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Micro-grid implementation of a rooftop photovoltaic system

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MICRO-GRID IMPLEMENTATION OF A ROOFTOP PHOTOVOLTAIC SYSTEM

by

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ABSTRACT

In recent years, solar power has been a popular form of renewable energy. This research conducts a cost analysis in implementing a rooftop photovoltaic system as part of an energy management schema for a university campus. The proposed system would be installed on the roof of one of the largest buildings on campus at Missouri University of Science and Technology, Toomey Hall; the objective function of the research involves reducing dependence on conventional energy sources on campus. Toomey Hall houses the Department of Mechanical and Aerospace Engineering (MAE) and is the largest academic unit on campus. Considering the vast expanse of the building it has a high energy demand. Toomey Hall may be thought of as an example of a micro grid considering its energy requirement. Part of the cost-benefit analysis includes an evaluation of the engineering economic aspects involved in implementing such a micro-grid renewable energy project. It considers the feasibility of powering the building by solar photovoltaic energy, to meet its energy demand. This study may be reviewed for implementing photovoltaic on other campuses and part of a similar micro-grid approach.

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NOMENCLATURE

Symbol / Abbreviation	Description
IRENA	International Renewable Energy Agency
kW	Kilo Watt
kWh	Kilo Watt Hour
MAE	Mechanical and Aerospace Engineering Department
MW	Megawatt
MARMET	MidAmerica Regional Microgrid Education and Training Consortium
MoPEP	Missouri Public Energy Pool
Missouri S&T	Missouri University of Science and Technology
n	Number of years
NASA	National Aeronautics and Space Administration
NREL	National Renewable Energy Laboratory
NEM	Net Energy Metering
PV	Photovoltaic
PR	Present value
r	Discount rate
RET	Renewable Energy Technology
RMU	Rolla Municipal Utilities

1. INTRODUCTION

Photovoltaic (PV) systems or the solar PV system is a power system designed to supply power by means of photovoltaics. A PV system is made up of Photovoltaic (PV) arrays. Each array consists of PV panels (modules) that have PV cells. A solar cell or a PV cell is an electrical device that converts the incident light rays into electricity. The words solar and photovoltaic are sometimes used interchangeably.

Generally, solar cells made from silicon are usually flat-plate and generally the most efficient. Some of the solar cells are made from amorphous silicon or similar materials such as cadmium telluride and hence are called thin film solar. Thin film solar cells use layers of semiconductor materials only a few micrometers thick. Thin film solar cells can be used as rooftop tiles and building facades due to their flexibility.

Recently, solar cells are being made from a variety of new materials other than silicon, using conventional printing press technologies, solar dyes, and conductive plastics. Some of the solar cells use lenses or mirrors to concentrate light rays onto small pieces of efficient PV material. The PV material is more expensive but efficient making the systems cost effective for use in general. The only thing to be considered is that the lenses must be facing the source of light. Hence, their use is limited to the areas of earth that have maximum sunshine.

A single panel (module) typically has an arrangement of 6 PV cells by 10 PV cells. Most solar PV systems available for use have an efficiency of about 18 percent to 22 percent with the most efficient having about 25 percent. There are a lot of factors affecting the efficiency of a solar cell some intrinsic such as material it is made up of and doping levels and some are extrinsic such as dust, amount of irradiation, location and arrangement.

There are many applications of the PV technology. It is used in street lighting, agriculture, telecommunications and residential and industrial applications. The modern photovoltaic applications came into existence only in the late 20th century.

Many nations around the world are implementing solar photovoltaic along with conventional energy sources to make them self-sufficient in renewable energy and reduce their dependence on conventional sources of energy. There are some organizations at the international level that help promote the use of renewable energy. The International Renewable Energy Agency (IRENA) is one such intergovernmental organization that promotes the adoption and sustainable use of renewable energy.

The objective of this work is to apply engineering economic concepts such as the payback period and time value of money to the economic decision of implementing photovoltaic on campus. This study may be reviewed for implementing photovoltaic on campus. The economic feasibility of powering the building by PV system was calculated. This work addresses the engineering economics aspects involved in implementing such microgrid level renewable energy project. It considers the cost involved and the possibilities of implementing the project.

Some of the literary works have focused on the cost analysis of implementing PV in an industrial setup. The uniqueness of this work lies in providing a study example of the implementation of such a system in an academic setup considered to be a working microgrid. This work will help in reviewing the possibilities of implementing such a system in an academic setup.

The results obtained are in terms of the payback period and discounted payback period. They give an estimate of the project cost and the time required to recover the cost involved. This work may be reviewed for deployment of renewable energy on campus with the objective to reduce dependence on the conventional energy sources.

2. BACKGROUND WORKING

2.1. ROOFTOP PHOTOVOLTAIC SYSTEM

A rooftop photovoltaic system is a method of generating electricity by means of photovoltaic (PV) panels on the rooftops of both commercial and residential structures. Other components include the mounting system accessories and tools, cables, inverter, switches, panels and other electrical components (Motiekaitis, 2010). The rooftop PV system usually is under One Hundred kW rated capacity. Figure 2.1 below shows a rooftop PV system in Australia.

Figure 2.1. Rooftop PV System in Australia (Gifford, 2015)

Some factors affecting the efficiency of rooftop PV system are as follows (5 Critical Factors Influencing Solar PV System Performance, 2015):

- Irradiance: Irradiance is the amount of solar light incident directly on the surface of the earth. The irradiance levels play a major factor affecting the efficiency of the rooftop PV system.
- Ambient Temperature: Ambient temperature is the temperature at the site of

installation. It significantly affects the efficiency of the PV System.

- Shading and Soiling: Shading is the effect caused by the shadow of nearby objects such as buildings, trees or other such objects that block the incident light falling on the PV Panels. (L.K. Wiginton, 2010)
- Weather Conditions: Weather conditions are another factor affecting the PV System efficiency. Bright and Sunny weather is preferable over cloudy and humid weather for PV electricity generation.
- Time of year: Time of year is important as the light in summer is incident for longer duration as compared to in winter months. The angle of incident light varies round the year based on the seasons.
- Inverter efficiency: Inverter efficiency is the efficiency of converting the direct current (DC) generated into alternating current (AC) that is used in most electrical appliances.

2.2. SOLAR IRRADIANCE

Solar irradiance plays an important role in PV system calculations. Higher solar irradiance levels result in greater amounts of electricity generated. It is for this reason that some of the regions with high irradiance levels have been able to tap the solar energy effectively. Irradiance is the amount of light energy that is incident per unit area per unit time. Photons that carrying the energy have wavelengths that may be found also in X-rays, gamma rays, visible light, infrared and radio waves. It may be measured as the incident light from any source of light.

With solar irradiance being the output of incident light on the earth, the solar spectral irradiance is a measure of the brightness of the sun at a wavelength of light.

Important spectral irradiance variations are seen in many wavelengths, from the visible and IR, through the UV, to EUV and X-ray. The Figure 2.2 below is of the solar irradiance map with average annual solar irradiance levels.

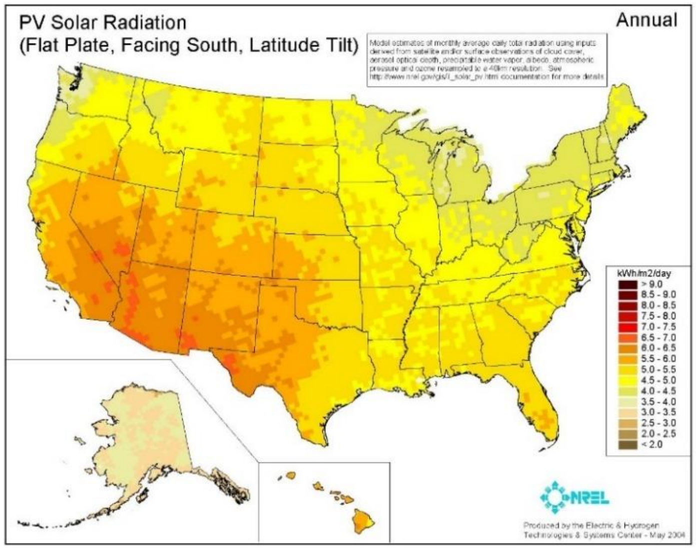


Figure 2.2. Solar Irradiance Map (Solar Maps, 2016)

Solar maps give an estimate of the total average solar irradiance. The insolation values give an account of the incident light on the photovoltaic panel that is oriented facing south at an angle from horizontal. This is typical practice for PV system installation, although other orientations are also used.

2.3. LOCATION AND TYPE OF INSTALLATION

Considering the limited space available rooftop mounted PV installation is the recommended choice. The panels may be of monocrystalline type which would have the highest possible efficiency of around twenty-two percent. Figure 2.3 below shows the solar irradiance levels at location.

ATMOSPHERIC SCIENCE DATA CENTER

NASA Surface meteorology and Solar Energy: RETScreen Data

Latitude 37.957 / Longitude -91.776 was chosen.

	Unit	Climate data location
Latitude	°N	37.957
Longitude	°E	-91.776
Elevation	m	252
Heating design temperature	°C	-4.22
Cooling design temperature	°C	30.87
Earth temperature amplitude	°C	19.07
Frost days at site	day	72

Month	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
	°C	%	$kWh/m^2/d$	kPa	m/s	°C	°C-d	°C-d
January	0.2	70.8%	2.19	99.1	5.0	-0.3	546	4
February	2.8	71.3%	2.91	99.0	5.0	2.5	424	7
March	7.3	68.7%	3.91	98.8	5.4	7.3	324	39
April	13.6	63.5%	5.01	98.5	5.2	13.6	141	130
May	19.2	63.1%	5.51	98.5	4.4	19.1	29	289
June	23.5	64.9%	6.00	98.6	4.0	23.4	1	410
July	25.7	65.3%	6.12	98.7	3.6	25.5	0	493
August	25.1	63.9%	5.51	98.8	3.5	24.9	0	474
September	20.9	62.5%	4.73	98.8	3.8	20.5	19	329
October	15.2	61.6%	3.56	98.9	4.3	14.7	106	175
November	8.1	69.8%	2.37	98.9	4.7	7.5	294	46
December	1.6	71.6%	1.95	99.1	4.9	1.0	501	7
Annual	13.6	66.4%	4.15	98.8	4.5	13.3	2385	2403
Measured at (m)					10.0	0.0		

Figure 2.3. Solar Irradiance Levels at Location (renewable energy resource 6.0, 2008)

Monocrystalline photovoltaic electric solar energy panels have been the go-to choice for many years. They are among the oldest, most efficient and most dependable ways to produce electricity from the sun. Each module is made from a single silicon crystal and is more efficient, though more expensive, than the newer and cheaper polycrystalline and thin-film PV panel technologies. Monocrystalline Silicon is a material widely used in semiconductor material. To make monocrystalline, the silicon is formed in bars and cut into wafers. As the cell is made of a single crystal structure, the electrons can move freely. It is for this reason that the monocrystalline silicone panels are more efficient than polysilicon panels. Monocrystalline silicone is more expensive and more efficient than polycrystalline silicone. Being more efficient, it is preferred if there is limited space available for the PV system. However, at the time of implementation the best fit type may be selected based on cost and availability. Figure 2.4 shows the actual area of Toomey Hall while Figure 2.5 shows the south side of Toomey Hall while Figure 2.6 shows the north side of Toomey Hall. Most of the PV panels come in the arrangement of 6 X 10 solar cells for a 250 W rated power capacity. For the power output of 100 kW, 400 panels would be required. Based on the available data for a polycrystalline solar module, each solar cell has a dimesnsion of about 156 X 156 mm. (Suntech Power, 2013) Total area required for 400 PV panels = 0.1560 X 0.156 X 6 X 10 X 400 = **584 sq. mtr** or 6287 sq ft. Consider a built-up area of an additional 30% for spacing, cabling and other electrical accessories, which makes the total area required to be about **759 sq.mtr** or 8173 sq. ft. This meets the requirements for the total available area.

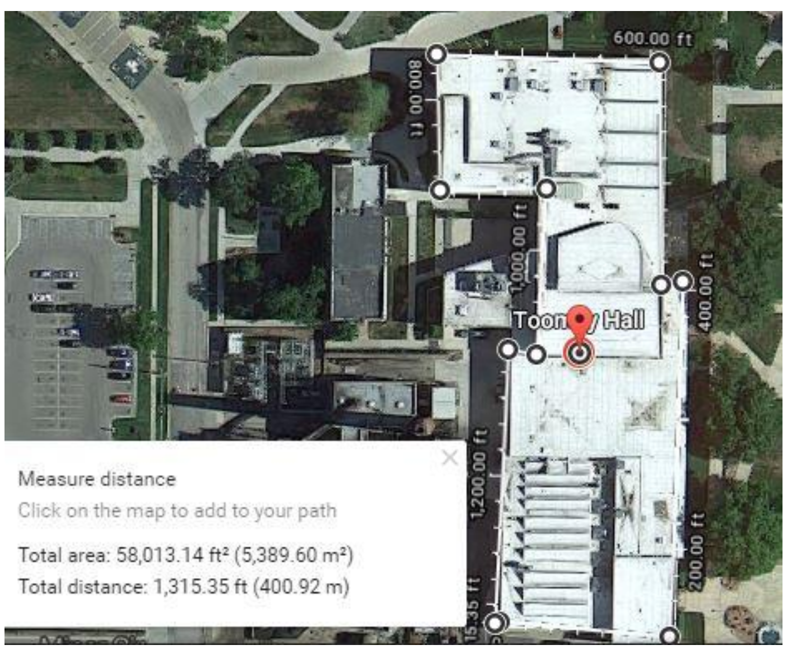


Figure 2.4. Total Area – Toomey Hall (Google, 2017)

Figure 2.5. South Side – Toomey Hall

Figure 2.6. North Side – Toomey Hall

3. LITERATURE REVIEW

The decision of going from conventional energy sources to renewable energy requires a considerable amount of time and money. If any new process is implemented, it must be economically viable and should break even at the earliest. That is, the project needs to repay all the investment. If the project is economically feasible, it is more likely to be implemented. There has been a lot of effort by the administration on campus to become energy sustainable and reduce energy dependence on the conventional energy sources. Figure 3.1 shows a photovoltaic cell while Figure 3.2 depicts the type of arrangement of a photovoltaic cell and Figure 3.3 shows the photovoltaic cell working.

Solar PV technology that converts sunlight directly into electricity is one of the fastest growing renewable energy technology (RET) in the world. PV is considered a clean, sustainable, renewable energy conversion technology that can help meet the energy demands of the growing world’s population while reducing the adverse anthropogenic impacts of fossil fuel use (K. Brankera, 2011). The PV effect is the basis for a working PV system. It is the creation of electric current in a material exposed to light. Silicon is the most widely used semiconductor material for constructing PV cells. The silicon atom has four valence electrons. In a solid crystal, each silicon atom shares each of its four valence electrons with the nearest silicon atom hence creating covalent bond between them. In this way silicon crystal gets a tetrahedral lattice structure. While light ray strikes on any materials some portion of light is reflected, some portion is transmitted through the materials and rest is absorbed by the materials. (Woodford, 2016)

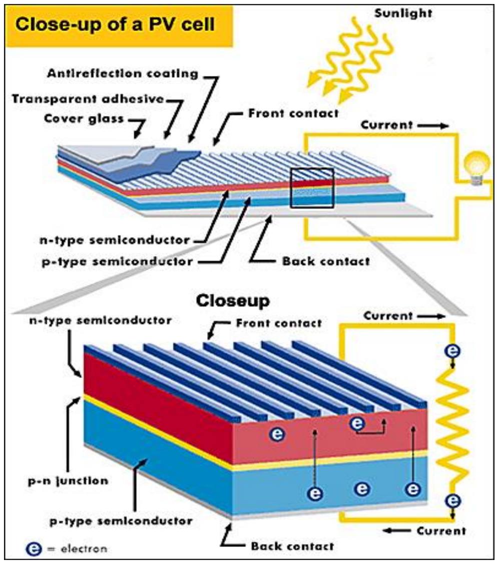


Figure 3.1. Photovoltaic Cell (pv-cell-close-up, 2013)

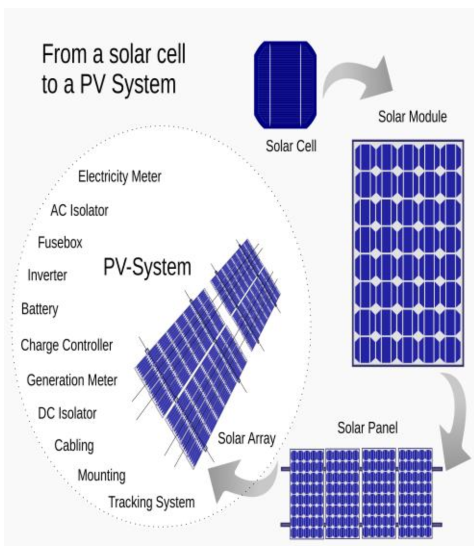


Figure 3.2. Types of Photovoltaic Arragement (Rfassbind, n.d.)

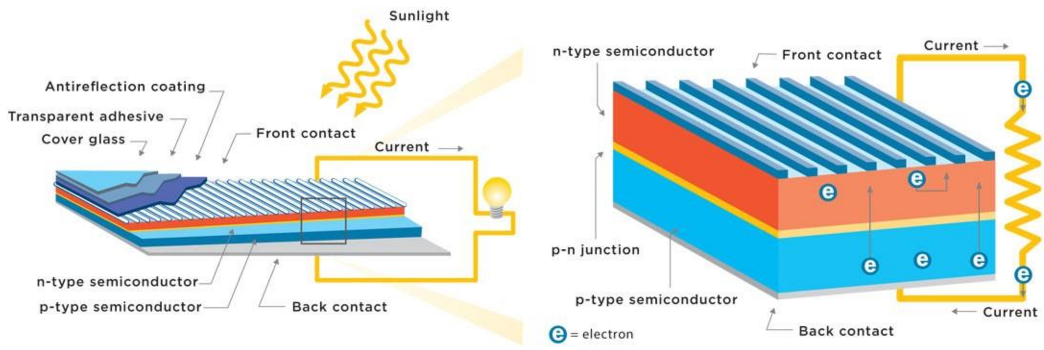


Figure 3.3. Photovoltaic cell working (Thompson, n.d.)

3.1. SUSTAINABLE ADVANTAGES OF PHOTOVOLTAICS

Darling and Yu 2013, discuss the need for sustainable energy due to an increase in the global energy demand.According to them, energy usage is an indicator of GDP. They go on to discuss the various types of renewable energy sources (Seth B. Darling, 2013). Nuclear energy accidents such as Three Mile Island in 1979, Chernobyl in 1986 and Fukushima Daiichi in 2011. It talks about having a diverse mix of energy sources for energy stability and security. The solar panels that dominate the market are of three basic types: monocrystalline, polycrystalline, and amorphous. The next largest market share of the PV market is taken by cadmium telluride (CdTe), that is racked like the crystalline silicon panels. (Seth B. Darling, 2013)

Burton (2002) discusses the high efficiency of monocrystalline cells. According to the author, high efficiency is important in applications where there is limited space and high labor cost and low solar radiation (T.M.Burton, 2003). The author gives examples of Northern European countries such as Germany, Netherlands, UK and Denmark where a lot of solar programs have been implemented. According to the authors, the PV module efficiency influences the LCOE because it accounts for the amount of solar energy converted into electricity (Rohatgi, 2015). A higher efficiency module is desirable because it produces more power per unit area, so fewer modules are required for a fixed size (kW) system. This reduces racking, mounting, wiring hardware, and installation cost.

3.2. PROBLEMS ASSOCIATED WITH PHOTOVOLTAICS

Like many technological innovations, recycling PV is a matter of concern as discussed by Temaki's (2000). A typical PV module manufacturing facility generates a significant amount of scrap at the start of its operation and will reach a steady-state level of production within six months to one year, generating relatively little waste.

According to Temaki's (2000) PV recycling should be considered with respect to distinguish near-term and future needs and capabilities. Some metallurgical processes are more suitable for recycling than other options to recycle used solar cells and manufacturing waste are being investigated. (Fthenakis, 2000)

The article explained that recycling is technologically and economically feasible with careful thinking. Recycled metals could be reclaimed from used solar panels by metal smelting and the environmental disposal and waste handling regulations need to be practiced (Fthenakis, 2000).

3.3. NET METERING

The utility billing mechanism that credits solar energy system owners for the electricity they add to the grid is called net metering. Net metering allows residential and commercial customers who are self-generators of electricity from solar power to feed electricity they do not use back into the grid (Distributed solar, n.d.).

Many states have passed net metering laws. In other states, utilities offer net metering voluntarily or as a result of regulatory decisions. Differences between states' legislation and implementation mean that the benefits of net metering can vary widely for solar customers in different areas of the country.

When a PV system is connected to the grid, any extra electricity that is left is put back on to the electricity grid. The customer receives full retail credit for this electricity on their bill. This is called a grid tied PV system and the type of connection is called the Net Metered connection (Distributed solar, n.d.). A PV System needs to be approved by utility before being connected to the grid. Approval may not be necessary in case the PV system is battery backed system. The Customers receive credit for their electricity. This credit is reflected on the monthly billing statement.

To be eligible, electricity must be produced from the renewable source needs to be approved and certified as renewable by the Department of Natural Resources. The approved sources of renewable energy are wind, solar PV, hydroelectricity and fuel cells using hydrogen (Net Metering and Easy Connection Act, 2010). By law that utilities cannot impose any fee, charge or other requirement not specifically authorized by the law or rules, unless it would also apply to similarly situated customers who are not customer-generators. The law requires the tariff or contract to be identical in rate structure and monthly charges and cannot charge any additional fee or charge that would be unique to a customer generator (Net Metering and Easy Connection Act, 2010).

Evaluating the economic feasibility of PV is somewhat complicated because it involves multiple uncertain variables. One such variable is the report on cost effectiveness of rooftop photovoltaic systems by the California Energy Commission.

The Energy and Environmental Economics, Inc. consultant report prepared for California Energy Commission, May 2013 have used the best publicly available data. They have stated unbiased assumptions about the future costs of PV (Katie Pickrell, 2013). Some of the conclusions in this report are based in part on the following key assumptions, which have a strong influence on the final results:

- Increasing the retail electricity rates at 2.11 percent per annum till 2020 and 1.46 percent per annum thereafter.
- Existing utility retail rate structures are maintained in the market analysis.
- Rooftop PV installations in the building standards are assumed to not qualify for some of the state CSI and NSHP incentives but do qualify for the federal ITC.

Some of the other key input assumptions that have a greater effect on the long-term results include but are not limited to:

- The decreasing capital costs for PV through 2020 are mainly due to mainly industry economies of scale.
- Current net-energy metering rules would remain applicable to all new PV installations.
- Maintenance of the federal investment tax credit for PV at 30 percent till 2016 and at 10 percent after 2016.
- These assumptions could alter the cost effectiveness of PV if any major changes occur.

The results were especially sensitive to the structure of California utility pricing and NEM rules, as they use utility bill savings to determine PV benefits and customer bill savings are very sensitive to rate structure under existing NEM policy. If the structure of utility pricing is changed, by reworking on the charges utility bill savings achieved installing PV could drop significantly. (Katie Pickrell, 2013) Similarly, if NEM were replaced with a different policy, such as a flat rate for compensation per unit of distributed generation, the cost-effectiveness of solar may decrease. In this report's rates and the NEM program will not change other than the overall forecasted rate level increase.

3.4. MISSOURI NET METERING LAW

By the Missouri State net metering law to all electric regulated utilities such as AmerenUE, Kansas City Power & Light Company – Greater Missouri Operations and Empire District Electric Company, municipal and rural electric cooperatives and utilities are required by the law to adopt policies establishing a simple contract to be used for interconnection and net metering.

For systems, up to 10 kW, the application process shall use an all-in-one document that includes a simple interconnection request, simple procedures, and a brief set of terms and conditions (Kimball, 2016). Missouri enacted legislation in June 2007 requiring all the investor-owned, municipal, cooperatives, electric utilities to offer net metering to customers with systems up to 100kW in capacity that generate electricity by one of the listed resources, and other sources of energy certified as renewable by the Missouri Department of Natural Resources. (Public Service Commission, 2016)

The net metered systems have to be primarily used to offset all or part of a customer's own electricity requirements. It must be located on premises owned, operated, leased or otherwise controlled by the customer (Public Service Commission, 2016). Net metering would be available until the total rated generating capacity of system is up to five percent of a utility's single-hour peak load during the previous year. In a calendar year, the average capacity of all approved applications for interconnection is only up to 1% of the utility's single-hour peak load for the previous calendar year.

The estimated generating capacity of all systems that are net metered helps the respective utilities meet the requirements for the Missouri renewable energy criterion (Kimball, 2016). Figure 3.4 below is of a net metered Solar PV System and Figure 3.5 is of a bi-directional net metered digital meter that is commonly used.

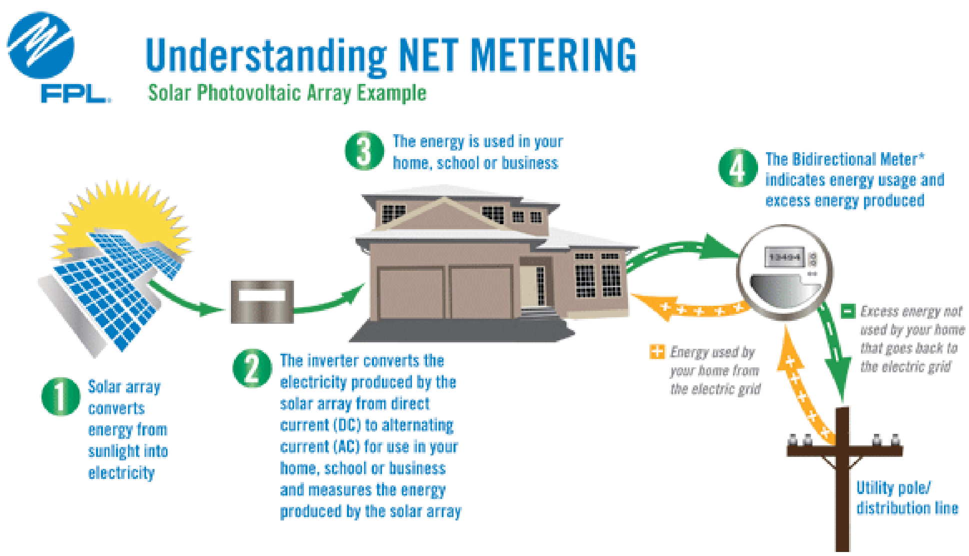


Figure 3.4. Net Metered Solar PV System (How Net Metering Works, n.d.)

Figure 3.5. Bi – directional Net Metered Digital Meter (Net Metering, n.d.)

3.5. ROLLA MUNICIPAL UTILITIES

Rolla Municipal Utilities (RMU) is the local utility company. It provides electricity and water to homes, businesses and industries in Rolla, MO. It is a locally owned and operated utility. The utility charges for the University Industrial tariff as shown below in Figure 3.6.

Industrial Applies to all non-residential customers whose actual monthly demand exceeds 1,000 kW twice within any twelve consecutive calendar months.

Energy Charge	
All kWh energy used per month	6.7 ¢/kWh
Demand Charge	
All kW of demand per month	$9.00/kW
*Service Availability Fee per month	$250.00 per meter

Figure 3.6. Rolla Municipal Utility Charges (Rates and Fees, 2016)

Electricity to Missouri S&T is fed by RMU, which primarily purchases power through the Missouri Public Energy Pool (MoPEP). RMU is one of 35 member cities in

MoPEP. MoPEP is expanding its renewable portfolio and recently commissioned a 3.2 MW solar facility on the north side of Rolla (Kimball, 2016).

Missouri S&T does not have any major generation facilities of its own. The main part of campus is fed by a single substation. Additional RMU feeders supply the Solar Village, the Ecovillage, and various residential facilities. (Kimball, 2016)

RMU has a full requirement contract with MoPEP, meaning that it is contractually obligated to buy power ONLY from MoPEP. There is an exception for systems covered by the Net Metering and Easy Connection Act. (Kimball, 2016) There are severe limits built into the net metering act, such as the following:

- Only systems less than 100 kW are eligible. MoPEP's lawyers have established that the 100 kW limit applies to the aggregate of all systems owned by a single customer (e.g. Missouri S&T).
- System-level annual growth is limited to one percent of the previous year's peak demand. RMU's peak is about 66 MW, so the total of all new PV systems serviced by RMU cannot exceed 660 kW.
- The total installed capacity on a system cannot exceed five percent of the previous year's peak demand. In RMU's case, that translates to 3.3 MW.

Therefore, a proposed 1 MW system would fall outside of the net metering statutes, and would instead need to be negotiated. As previously noted, RMU may only purchase power from MoPEP, and Missouri S&T may only purchase power from RMU. Therefore, the output of the 1 MW system would need to be sold to MoPEP at a price to be negotiated. The price would certainly not exceed the price paid to the operators of the new 3.2 MW system, which is about 6.5 ¢/kWh or less (Kimball, 2016).

If Missouri S&T negotiated such an arrangement, the energy produced would then be considered MoPEP's energy. If the campus wanted renewable energy, MoPEP has indicated that they would sell back the energy at a much higher cost. Currently, non-energy-related costs of service amount to about 4 ¢/kWh, which would need to be recovered somehow (Kimball, 2016).

Further complicating the situation is that MoPEP does not have an active interest in expanding PV. There are no legal or regulatory requirements for Missouri municipal utilities to use renewable energy (unlike investor-owned utilities). However, they are expanding their renewable portfolio in part to forestall future legal requirements. In that sense, though, MoPEP has already met its goal, between existing PV installations and already-contracted new PV systems (Kimball, 2016).

4. METHODOLOGY

The application of this research is in evaluting the feasibilibity of partially powering the campus with renewable energy. Out of all the major renewable energy sources the possibility of powering the campus with solar photovoltaic energy is studied. Engineering economic principles such as time value of money, payback period, discount rate are applied to the capital cost in implementing the project.

The data collected consisted of the monthly electricity consumption patterns of Toomey Hall, the net metering policies and the location details. The methods used in the research were analyzed and the results were evaluted in order to select the best outcomes. The decision analysis was based on the period of recovery of the investment and its lifetime cost benefits. Below is a detailed description of the research methodology applied.

4.1. PRINCIPLE ANALYSIS OF METHODS USED

The project involves estimating the capital cost and investment in implementing the project. The cost to implement the project is weighed against the current cost and the time to recover the investment. The engineering economic principles are used for this analysis such as time value of money, discount rate, payback period and discounted payback period.

The time value of money (TVM) is the concept that compares the present value of money to its value in past and future. An example of this may be considered as the value of $1. The value of $1 last year will be greater than $1 today and the value of $1 today will be greater than the value of $1 after a year. This is because the $1 last year would have gained value had it been invested (Carther, 2016).

The amount by which this variation occurs over a period of time is governed by the discount rate. The discount rate is the rate of interest that is applied over the investment. The discounted rate is used in the discounted cash flows (DCF) used to calculate the present value of future cash flows (Discount Rate, n.d.).

The length of time required to recover the cost of an investment is called the payback period. It is an important factor in deciding if the project can be undertaken. In general, longer payback periods are not desirable for investment as they result in the investment getting locked in for that period of time. It is basically the period of time required to recover the investment or to reach the break-even point. The major disadvantage of the simple payback period is that it does not take into consideration the time value of money. An alternative procedure to overcome this is called discounted payback period. The discounted payback period account for time value of money by discounting the cash flows of the project.

Another important term used in the case of renewable energy is the grid parity. It may be defined as the condition when the cost to generate power from the renewable energy source becomes less than the cost to purchase power from the utility grid. It is the ratio of the total cost to generate electricity from the renewable source to the total electricity generated.

4.2. METHODS AND DESCRIPTION

While studying the energy consumption patterns and the economic analysis of it, certain methods need to be followed. The methods used in the analysis are based on the engineering economic concepts. The methods used and their description is as follows.

4.2.1. Grid Parity. Grid parity is achieved when this ratio becomes less than 1. The total cost to generate electricity includes all the related costs such as the capital, operation and maintenance, etc. and the total electricity generated includes the total kWhr. generation cost at a discounted rate (Grid Parity, n.d.).

$$\text{Grid Parity} = \frac{\text{Total Electricity Generation cost at discounted rate}}{\text{Total Cost of the Electricity generated at discounted rate}}$$

The discounted rate takes into account the time value of money over the project's lifetime. It is applied to the give the present value of future cash flows. Present value is the future amount of money that is worth today. It is represented by the equation, $PR = \text{Cash Flow} / (1+r)^n$ where PR = present value, r = discount rate and n = number of years (Present value, n.d.).

4.2.2. Payback Period. The payback period is an important way of finding out if the project is feasible. Generally, the shorter the payback period, the greater the chances of the project being implemented. It is important that different investment projects be evaluated at their individual level. An accurate determination must be made to find out if the project is the most profitable. Payback period calculations do not take into consideration the cash flows beyond the payback period. Most of the large scale investments have a long life span and provide cash inflows even after the payback period. As the payback period is more focused for a short term consideration, it may not be the best option to decide if investment in the project could turn profitable. Since the payback period does not take into consideration the time value of money it may not be the correct representation of the project cash flows. It is in that case that the discounted payback period may be used. As the name suggests it discounts the cash flows considering the time value of money.

4.2.3. Discounted Payback Period. The major disadvantage of the simple payback period is that it does not take into consideration the time value of money. An alternative procedure to overcome this is called discounted payback period. The discounted payback period accounts for time value of money by discounting the cash flows of the project. In discounted payback period calculation, the present value of each cash flow is considered. The starting of the first period is referred to as period zero. An important decision is considering a suitable discount rate (Discounted Cash Flow, n.d.) The discounted cash flows for each period are calculated using the following formula: Discounted Cash Inflow = $\frac{\text{Actual Cash Inflow}}{(1+i)^n}$ where, i is the discount rate; n is the period of the cash inflow. Generally, the above formula is split into two components: as actual cash inflow and present value of the cash flow. The present value is given as (1 / (1 + i) n). Thus, the discounted cash flow is the product of actual cash flow and present value factor.

If the discounted payback period is less that the period of time required, it is likely to be accepted. If it is more than the period of time required, it is likely to be rejected. Discounted payback period is more reliable than payback period as it accounts for time value of money. If a project has negative net present value it won't recover the initial investment. However, like discounted payback period it ignores the cash inflows from the project after the payback period.

5. DATA COLLECTION AND METHODS

The data was collected in collaboration with the Facilities Operations at Missouri S&T. It provides campus support with maintaining and operating building heating, air conditioning and ventilation systems, electrical and plumbing systems, building interiors, building exteriors, utility distribution systems, sidewalks, staircases and parking lots etc. It also provides coordination and support for campus special events and setups, provides support for moving equipment and furniture, and administration and maintenance of the campus. It also provides energy management for campus utilities. Electrical power is purchased from Rolla Municipal Utilities (RMU) and distributed from the substation to major campus buildings and some outlying locations. The Facilities Operation maintains records of all energy consumption of the various buildings on campus.

5.1. DATA COLLECTION

The table below shows the information of the electricity demand of Toomey Hall for a period of 12 months from June 2015 to June 2016. It was obtained in collaboration with the Facilities Operations. It may be observed that the electricity consumption is higher during July–August and in December–January during the winter. The average annual electricity consumption is about 205,640 Kwh/month for the last 12 months. Table 5.1 is the Toomey Hall Billing cycle from July 2015-June 2016 while Figure 5.1 shows the consumption of electricity during the 12 month cycle.

Table 5.1. Toomey Hall Billing Cycle July 2015- June 2016

			POWER (kWh)		
		PRESENT -	PREVIOUS x	MULT. =	USAGE
July-15	TOOMEY HALL	660,006.1	390,133.4	1	269,873
August-15	TOOMEY HALL	961,749.1	660,006.1	1	301,743
September-15	TOOMEY HALL	1,180,607.0	961,749.1	1	218,858
October-15	TOOMEY HALL	1,355,786.0	1,180,607.0	1	175,179
November-15	TOOMEY HALL	1,526,117.0	1,355,786.0	1	170,331
December-15	TOOMEY HALL	1,750,521.0	1,526,117.0	1	224,404
January-16	TOOMEY HALL	1,935,234.0	1,750,521.0	1	184,713
February-16	TOOMEY HALL	2,120,771.0	1,935,234.0	1	185,537
March-16	TOOMEY HALL	2,293,251.0	2,120,771.0	1	172,480
April-16	TOOMEY HALL	2,484,665.0	2,293,251.0	1	191,414
May-16	TOOMEY HALL	2,661,462.0	2,484,665.0	1	176,797
June-16	TOOMEY HALL	2,874,406.0	2,661,462.0	1	212,944
				Average kWh/ Month	207,023

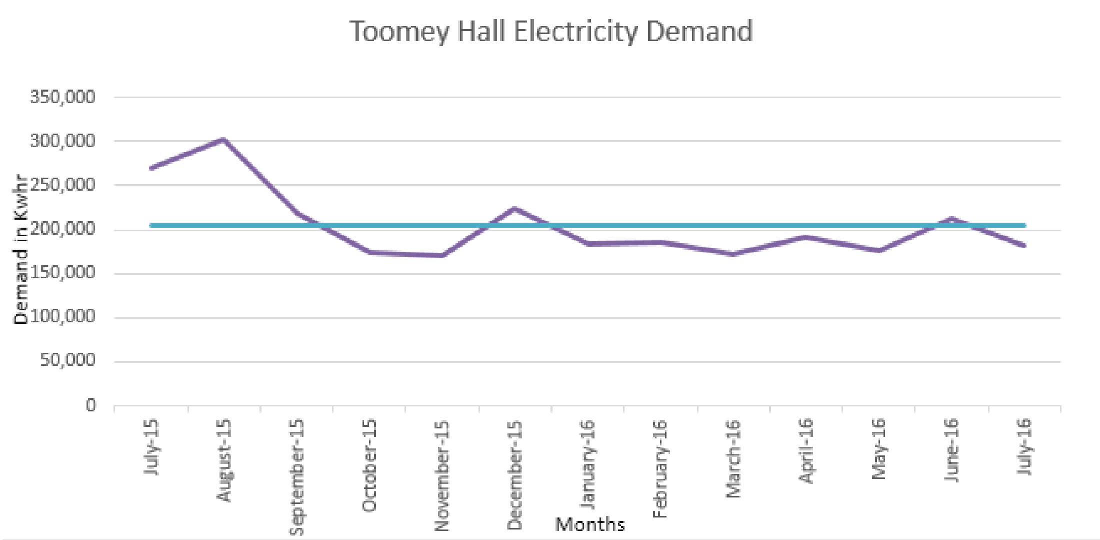


Figure 5.1. Graphical Representation of Billing Cycle

5.2. SAMPLE CALCULATIONS

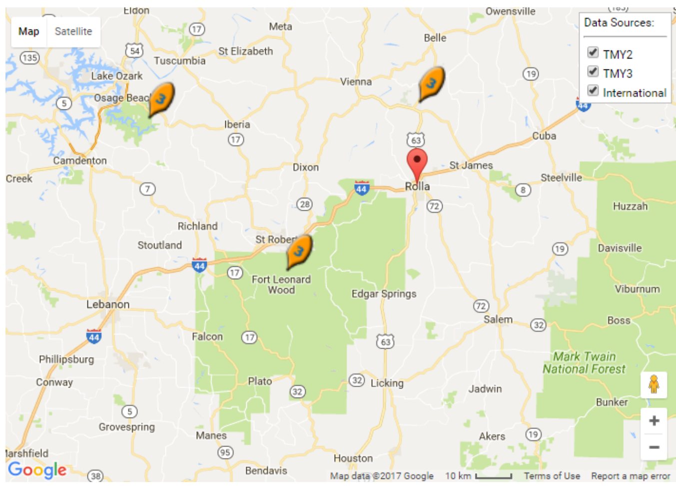
The data was analyzed based on the data collected from the facilities operation and RMU billing tariff. It is shown in Table 5.2. The cost required to set up would include the sum total price of all of the components of the system. Table 5.2 shows an estimate of the cost required to set up the 100kW system.

Table 5.2. Estimated Cost

Power provided from PV KW/per month		100
Cost of 10 kW PV System approx.	$	15,000.00
Number of PV System setup required		10
Cost of Setup	$	150,000.00
Inverter, cabling, installation and accessories approx.	$	30,000.00
Total Cost	**$**	**180,000.00**

Depending on how electricity is used, electric utility customers are charged for different electric services. Along with a basic customer charge, which is a set fee paid monthly or seasonally most customers pay for the energy they use (measured in kilowatt-hours, abbreviated kWh). The daily annual solar irradiance may be obtained from PVWatts Calculator by selecting the location. Other parameters such as the total output power and type of connection are then entered to give the results. First the location is selected. Next, the data such as DC system size, module type, array type are entered and finally the results are obtained. The PV Watts gives the annual energy savings as

$12,889. However, this is by the commercial tariff where the average cost of electricity purchased from Utility is 0.09$/kWh. Missouri S&T being an Industrial customer this tarrif comes to about 0.085$/kWh. So the actual annual savings are **$12,172.94**. Figure 5.2 shows the PV Watts Output stage of Selecting the location, Figure 5.3 shows the PV Watts output of System Information and Figure 5.4 shows the PV Watts Output of the results.



Location and Station Identification	
Requested Location	Rolla, MO
Weather Data Source	(TMY2) COLUMBIA, MO 65 mi
Latitude	38.82° N
Longitude	92.22° W
PV System Specifications *(Commercial)*	
DC System Size	100 kW
Module Type	Standard
Array Type	Fixed (open rack)
Array Tilt	20°
Array Azimuth	180°
System Losses	14%
Inverter Efficiency	96%
DC to AC Size Ratio	1.1
Economics	
Average Cost of Electricity Purchased from Utility	0.09 $/kWh
Performance Metrics	
Capacity Factor	16.2%

Figure 5.2 PV Watts Output – Selecting Location

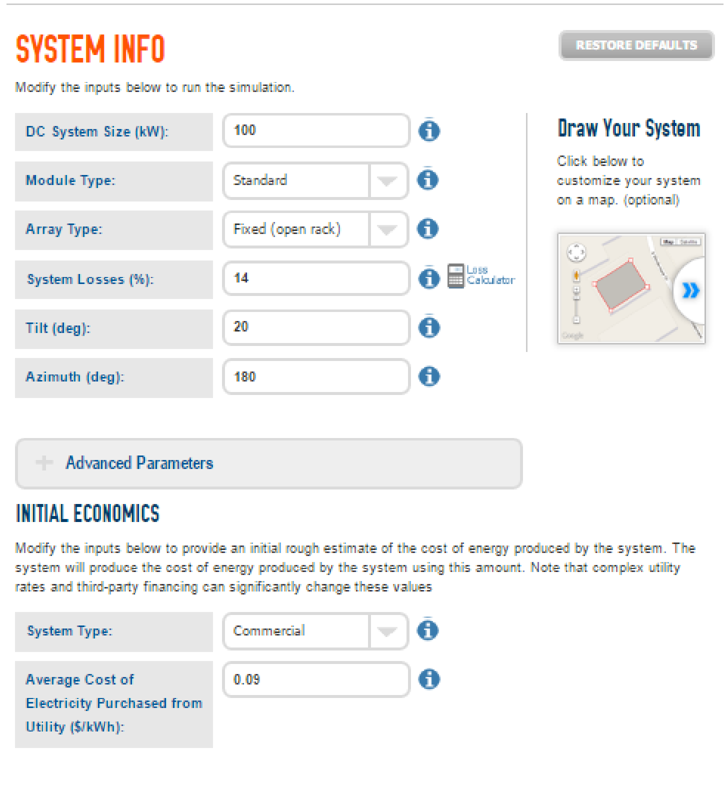


Figure 5.3. PV Watts Output – System Information

RESULTS

Print Results

141,643 kWh per Year *

System output may range from 135,382 to 147,521kWh per year near this location.
Click HERE for more information.

Month	Solar Radiation (kWh / m² / day)	AC Energy (kWh)	Energy Value ($)
January	3.12	8,421	766
February	4.18	9,981	908
March	4.83	12,290	1,118
April	5.82	13,898	1,265
May	5.99	14,324	1,303
June	6.64	15,107	1,375
July	6.46	14,863	1,353
August	6.25	14,349	1,306
September	5.32	12,290	1,118
October	4.59	11,332	1,031
November	3.07	7,636	695
December	2.68	7,153	651
Annual	4.91	141,644	$ 12,889

Figure 5.4. PV Watts Output – Results

6. ANALYSIS AND RESULTS

The payback period calculations below show the period of time required for the project cost to break even. According to the calculations, the project cost or capital investment is $180,000. The greater the time value of money, that is the higher the percent of discounted rate the longer the payback period. Here, the discount rate takes into account the time value of money. Had the time value of money not been considered the payback period would have been 14.79 years. The Table 6.1 below shows the payback period when time value of money is not considered while Table 6.2 below shows the payback period when time value of money considered.

Table 6.1. Payback Period

Payback Period (Time value of money not considered)				
r =	0%			
Year	Amount	PV CF	Balance	
0	$ (180,000.00)	$ (180,000.00)	$ (180,000.00)	
1	$ 12,172.94	$12,172.94	$ (167,827.06)	
2	$ 12,172.94	$12,172.94	$ (155,654.12)	
3	$ 12,172.94	$12,172.94	$ (143,481.18)	
4	$ 12,172.94	$12,172.94	$ (131,308.24)	
5	$ 12,172.94	$12,172.94	$ (119,135.30)	
6	$ 12,172.94	$12,172.94	$ (106,962.36)	
7	$ 12,172.94	$12,172.94	$ (94,789.42)	
8	$ 12,172.94	$12,172.94	$ (82,616.48)	
9	$ 12,172.94	$12,172.94	$ (70,443.54)	
10	$ 12,172.94	$12,172.94	$ (58,270.60)	
11	$ 12,172.94	$12,172.94	$ (46,097.66)	
12	$ 12,172.94	$12,172.94	$ (33,924.72)	
13	$ 12,172.94	$12,172.94	$ (21,751.78)	
14	$ 12,172.94	$12,172.94	$ (9,578.84)	
15	$ 12,172.94	$12,172.94	$ 2,594.10	**14.79**
16	$ 12,172.94	$12,172.94	$ 14,767.04	
17	$ 12,172.94	$12,172.94	$ 26,939.98	
18	$ 12,172.94	$12,172.94	$ 39,112.92	
19	$ 12,172.94	$12,172.94	$ 51,285.86	
20	$ 12,172.94	$12,172.94	$ 63,458.80	
21	$ 12,172.94	$12,172.94	$ 75,631.74	
22	$ 12,172.94	$12,172.94	$ 87,804.68	
23	$ 12,172.94	$12,172.94	$ 99,977.62	
24	$ 12,172.94	$12,172.94	$ 112,150.56	
25	$ 12,172.94	$12,172.94	$ 124,323.50	

Table 6.2. Discounted Payback Period

Discounted Payback Period				
r =	5%			
Year	Amount	PV CF	Balance	
0	$ (180,000.00)	$ (180,000.00)	$ (180,000.00)	
1	$ 12,172.94	$11,593.28	$ (168,406.72)	
2	$ 12,172.94	$11,041.22	$ (157,365.51)	
3	$ 12,172.94	$10,515.44	$ (146,850.07)	
4	$ 12,172.94	$10,014.71	$ (136,835.36)	
5	$ 12,172.94	$9,537.82	$ (127,297.54)	
6	$ 12,172.94	$9,083.64	$ (118,213.91)	
7	$ 12,172.94	$8,651.08	$ (109,562.82)	
8	$ 12,172.94	$8,239.12	$ (101,323.70)	
9	$ 12,172.94	$7,846.79	$ (93,476.91)	
10	$ 12,172.94	$7,473.13	$ (86,003.78)	
11	$ 12,172.94	$7,117.27	$ (78,886.52)	
12	$ 12,172.94	$6,778.35	$ (72,108.17)	
13	$ 12,172.94	$6,455.57	$ (65,652.60)	
14	$ 12,172.94	$6,148.16	$ (59,504.44)	
15	$ 12,172.94	$5,855.39	$ (53,649.05)	
16	$ 12,172.94	$5,576.56	$ (48,072.48)	
17	$ 12,172.94	$5,311.01	$ (42,761.47)	
18	$ 12,172.94	$5,058.11	$ (37,703.36)	
19	$ 12,172.94	$4,817.25	$ (32,886.11)	
20	$ 12,172.94	$4,587.85	$ (28,298.26)	
21	$ 12,172.94	$4,369.38	$ (23,928.88)	
22	$ 12,172.94	$4,161.32	$ (19,767.56)	
23	$ 12,172.94	$3,963.16	$ (15,804.40)	
24	$ 12,172.94	$3,774.44	$ (12,029.96)	
25	$ 12,172.94	$3,594.70	$ (8,435.26)	
26	$ 12,172.94	$3,423.53	$ (5,011.73)	
27	$ 12,172.94	$3,260.50	$ (1,751.23)	**27.56**
28	$ 12,172.94	$3,105.24	$ 1,354.01	
29	$ 12,172.94	$2,957.37	$ 4,311.38	
30	$ 12,172.94	$2,816.54	$ 7,127.92	
31	$ 12,172.94	$2,682.42	$ 9,810.35	
32	$ 12,172.94	$2,554.69	$ 12,365.03	
33	$ 12,172.94	$2,433.04	$ 14,798.07	
34	$ 12,172.94	$2,317.18	$ 17,115.25	
35	$ 12,172.94	$2,206.84	$ 19,322.08	
36	$ 12,172.94	$2,101.75	$ 21,423.83	
37	$ 12,172.94	$2,001.67	$ 23,425.50	
38	$ 12,172.94	$1,906.35	$ 25,331.85	
39	$ 12,172.94	$1,815.57	$ 27,147.42	
40	$ 12,172.94	$1,729.11	$ 28,876.53	

When considering a discount rate of 5% per annum, the discounted payback period is 27.56 years. That is, the invested amount would be profitable after 27.56 years. Let us take into consideration two cases, that is, if project is implemented and if the project is not implemented. The two cases with their advantages and disadvantages are shown in Table 6.3 and Table 6.4 below.

Alternative 1 : Project is implemented. If the project is implemented it will cost an investment of about $180,000. The discount rate that is the amount that the investment would earn every year is taken to be 5%. Going by this scenerio, it would take a little over 21 years for the project to recover its investment cost. The benefit is that it would provide about one hundred kW of renewable energy which is much less than the total energy demand of Toomey Hall. The energy will be free of cost after 21 years. In these calculations, the cost of labor, maintenece, equipment replacement and other such factors is variable.

Alternative 2: Project is not implemented. If the project is not implemented, there would be complete dependence on the utility for the energy demand. There would be no investment involved but there would be a monthly electricity charge for the supply and consumption. The electricity consumed would be from the conventional energy sources that are limited in nature. The price of electricity would be dependent on the price on the conventional energy source. The biggest advantage of not implemeting the project would be that there would be no investment lock in period and space area savings.

Table 6.3. Alternative 1

Sr.no.	Advantages	Disadvantages
1	Around 100 kW of renewable energy generated every month.	Long energy life cycle of 21.43 years and an intial investment of about $180,000.
2	The energy would be free to use.	The energy is much less than the avg. monthly consumption of 2 MW. With time, the energy demand would only increase.
3	The dependence on utility supplied power would be reduced	The dependence on the utility would decrease only marginally and the cost diffrence would not be significant.

Table 6.4. Alternative 2

Sr.no.	Advantages	Disadvantages
1	No investment lock in period for the conventional energy.	Complete dependence on utility supplied power.
2	No separate allotment of space and equipment required.	The price of electricity would depend on the price of conventional energy source.
3	No maintence and equipment replacement costs.	There would be need for back up power in case of emergency power in case of an outage.

Both alternatives have their own advantages and disadvantages. It is up to the administration on campus to decide the usefulness of implenting the project. The cost and benefits need to be evaluted based on the price quotations from a licensed electrical contractor. After careful observation of all these possiblities a decision may be made. The discount rate is highly variable. A higher the discount rate considered for the project longer will be the time required for the project to break even. The treasuary rates are usually higher for energy projects than other investment projects. The energy production limit of 100 kW is another major drawback. The cost to generate the renewable energy would be much higher than the cost to consume the energy. All these factors need to be weighed against the need for to implement rewable energy on campus.

7. CONCLUSION

A lot has been said about the need to switch over to renewable energy. The reasons for the feasibility have been discussed and it may be said that it is still not completely feasible. From the results, it may be inferred that the discount rate is an important factor. In the study the discount rate is taken as 5%. However, the actual discount rate may vary over the entire project lifespan. It may be constant for some time as well as increase or decrease considerably. The higher the discount rate, the longer the payback period.

The total project cost is based on the limited available market data. In reality, the project cost also varies with time. Factors such as labor charges, equipment charges and utility rates can vary significantly over the entire life of the project. The cost of the equipment, the set up required and the total cost is based on the preliminary study and available market data. Only a licensed contractor would be able to give the actual cost required to set up the installation.

The limit on the net metered grid tied connection is an important factor affecting the project's implementation. The limit is more suited for a residential setup over an industrial micro grid setup. In case the limit is raised/waived off it will have a significant role in the final planning and cost. The government regulations to promote the renewable energy could help in promoting renewable energy.

Implementing this project is a major decision. It involves a lot of investment and depends on the availability of funds. It needs a lot of careful planning and prior working. Going by the energy trends, the demand for energy would only increase in the years to come. The present energy laws for net metering may be in line with residential consumers but not very suitable for medium to large scale industrial setup. Making the laws more customer friendly for largescale energy consumers would be highly encouraging. Also, the possibility of providing incentives to educational campuses for such projects would be highly beneficial. All factors including financial, human, technical, etc. should be considered before the management reaches a decision.

8. REMARKS AND FUTURE WORK

The work was a look into the overall picture of powering a part of the building on campus. In implementing the project, more work would be required in terms of the project cost. A detailed report considering the actual cost needs to be evaluated. The project cost needs to be calculated with the help of a licensed electrical contractor. The pricing for the electrical components and the quantity required needs to be performed.

Factors affecting the capital investment and budget need to be evaluated considering the real-time flexible scheduling mechanism. The possibility of solar trackers need to weighed. The manufacturer data sheets need to be evaluated with respect to the type of fixture. The best fit fixture and arrangement need to be obtained. Prices between manufacturers should be compared.

BIBLIOGRAPHY

1. 5 Critical Factors Influencing Solar PV System Performance. (2015). Retrieved from Powervault: http://powervault.net/education/5-critical-factors-influencing-solar-pv-system-performance/

2. A renewable energy resource web site release 6.0. (2008, March 26). Retrieved from Surface meteorology and Solar Energy: https://eosweb.larc.nasa.gov/sse/RETScreen/

3. Carther, S. (2016, October 20). Understanding the Time Value of Money. Retrieved from Investopedia: http://www.investopedia.com/articles/03/082703.asp

4. Discount Rate. (n.d.). Retrieved from Investopedia: http://www.investopedia.com/terms/d/discountrate.asp

5. Discounted Cash Flow. (n.d.). Retrieved from Investopedia: http://www.investopedia.com/terms/d/discounted-after-tax-cash-flow.asp

6. Distributed solar. (n.d.). Retrieved from Solar Energy Industries Association : http://www.seia.org/policy/distributed-solar/net-metering

7. Fthenakis, V. M. (2000). End-of-life management and recycling of PV modules. Energpolicy , 8.

8. Gifford, S. A. (2015, August 13). Australian commercial market hits new high. Retrieved from PV Magazine: http://www.pv-magazine.com/news/details/beitrag/australian-commercial-market-hits-new-high_100020592/#axzz4SqCCMysD

9. Google. (2017). Map data.

10. Grid Parity. (n.d.). Retrieved from Renewable Energy Advisors: http://www.renewable-energy-advisors.com/learn-more-2/what-is-grid-parity/

11. How Net Metering Works. (n.d.). Retrieved from FPL Florida Light and Power: https://www.fpl.com/clean-energy/solar/images/net-metering-diagram.gif

12. How to Calculate the Surface Area Required by Solar Panels. (2013, May 27). Retrieved from RAYMaps: http://www.raymaps.com/index.php/how-to-calculate-the-area-required-by-solar-panels/

13. K. Brankera, M. P. (2011). A review of solar photovoltaic levelized cost of electricity. Renewable and Sustainable Energy Reviews, 13.

14. Katie Pickrell, A. D. (2013). Cost-Effectiveness Of Rooftop Photovoltaic Systems For Consideration In California's Building Energy Efficiency Standards. San Francisco.

15. Kimball, D. J. (2016). Campus PV Development Roadmap. Rolla, Missouri, US.

16. L.K. Wiginton, H. N. (2010). Quantifying rooftop solar photovoltaic potential for regional renewable energy policy. Computers, Environment and Urban Systems, 13.

17. Motiekaitis, R. (2010). Building integrated photovoltaic. Retrieved from Baltic Environmental Forum : http://www.bef-de.org/fileadmin/files/Our_Topics/Energy/energy_efficient_buildings_in_the_Baltic_States/p2_photovoltaic-power_motiekaitis_lt.pdf

18. Net Metering. (n.d.). Retrieved from SEIA Solar Energy Industries Assoiation : http://www.seia.org/policy/distributed-solar/net-metering

19. Net Metering and Easy Connection Act. (2010, May). Retrieved from Missouri Department of Natural Resources: https://dnr.mo.gov/pubs/pub2238.pdf

20. Payback period. (n.d.). Retrieved from Investopedia: http://www.investopedia.com/terms/p/paybackperiod.asp

21. Present value. (n.d.). Retrieved from Investopedia: http://www.investopedia.com/terms/p/presentvalue.asp

22. Public Service Commission. (2016, Aug 28). Retrieved from Missouri Revised Statutes: http://www.moga.mo.gov/mostatutes/stathtml/38600008901.html

23. pv-cell-close-up. (2013, August 16). Retrieved from Banner Power Solutions: http://www.bannerpowersolutions.com/services/solar-power-systems/attachment/pv-cell-close-up/

24. Rates and Fees. (2016, October 1). Retrieved from RMU Rolla Municipal Utilities: http://www.rollamunicipalutilities.org/customer-service/rates-fees/

25. Rfassbind. (n.d.). Photovoltaic system. Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Photovoltaic_system

26. Rohatgi, M. H. (2015). Quantitative analysis of the levelized cost of electricity of commercial scale photovoltaics systems in the US. Solar Energy Materials and SolarCells, 7.

27. Seth B. Darling, F. q. (2013). The case for organic photovoltaics. RSC Advances

28. Solar Maps. (2016, July 18). Retrieved from National Renewable Energy Laboratory http://www.nrel.gov/gis/solar.html

29. Suntech Power. (2013). Retrieved from Suntech Power Module: https://es-media-prod.s3.amazonaws.com/media/u/bad/9e9/d9b/4a377fac554a5266604e7b20285d4e78/Suntech%20STP%20230-260_20%20Wd(poly)_EN_web_1.pdf

30. T.M.Burton. (2003). General trends about photovoltaics based on crystalline silicon. Solar Energy Materials and Solar Cells, 8.

31. Thompson, A. (n.d.). How Solar Panels Work. Retrieved from Union of concerned scientists: http://www.ucsusa.org/clean-energy/renewable-energy/how-solar-panels-work#.WFGoCvkrLIU

32. Woodford, C. (2016, April 28). Solar Cells. Retrieved from Explain That Stuff: http://www.explainthatstuff.com/solarcells.html

VITA

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