Economic Study on the Effectiveness of Photovoltaic Street Lighting In Universiti Teknologi Malaysia

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***Abstract*-This paper presents a feasibility study of installing the photovoltaic street lighting at 15 sites in the Univeristi Teknologi Malaysia (UTM), Johor Bahru campus. A comparative economic analysis on the actual electricity bill for UTM with and without photovoltaic (PV) street lighting was performed. The finding shows that there is approximately 1% reduction in the electricity bill with the pay back period of 7.5 years for the complete installation of PV system. In selecting the suitable module for the PV street lighting, two types of PV technologies; amorphous Silicon and monocrystalline Silicon were studied and compared.**

Key words: Photovoltaic Street Lighting, Photovoltaic Technologies, Economic Study

I. INTRODUCTION

For the past decade, the environmental phenomena, such as global warming and depletion of ozone layer attributed to emissions from massive fuel combustion are slowly but surely causing problems to every living thing on earth. Renewable energy, particularly photovoltaic technology is very attractive solution available today [1].

Photovoltaic (PV) panels, commonly called solar cells, are simply converters. When exposed to light, solar cells are capable of producing electricity without any harmful effect to the environment or device, meaning power can be generated for many years while requiring minimal maintenance and operational costs. Currently the wide-spread use of photovoltaic over other energy sources is limited by the relatively high cost and low efficiency of solar cells.

Photovoltaic power systems are generally classified according to their functional and operational requirements, their component configurations, and how the equipment is connected to other power sources and electrical loads. The types and applications of photovoltaic system are as indicated in Table 1.

TABLE 1
TYPES OF PHOTOVOLTAIC SYSTEM

	Energy source	Connected to the electricity grid	Energy storage device in the system	Examples
Grid-tied solar system	Solar Cells	Yes	No	Home system that draws on the electricity grid at night and exports excess power in the day
Stand alone grid-tied solar system	Solar Cells	Yes	Yes (batteries)	Home or business system uninterruptible power
Stand alone solar system without energy storage	Solar Cells	No	No	Water pumping
Stand alone solar system with energy storage	Solar Cells	No	Yes (batteries)	Remote homes, lighting, TV, radio, telemetry
Stand alone off-grid hybrid solar system	Solar Cells in combination with another energy source	Most often not	No	Remote large scale communication, industrial uses

The systems consist of four main elements which are PV collector, power conditioning system, battery storage and load. The two principle classifications are grid-connected or utility-interactive systems and stand-alone systems. Stand-alone system is a system that is not connected to the generator. This gives an advantage for the

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system to be used in hinterland because the location is isolated from utility lines. Stand-alone system is suitable for the usage of small and medium applications such as street lighting and telephone booth lighting.

Lighting should always be designed to fulfill a specific purpose; efficient, effective lighting installations provide enough light for the task in hand without impinging on surrounding areas. Over the years, lighting products have been developed to secure property, to allow people and vehicles to move safely at junctions and in residential areas and to extend the period during which people can work or enjoy leisure activities out-of-doors during the winter months. Lighting equipment has also been developed for advertising commercial premises such as supermarkets and petrol filling stations and, in a more subtle vein, for enhancing the amenity value of important buildings and historic settlements. PV lighting systems for municipalities represents one of the largest cost effective markets for PV now. The installation cost of just one or two utility power poles can justify the initial cost of a PV street lighting [2]. The PV street lighting systems have been used in many countries, especially in many developing countries. According to a typical rural environment, stand-alone PV street lighting systems can be mainly applied as lighting for dangerous points or intersections, pedestrian crossings, ferry station, access to the villages or the town, public's places, bus stop, camping sites and area for activities [3]. In addition, they are highly economical in places without an electrical network as neither cabling nor main's connection is necessary. In designing of PV street lighting system the following items should be considered [3]: (i) types of lamp for the street lighting, (ii) control unit for the system, and (iii) battery and box.

II. METHODOLOGY

As the conventional fossil fuel is depleting at a faster rate while the cost of electrical energy is increasing due to growing consumer demand, photovoltaic energy becomes a promising renewable alternate source. It is anticipate that within the next 5 to 10 years, PV solar arrays will become cost competitive with traditional power sources [4]. Photovoltaic system has many applications due to its potential in converting solar energy to electricity and one of the applications is street lighting. The cost to install PV street lighting system and the characteristic of two PV technologies in selection for the suitable solar panel were performed.

Malaysia is a country with a lot of sunshine and has great potential for PV applications. During the day, an average of about 18 to 21.4 MJm^{-2} of solar radiation was received which is above the normal range and the lowest solar radiation was recorded at South Johor with the value between 12 to 13 MJm^{-2}. Universiti Teknologi Malaysia (UTM) is situated in Johor Bahru, South of Malaysia with the latitude of 1.4ºN and receives an average of 1.67 MWh/m^2 solar irradiation. In this feasibility study, fifteen sites in the Univeristi Teknologi Malaysia (UTM), Johor Bahru campus were identified for the installation of PV street lighting.

Figure 1 illustrates the flow chart of evaluating the economic effectiveness in installing the PV street lighting at Universiti Teknologi Malaysia (UTM) and it was divided into five tasks; namely (i) data input and preparation, (ii) data pre-analyzing, (iii) data analyzing which include street lighting requirement, solar panel performance and pricing, (iv) assessment of output where solar panel being choose and (v) end-output where the system pay-back period and electricity after installing solar system were obtained.

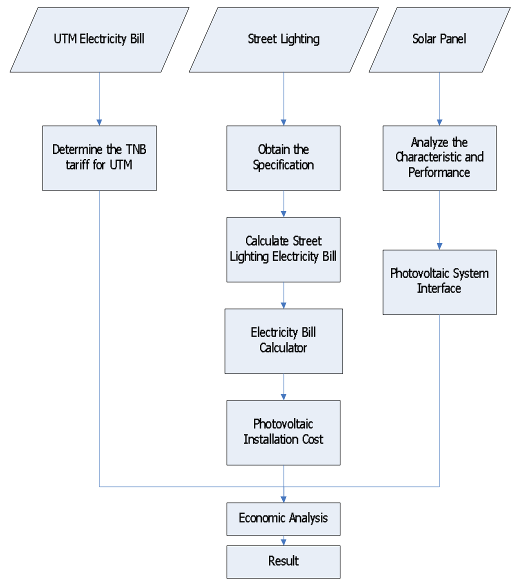

Figure 1. Chart of evaluating economic effectiveness.

PV materials can be categorized as either *crystalline* or *thin film* and are judged on two basic criteria: efficiency and economics. Crystalline cells are basically silica-based materials that has been melted and crystallized. Thin film cells are produced by depositing a liquidized semiconductor material directly onto glass, plastic or stainless steel substrate. Semiconductor materials most frequently used in thin film technology are copper indium diselenide or cadmium telluride. While thin film cells achieve lower efficiencies than crystalline cells, the production process is considerably less expensive, and because thin film cells can be extremely light and flexible, they can meet a variety of needs for which crystalline solar cells are too big and too rigid [1, 5].

In comparing the power generation technologies, the PV energy conversion efficiency is an important factor to be determined. It indicates how much power being delivered to the system. Table 2 compares the parameters of amorphous Silicon (a-Si) and monocrystalline Silicon (m-Si) which are important in identifying the most suitable technology in the solar cell design.

TABLE 2
COMPARISON of m-SI AND a-SI

Item	m-Si	a-Si
Atomic arrangement	Regular	Disorder
Forbidden band gap (eV)	1.1	1.6-1.8
Absorption coefficient (visible spectrum)	Small	Large
Minority carrier diffusion	10-100	0.1-2
length (µm)	~1000	0.1-1
Electron mobility ($cm^2V^{-1}s^{-1}$)	10^{-4}-10^4	10^{-13}-10^2
Conductivity ($S\ cm^{-1}$)	Rectifying	Ohmic
p-n junction characteristics	1-10 µm	0.5-1 µm
p-i-n junction depletion layer width	~200 µm	0.5-1 µm

Besides the physical properties comparison between a-Si and m-Si, other factors to be considered are (i) physical properties and device structure, (ii) solar cell characteristic, (iii) spectral sensitivity characteristic and (iv) Dark state I/V characteristic and I_{sc}/V_{oc} characteristic [6]. Amorphous Si is a very intriguing material. The lack of long-range order relaxes the momentum conservation rule in this material, and it can absorb photons more efficiently [7]. The study shows amorphous solar panel is more suitable due to the factors: structure, energy pay-back time is short, it can be formed on any substrate and continuous production is easy. [6].

III. RESULTS AND DISCUSSIONS

As indicated in the flow chart (refer Figure 3.0), the effectiveness of implementation PV street lighting in UTM depends on the economic cost of photovoltaic system installation and also in identifying the most suitable PV technology.

A. Determination of Parameter for Street Lighting

Fifteen sites in UTM were chosen for the study and Table 3 shows the measurement parameters obtained, the energy usage and the monthly energy cost. The locations are: (i) Sekolah Agama UTM, (ii) road from FAB to CICT, (iii) Lingkaran Ilmu, (iv) road from FS to MSI, (v) road along kindergarten, (vi) road at FKE, (vii) road from KRP to Pusat Kesihatan Mahasiswa, (viii) at KP, (viiii) road from FP to FPPSM, (x) main entrance, (xi) road to K 17 from Pusat Kesihatan Mahasiswa, (xii) Meranti and Cengal, (xiii) KTHO and KTDI, (xiv) K 9 and K 10, and (xv) KTC.

TABLE 3
MEASUREMENT RESULT

Location	Quantity	Current (A)	Voltage (V)	P.F	Hours	Unit (kWh)	Cost(month) (RM)
Sekolah Agama	6	3.35	225	0.53	12	4.7880	179.26
FAB to CICT	51	3.35	225	0.53	12	4.7880	1523.73
Lingkaran Ilmu	37	3.35	225	0.53	12	4.7880	1105.45
FS to MSI	20	3.35	225	0.53	12	4.7880	597.54
Kindergarten	15	3.35	225	0.53	12	4.7880	448.16
FKE	5	3.35	225	0.53	12	4.7880	149.39
KRP to P.Kesihatan	24	1.3	219	0.41	12	1.3560	203.07
KP	43	1.3	219	0.41	12	1.3560	363.84
FP to FPPSM	16	1.3	219	0.41	12	1.3560	135.38
Main entrance	6	3.96	244	0.57	12	6.6360	248.45
Road to K 17	74	2.41	248	0.48	12	3.4440	1590.30
Road to K 17	4	1.24	250	0.5	12	1.8240	45.53
Meranti, Cengal KTHO, KTDI	63	1.24	250	0.5	12	1.8240	717.05
K 9 and 10	50	1.24	250	0.5	12	1.8240	569.09
KTC	33	0.261	252	0.81	12	0.6276	129.24
Total	**447**						**8005.48**

TABLE 4
SPECIFICATIONS OF STREET LIGHTING IN UTM

Location	Quantity	Type of lighting	Brightness Lumens	Cost Per unit RM	Total Cost RM (per day)
Sekolah Agama	6	Sodium	221	696.00	4176.00
FAB to CICT	51	Sodium	221	696.00	35496.00
Lingkaran Ilmu	37	Sodium	220	696.00	25752.00
FS to MSI	20	Sodium	230	696.00	13920.00
Kindergarten	15	Sodium	230	696.00	10440.00
FKE	5	Sodium	230	696.00	3480.00
KRP to P.Kesihatan	24	Sodium	230	696.00	16704.00
College Perdana	43	Sodium	230	696.00	29928.00
FP to FPPSM	16	Sodium	230	696.00	11136.00
Main entrance	6	sodium	430	1239.00	7434.00
Highway to college17	74	sodium	220	696.00	51504.00
Highway to college17	4	sodium	220	696.00	2784.00
Meranti, Cengal KTHO, KTDI	63	sodium	220	696.00	43948.00
Kolej 9 and 10	50	sodium	220	696.00	34800.00
KTC	33	sodium	77	696.00	22968.00
Total	**447**				**314370.00**

B. Initial Cost of PV Street Lighting Installation

Cost of solar electricity generating systems for street lighting from dusk to dawn operation including solar panels, solar batteries, controller, wires, plugs, lamps and electronic ballast-warranty for ten years *(Solar Voltaic Sdn. Bhd.)*

220 lumens (18Wp/26A/h) RM 696.00
440 lumens (37Wp/52 A/h) RM 1239.00

The initial costs to install photovoltaic system for the street lighting in UTM are based on the specification given by Pejabat Harta Bina UTM and also from the measurement performed. Total costs for the installation are concluded as in Table 4. Basically, there are two types of brightness need to be considered in choosing the suitable photovoltaic system for street lighting in UTM: (i) 220 lumens and (ii) 440 lumens.

C. Calculation of Payback Period

Pay-back period indicates the reliability and cost reduction between two systems: (i) electricity supplied by Tenaga Nasional Berhad and (ii) electricity supplied by the photovoltaic system.

Example of pay-back period calculation:

Monthly street lighting electricity bill = RM 8005.00
Electricity bill for 1 year = RM 96060.00
Electricity bill for 10 years = RM 960600.00
Cost of battery box and mounting frame (RM 500.00 each) = RM 500.00 x 447 = RM 223500.00
Cost of battery and controller replacement (RM 400.00 each) = RM 400.00 x 447 = RM 178800.00
Total cost of PV street lighting system = **RM 716670.00**

The payback period = $\frac{10 \times 716670}{960600}$ = **7. 5 yrs**.

The example shows a pay-back period of 7. 5 years if the street lighting needs to be changed with new set of battery and controller. Figure 2 and Table 5 show the pay-back period if a percentage of street lighting were to be implemented using PV with new set of battery and controller.

TABLE 5
PAY-BACK PERIOD AND COST

Percentage of Replacement (%)	Payback Period Years	Cost (RM)
0	3.3	314370
10	3.7	354600
20	4.1	394830
30	4.5	435060
40	4.9	475290
50	5.4	515520
60	5.8	555750
70	6.2	595980
80	6.6	636210
90	7.0	676440
100	7.5	716670

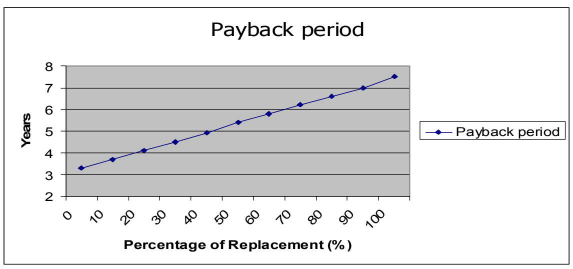

Figure 2. Percentages of payback period

TABLE 6
PERCENTAGES OF REDUCTION

Year	Bill Before Installation (RM)	Bill After Installation (RM)	Street Lighting Bill (RM)	Percentage of Reduction (%)
2006	11183077.93	11079085.75	103992.18	0.930
2007	11406739.49	11296299.79	110439.7	0.968
2008	11634874.28	11517587.32	117286.96	1.008
2009	11867571.76	11743013.01	124558.75	1.050
2010	12104923.2	11972641.8	132281.4	1.093
2011	12347021.66	12206538.82	140482.84	1.138
2012	12593962.1	12444769.32	149192.78	1.185
2013	12845841.34	12687398.61	158442.73	1.233
2014	13102758.17	12934491.99	168266.18	1.284
2015	13364813.33	13186114.65	178698.68	1.337
2016	13632109.6	13442331.6	189778	1.392

** 2% increases per year for UTM overall electricity bill*
** 6.2% increases per year for street lighting electricity bill*

D. Prediction for ten years reduction of electricity bill using PV Street Lighting

Equation (1) and (2) can be used to predict the electricity bill using PV street lighting. This calculation covers 10 years period and can be summarized as tabulated in Table 6.

$$A_i = B_i - Sl_i \quad (1)$$

$$\text{Reduction (\%)} = \frac{B_i - A_i}{B_i} \times 100 \quad (2)$$

Where: A_i = bill after installation
B_i = bill before installation
Sl_i = street lighting bill

Example of calculation:

Year 2006

A_i = RM11 183 077.93 – RM 103 992.18
= RM 11079085.75

$$\text{Reduction (\%)} = \frac{11\ 183\ 077.93 - 11\ 079\ 085.75}{11\ 183\ 077.93} \times 100\%$$
$$= 0.930\ \%$$

Figure 3 shows the comparison of electricity bill for UTM with and without PV street lighting while Figure 4 shows the percentage of electricity bill reduction for ten years from 2006 to 2016.

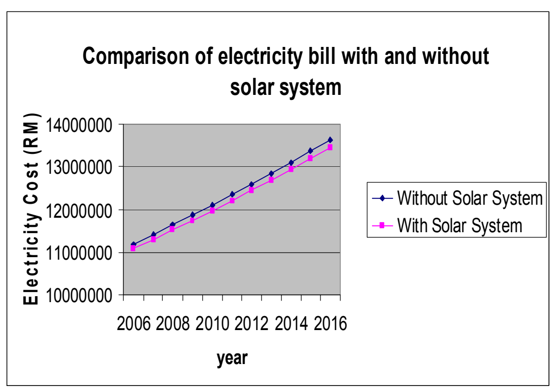

Figure 3. Comparison of electricity bill

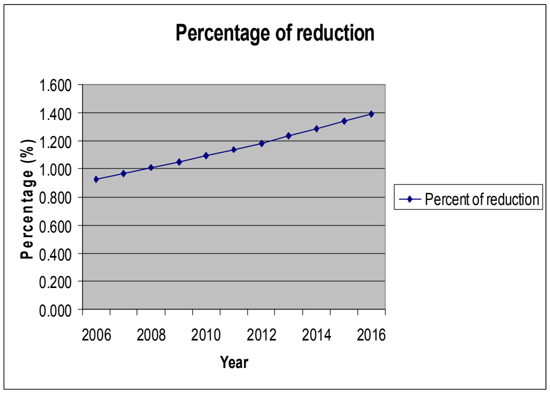

Figure 4. Percentage of reduction

IV. CONCLUSION

Results from this study have shown that photovoltaic street lighting is feasible to be installed in Universiti Teknologi Malaysia, Johor Bahru. The finding shows that there is approximately 1% reduction (savings of RM117286.96) in the electricity bill with the pay back period of 7.5 years for the complete installation of PV system. In selecting the suitable module for the PV street lighting, the study found that amorphous Silicon (a-Si) is the most suitable technology due to greater absorption coefficient in visible light region; thin film thickness required for photoelectric conversion; small quantity of Si required per watt and the most promising material for long term stability. Hence, from the feasibility study on the PV street lighting system, the stand-alone system is the effective techniques that could be applied for an isolated location without interaction with utility lines.

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