the graph represent the average values of power generated from the solar panel during various intervals of time during the day

Furthermore, during those rare days (in some of the seasons) of unexpected continued adverse weather conditions that may cause a consequent temporary dip in solar power generation, we propose the deployment of usage control panels, which employ smarts to adaptively fine-tune consumption by dynamically adjusting the number and duration of operation of various appliances so as to not exceed the solar energy generated on that day of the season.

SUSTAINABILITY MODEL

Let us suppose that, Area of solar panel = A_S, Roof top area = A_F per household, A_U for whole campus Maximum number of solar panels that can be installed =A_F/A_S per household, A_U/A_S for whole campus Total power generation in a day by a panel averaged over all seasons = G_S units Total power consumption in a day = C_F per household, C_U for whole Power generation in a day $P_F = A_F \times G_S/A_S$ per household, $P_U = A_U \times G_S/A_S$ for whole campus

After the initial formulation, when comparing power generation vis-à-vis power consumption at the aggregate campus community level, there are three possibilities:

- **Deficit:** Power generated, $A_U x\ G_S/A_S < C_U$, as a result of which, it is insufficient to meet the consumption needs, and thus it demands for additional solar panel implementation.The required additional area to make up for the deficit, $D_A= (C_U/G_S)x\ A_S-A_{U.}$ The community becomes public power grid dependent.
- **Surplus:** Maximum power generation is greater than the total power consumption, that is, $AUx\ G_S/A_S > C_U$. Then it becomes public power grid independent and the surplus electricity can be pushed back to the grid.
- **Balanced:** Maximum power generation in a day by solar panels at campus is equal to the total power consumption in a day of campus. ($A_U \times G_S/A_S = C_U$)

Validation of The Sustainability Model

Table 1 presents how the sustainability model is validated at both the individual household level and the entire campus community level. At the individual household level, the power generated in a day $P_F = A_F x G_S/A_S >$ power consumption C_F, and the surplus is, $A_F x G_S/A_S - C_F = 27.02 – 18 = 9.02$ kWh, and it becomes public power grid independent. Since we have taken the maximum consumption per household and average solar power generation, we are guaranteed to save a minimum of 9.02 kWh in a day per household.

Likewise, maximum power generation in a day in the entire campus community is, $P_U = A_U\ x\ G_{S/}A_S = 46731.524$ kWh, which is greater than Cu, and the campus-wide surplus is: $A_U\ x\ G_S/A_S - C_U = 46731-12050 = 34,681$ kWh. Thus it becomes public power grid independent and we can save 34,681 kWh per day in the entire campus community.

Table 1: Validation of Sustainability Model

	Individual Household	Campus as a whole
Area of a solar panel	A_s=0.0462m^2	A_s=0.0462m^2
Roof top Area	A_F =44.57m^2 (average)	A_u =77,107 m^2(total)
Max number of solar panels that can be installed	A_F/A_S = 965 panels	A_U/A_S =16,68,983 panels
Total power generated per day averaged over all types of weathers in watthours	G_S = 0.028kWh units	G_S = 0.028kWh units
Total Power consumption in a day	C_F = 18 kWh	Cu=12,050 kWh
Power generation in a day	$P_F = A_F \times G_S/A_S$ = 27.02 kWh	$P_U = A_U \times G_S/A_S$ = 46,731.524 kWh

Annualizing the Sustainability Model

In order to annualize the above sustainability model, we compute the solar power production during various seasons taking into consideration the number of days of sunlight for each season, number of hours of sunlight in a day for each season, etc., the outcome of which is presented in Table 2.

Table 2: Annualizing the sustainability model and the computations for each household& the entire campus community as a whole. In column F, the numbers 965 panels and 1,668,983 panels are taken from 4th row of Table 1

A. Seasons	B. Months	C. Daily kWh/solar panel	D. Equivalent days of sunlight	E. Max. kWh used		F. Total power generated by solar panels, kWh Per Household: C x D x 965panels For the Campus: C x D x 1,668,983panels		G. F – E Surplus Power kWh	
				Household	Campus	Household	Campus	Household	Campus
Summer	4	0.037	120	2160	1,445,996	4284	7,410,284	2124	5,964,288
Winter	4	0.025	90	2160	1,445,996	2171	3,755,211	11	2,299,215
Monsoon	4	0.022	60	2160	1,445,996	1273	2,203,057	-887	757,061
Total	12		270	6480	4,337,988	7728	13,368,552	1248	9,030,564

Economic Viability

The economic viability for sustainability is an important criteria for decision-makers on whether to go in for deployment or not. Since the lifetime of a solar panel is 20 years, it is required to compare the expenditure of consumption and the revenue from generation for 20 years.

The total annual consumption being 4,337,988 kWh (from Table 2), in the absence of solar panels, at the billing rate of $0.15 per kWh, multiplying the kWh consumption by $0.15 x 20 years will peg the total 20 year expenditure on electricity at $13,013,964.

On the supply side, maximum number of solar panels that can be deployed is 1,668,983. At a cost of $4.48 per solar panel, the total deployment cost will amount to $7,477,043. The power produced by the solar panels in a year is 13,368,552 kWh. Of this we are using 4,337,988 kWh per year. So the surplus that we can sell per year to the public grid is 9,030,564 kWh. At a bulk rate of $0.07 per kWh, the revenue per year is $ 632,139.

So, the revenue for 20 years is $ 12,642,789. Subtracting the cost of solar panels, the net earnings in 20 years is $ 5,165,745.

The number of years in which the break-even is achieved on solar panels = cost of solar panels ÷ revenue per year = $7,477,043 ÷ 632,139 = **11 years**

CONCLUSION

Self-sustainability isn’t anymore a fictional concept. Our study gave an insight on how to sustainably and practically solve rising energy demands within communities. The study conducted at our campus proves that a whole organization can absolutely become self-sustainable if the willingness is backed by initial economic resources. The chief outcome or finding from the study is that university communities are highly suitable for the deployment of this concept, but this isn’t a niche model so it can be implemented in any type of organization or institution

By deploying solar panels, communities can become capable of sourcing their own power without depending on public power grids thereby becoming a net zero energy consuming community. By using smart power comparators and bidirectional routers we can send the excess electricity produced from solar panels to the public power grid. Many ways are there to utilize the surplus: in one approach, the excess electricity can be used to fully power all the cars in the campus, with each vehicle running for about 400 km/day consuming about 80kWh/day and 29,200 kWh in a year. So using the surplus of 9,030,564 kWh we can support 309 vehicles which is ample to cover all the vehicles of the campus. In another approach, the surplus energy of 9,030,564 kWh be used to power 50,169 households belonging to neighbouring low-income rural communities which otherwise would have been without power.

The rising temperature of our planet isn’t something to which we can’t close our eyes but they are the indicators for a change. Many organizations and nations have recently joined hands to help our planet to come out of its present trauma. United Nations Climate Change Conference at Paris 2015 (COP21) has boosted its members to take up initiatives for conserving our planet. As a result, many governments are actively launching numerous promotional schemes such as *'solar cities'* to actively encourage communities to embrace solar power. However, most communities are either ignorant of how and where to start, or exhibit hesitation regarding prospects of economic viability in the face of significant initial investments. We have presented a definite methodology and derived its sustainability and economic viability. Our methodology is replicable in any community aspiring for energy self-sustainability, and provides a fast track implementation roadmap as well, hastening all of our efforts towards protection of our Mother Earth.

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