UNIVERSITI PUTRA MALAYSIA

ECONOMIC ANALYSIS OF SOLAR PV FARM EFFICIENCY USING HERBAL PLOTS

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ECONOMIC ANALYSIS OF SOLAR PV FARM EFFICIENCY USING HERBAL PLOTS

By

NOOR FADZLINDA OTHMAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

May 2016

DEDICATION

First and foremost, alhamdulillah, praise be to Allah The Al-Mighty, The Most Gracious and The Most Merciful for enlightening my way and directing me with continuous enthusiasm through each and every stage of my study.

I would like to dedicate and express my full appreciation to my chairman of supervisory committee, Associate Prof. Dr. Abdul Rahim Abdul Samad, and my co-supervisor Prof. Dr. Mohd. Shahwahid Hj. Othman for their encouragement and support throughout my research work. It has been my honor and privilege to work under their supervision. I would like to thank all staff and my colleagues at the Faculty of Economics and Management, UPM who supported and helped me during my work. I would like to express my sincere gratitude, thanks and love to my mother, Hjh Kasimah binti Musa and my father, Hj Othman bin Ab. Gani also my parents-in-law, Hj Yaacob bin Sharif and Hjh Hairani Md Taib for their continuous encouragement and *ad-doa* during my period of study. I would like to extend my gratitude to my family for their support and care all these years.

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Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

ECONOMIC ANALYSIS OF SOLAR PV FARM EFFICIENCY USING HERBAL PLOTS

By

NOOR FADZLINDA OTHMAN

May 2016

Chairman: Abdul Rahim Abdul Samad, PhD
Faculty: Economics and Management

Renewable Energy (REs) resources such as wind, solar photovoltaic (PV) and biomass are the future sustainable energy for various industrial applications. In most developing countries especially Malaysia, dependence on fossil fuel like coal, oil and natural gas are at stake. In the near future, these fossil-based energy which are depleting has consistently and produces negative impacts to the environment like global warming and greenhouse gas (GHGs) emissions. Thus, to meet the increasing energy demand, Malaysia needs to shift its energy policies by adapting the REs which assist to protect the environment. Furthermore, the introduction of REs especially solar PV flows in line with green economy requirement. The significant advent of this study is targeted to reveal the economic feasibility of improving solar PV efficiency on Agro-PV project using herbal plots under the PV array with economic viewpoints.

As means of strategic approach, Sustainable Energy Development Authority of Malaysia (SEDA Malaysia) has been established under the Sustainable Energy Development Authority Act 2011 with a clear focus on economic development and environment conservation. It visions to deploy sustainable energy measures as part of the solutions towards achieving energy security where it is in line with the scope of this study on agro PV integration. The adaptation of green technologies is important to ensure a sustainable economic growth thus, it should be effectively manage towards greener environment and future development.

In conjunction with green growth, renewable technology becomes a new economic driver to effectively manage the food supply and energy demands. The integration of renewable energy in agriculture are addressed via the adaptation of solar PV technologies in high value herbal crops cultivation. The concept of herbal plots under PV structures as the cooling mechanism are also a new technique proposed with significant carbon reduction outcomes. Morphological analysis for four types of potential herbal plants namely *Orthosiphon Stamineus, Andrographis Paniculata, Euphorbia Tirucalli and Hibiscus Sabdariffa* under this specific condition proves that *Orthosiphon Stamineus (Java Tea)* as the chosen High Value Herbal crops (HVHc). These scope covers the first objective

which is to identify and choose the most suitable herbal crops deployed under solar PV arrays. The second objective is to determine and estimate the relevant cost and benefits elements involved in the project. Then third objective is to assess the economic feasibility of herbal plants as cooling mechanism as reflected in the heat sink concept. This study differentiate the direct and indirect cost and benefit elements of the Agro-PV project. To fulfil the objectives and test the hypotheses, the CBA criteria used are Internal Rate of Return (IRR)), Net Present Value (NPV) and Monte Carlo Simulation (MC-Sim). The study applies the cost-benefit analysis (CBA) framework.

Temperature plays a significant role in Solar PV technology and herbal growth where approximately 0.5 % electricity from PV generators are reduced based on 1 °C increase of the module temperature. Some study proves that significant amount of electricity generated from the PV system will be reduce or disperse as heat energy due to the increasing module temperature. Thus this brings the idea of green plants as urban infrastructure. This study suggests cooling effect by herbal plots under Solar PV array justified by means of measured temperature within herbal plant surroundings which are comparatively lower as compared to the mid-air temperature under the solar PV array.

The calculation proven that integrating herbal plants under the solar PV array is proven to be economically viable. This study also highlights the existence of cooling mechanism by herbal plant surroundings under the solar PV array which is 0.85 ^{0}C much lower as compared to the mid-air temperature. Herbal plants have the ability in absorbing heat discharge from solar PV arrays thus increase the solar PV power conversion efficiency up to 0.425%. The hypothesis is supported by the field of green infrastructure which concludes that strategic positioning of plants could reduce urban heat energy consumption by 20 – 40 %. The Agro-PV Solar Farm gain surplus from the carbon credit scheme that blends smoothly with herbal plots as the cooling mechanism under solar PV arrays. The crucial findings of this work are explained by means of inculcating herbal plots as an effective cooling mechanism in solar PV farms which proves to be technically sound and economically feasible. It is expected to increase the annual Solar PV energy generation up to 2.77 % or RM156k/ year. The Agro-PV concept produces sufficient IRR value of 13.51% with a reduction of one year for ROI. Thus, the information obtained from this study can fill the information gaps via providing field measurement and insights to policy makers and stakeholders for better decision in agro-pv industry.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

ANALISA EKONOMI TERHADAP KECEKAPAN SOLAR PV MENGGUNAKAN PLOT HERBA

Oleh

NOOR FADZLINDA OTHMAN

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Sumber tenaga boleh diperbaharui (RE) seperti angin, solar Photovolta (PV) dan biomas adalah tenaga lestari masa depan yang digunakan dalam pelbagai aplikasi industri. Di negara-negara membangun terutama Malaysia, pergantungan kepada bahan api fosil seperti arang batu, minyak dan gas asli menjadi pertaruhan. Pada masa akan datang, tenaga berasaskan fosil ini akan menjadi semakin berkurangan dan boleh menghasilkan kesan negatif kepada alam sekitar seperti pemanasan global dan kesan pelepasan gas rumah hijau. Oleh itu, untuk memenuhi permintaan tenaga yang semakin meningkat, Malaysia perlu beralih kepada tenaga boleh dperbaharui yang bersesuaian yang dapat membantu untuk melindungi alam sekitar. Tambahan pula, pengenalan kepada tenaga boleh diperbaharui terutama solar PV adalah selaras dengan keperluan ekonomi hijau. Kepentingan kajian ini disasarkan adalah untuk mengenalpasti kebolehlaksanaan ekonomi dalam projek Agro-PV menambahbaik kecekapan solar PV menggunakan plot herba di bawah struktur solar PV dari sudut pandangan ekonomi.

Sebagai langkah pendekatan strategik, Pihak Berkuasa Pembangunan Tenaga Lestari Malaysia (SEDA Malaysia) telah ditubuhkan di bawah Akta Lembaga Pembangunan Tenaga Lestari 2011 dengan fokus yang jelas mengenai pembangunan ekonomi dan pemuliharaan alam sekitar. Melalui integrasi projek Agro-PV, ia antara langkah-langkah menggunakan tenaga lestari sebagai sebahagian daripada penyelesaian ke arah mencapai keselamatan tenaga selaras dengan skop kajian ini. Adaptasi teknologi hijau adalah penting untuk memastikan pertumbuhan ekonomi yang mampan, justeru, ia perlu diurus dengan berkesan untuk persekitaran dan pembangunan yang lebih hijau pada masa hadapan.

Melalui pertumbuhan hijau, teknologi boleh diperbaharui menjadi pemacu ekonomi baru dalam menguruskan bekalan makanan dan permintaan tenaga dengan lebih berkesan. Integrasi tenaga boleh diperbaharui dalam bidang pertanian ditangani melalui adaptasi teknologi solar PV dalam penanaman tanaman herba bernilai tinggi. Konsep plot herba di bawah struktur PV sebagai mekanisme penyejukan juga satu teknik baru yang dicadangkan dalam pengurangan karbon. Analisa morfologi terhadap empat jenis

tumbuhan herba yang berpotensi iaitu *Misai Kucing, Andrographis Paniculata, Pokok Tetulang dan Hibiscus Sabdariffa* yang ditempatkan di bawah keadaan khusus telah membuktikan bahawa *Misai Kucing (Java Tea)* terpilih sebagai tanaman Herba Bernilai Tinggi (HVHc). Kajian ini meliputi objektif pertama iaitu untuk mengenal pasti dan memilih tanaman herba yang paling sesuai untuk ditempatkan di bawah struktur solar PV. Objektif kedua adalah untuk menentukan dan menganggarkan elemen kos dan faedah yang terlibat dalam projek ini. Manakala, objektif ketiga ialah untuk menilai daya maju ekonomi tumbuhan herba sebagai mekanisme penyejukan seperti yang digambarkan melalui konsep pembebas haba. Kajian ini membezakan kos langsung dan tidak langsung yang memberi manfaat kepada unsur-unsur projek Agro-PV. Untuk memenuhi objektif dan menguji hipotesis, kriteria CBA digunakan adalah Kadar Pulangan Dalaman (IRR)), Nilai Kini Bersih (NPV) dan Monte Carlo Simulasi (MC-Sim). Kajian ini mengaplikasikan rangka kerja analisis kos-faedah (CBA).

Suhu memainkan peranan penting dalam teknologi solar PV dan pertumbuhan herba di mana dianggar kira-kira 0.5% tenaga elektrik daripada janakuasa PV berkurangan berdasarkan peningkatan 1°C suhu modul PV. Beberapa kajian membuktikan bahawa peningkatan suhu modul PV yang tinggi boleh menyebabkan kehilangan tenaga elektrik yang agak ketara dan ianya terbebas sebagai tenaga haba. Justeru, timbul cetusan idea dengan mengambil tumbuh-tumbuhan hijau dalam membangunkan infrastruktur bandar. Kajian ini menunjukkan kesan penyejukan oleh plot herba di bawah solar PV array telah menyebabkan suhu yang diukur dalam persekitaran tanaman herba agak rendah berbanding dengan suhu udara di bawah solar PV array tanpa plot tanaman herba.

Penemuan kajian ini secara umumnya mencadangkan bahawa penggunaan tumbuh-tumbuhan herba di bawah struktur solar PV adalah positif dari segi kewangan dan ekonomi. Kajian ini juga menunjukkan kesan penyejukan oleh persekitaran tumbuhan herba iaitu 0.85 0C jauh lebih rendah berbanding dengan suhu pertengahan udara di bawah solar PV. Dengan itu, keupayaan tumbuhan herba dalam menyerap pembebasan haba boleh membawa kepada peningkatan kecekapan penukaran tenaga oleh penjana solar PV sehingga 0.425%. Berdasarkan kajian terkini dalam bidang infrastruktur hijau yang menyimpulkan bahawa penempatan atau penyusunan tumbuhan secara strategik boleh mengurangkan penggunaan tenaga dalam kawasan perbandaran sebanyak 20 - 40%. Dengan itu, cadangan kepada ladang solar Agro-PV mengintegrasikan gabungan plot herba sebagai mekanisme penyejukan di bawah struktur solar PV untuk mendapat faedah tambahan dari skim kredit karbon. Oleh itu, maklumat yang diperolehi daripada kajian ini diharapkan boleh memenuhi jurang maklumat dengan menyediakan pengukuran di tapak projek dan pandangan kepada pembuat polisi serta pihak yang berkepentingan dalam pembuatan keputusan yang lebih baik dalam industri Agro-PV.

Kira-kira terbukti bahawa mengintegrasikan tumbuhan herba di bawah solar PV array terbukti berdaya maju. Kajian ini juga menunjukkan kewujudan mekanisme penyejukan dengan suhu dalam persekitaran tumbuhan herba di bawah solar PV array adalah 0.85^{0}C jauh lebih rendah berbanding dengan suhu pertengahan udara udara. Tanaman herba mempunyai keupayaan menyerap pembebasan haba daripada penjana solar PV seterusnya meningkatkan kecekapan penukaran tenaga oleh penjana solar PV sehingga 0.425%. Hiphotesis ini adalah berdasarkan kajian terkini dalam bidang infrastruktur hijau yang menyimpulkan bahawa penempatan atau penyusunan tumbuhan secara

strategik boleh mengurangkan penggunaan tenaga dalam kawasan perbandaran sebanyak 20 peratus sehingga 40 peratus. Dengan itu, cadangan kepada ladang solar Agro-PV mengintegrasikan gabungan plot herba sebagai mekanisme penyejukan di bawah struktur solar PV untuk mendapat faedah tambahan dari skim kredit karbon. Penemuan penting dalam kajian ini diterangkan dengan cara menyemai plot herba di ladang-ladang solar PV untuk membuktikan ia sebagai mekanisme penyejukan yang berkesan dari segi teknikal dan ekonomi. Ia dijangka meningkatkan penjanaan tenaga solar PV tahunan sehingga 2.77% atau RM156k/ tahun. Konsep Agro-PV menghasilkan nilai IRR 13.51% dengan pengurangan satu tahun ROI. Oleh itu, maklumat yang diperolehi daripada kajian ini diharapkan boleh memenuhi jurang maklumat dengan menyediakan pengukuran di tapak projek dan pandangan kepada pembuat polisi serta pihak yang berkepentingan dalam pembuatan keputusan yang lebih baik untuk industri agro-pv.

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I certify that a Thesis Examination Committee has met on 20 May 2016 to conduct the final examination of Noorfadzlinda binti Othman on her thesis entitled "Economic Analysis of Solar PV Farm Efficiency using Herbal Plots" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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AgroPV	Agrophotovoltaic
CAPER	Centre for Advance Power and Energy Research
CBA	Cost Benefit Analysis
CDM	Clean Development Mechanism
CER	Carbon Emission Reductions
CM	Cooling Mechanism
CO_2	Carbon Dioxide
DART	Data Acquisition in Real-Time
ETP	Economic Transformation Programme
EPP	Entry Point Project
FiT	Fit-In-Tariff
FF_b	Bottom-side Temperature for Fixed Flat PV Generator
FF_s	Surface Temperature for Fix Flat PV Generator
GDP	Gross Domestic Product
GHG	Greenhouse gas
GI	Green infrastructure
GNI	Gross National Income
G_{mea}	Measured Solar Radiation (based on Pyranometer output)
G_{ref}	Reference radiation value of 1000 W/m^2
G_e	Effective solar radiation which the cells inside actually respond
h	length of object
HDO	Herbal Development Office
HDC	Herbal Development Council
HCP	Herbal Cultivation Parks

HVHc	High Value Herbal crops
IRR	Internal Rate of Return
IEC	International Electrotechnical Commission
I_{dc}	DC Current (A)
ISI®	Institute for Scientific Information®
I_{sc}	Short-circuit current (A)
k	Boltzmann constant ($1.380658 * 10^{-23}$ J/K)
kWh	Kilowatt hour
KWp	Kilowatt peak
LCA	Life Cycle Analysis
MC-Sim	Monte Carlo Simulation
$MtCO_2$	Metric Tonne Carbon
MS	Mean Square
MSE	Mean Square Errors
MW	Megawatt
MYR	Malaysia Ringgit
NKEA	National Key Economy Area
NPV	Net Present Value
NOCT	Nominal Operating Cell Temperature
NRM	Natural Resource Management
NI	National instrument
PCM	Phase Change Materials
PV	Photovoltaic
PV/T	Photovoltaic-Thermal
P_{rated}	Rated power for PV modules/ generator
P_{mpp}	Output Power at maximum power point

RHM	Rainwater harvesting mechanism
R & D	Research and Development
RE	Renewable Energy
RER	Renewable Energy Resources
ROI	Return of Investment
R squared	Correlation Coefficience
RMSE	Root Mean Square Error
SEDA	Sustainable Development Authority of Malaysia
SPMS	Solar PV Monitoring Station
SS	Sum of Squares
SE	Standard Errors
Sig. F	Significance of F-Test
STC	Standard Testing Condition (G=1000W/m^2, T_a = 25^{0}C, AM=1.5)
T	absolute temperature in Kelvin (θ + 273.15 K)
T_a	Ambient Temperature
T_c	Cell Temperature
T_m	Module Temperature
UNFCCC	United Nations Framework Convention on Climate Change
V_{mpp}	Voltage value at maximum power point
V_{dc}	DC Voltage (V)
w	Wind speed (m/s)
η	efficiency

CHAPTER 1

INTRODUCTION

1.1 Overview

New technologies have been introduced with specific focused on environmental friendliness including the integration of renewable energies (REs) such as wind, Solar Photovoltaic (PV), biomass, battery, fuel cells, and distributed generation (DG) (Foo, 2015; Maltini, 2015; Tan et al., 2015). Renewable energy generally known as an energy collected is secured from natural resources, environmental impact and will not be exhausted as conventional energy like oil and gas. The rapid growth in population and economy has called for the need to explore alternative energy sources to support population growth and rapidly increasing commercial energy demand (Amaral et al., 2014). Malaysia needs to optimize green resources as described in Figure 1.0 to support these developments and to enhance the productivity of capital, labor and other production factors (Awalludin et al., 2015; Foo, 2015).

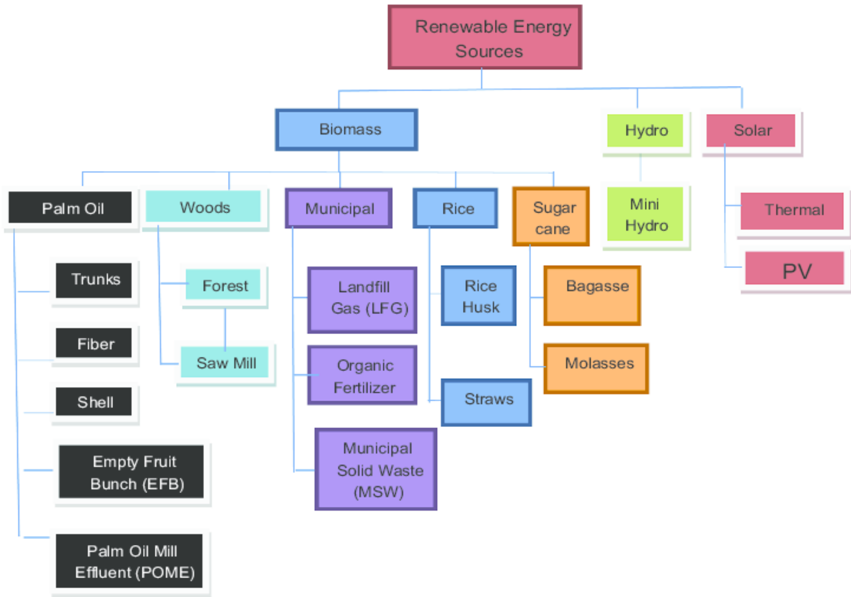

Figure 1.0: Renewable resources in Malaysia based on their availability and utilization prospects (Islam et al., 2009; Petinrin & Shaaban, 2015)

In 2050, the cumulative renewable energy installation capacity in Malaysia is estimated about 34% from the power mix as explained by Mekhilef et al. (2014). Some overview on the renewable energy resources in Malaysia are as follows:

Solar: Solar radiation in Malaysia which achieved average daily between 4.21 kW h/m^2 and 5.56 kW h/m^2 with Building Integrated Photovoltaic (BIPV) project announced to increase the grid-connected PV system installations up to 850 MW by 2030 and more than 8000 MW by 2050.

Biomass: Currently, biomass is the most viable among the RE resources in Malaysia with 4000 ha of palm trees and is the world's second-largest producer of palm oil. Palm oil production increased by 17.4% between 2005 and 2009 to reach 17.6 million tonnes with huge potential for biomass from Empty fruit bunches (EFB) estimated to be 1340 MW by 2030

Biogas: The major sources of biogas are palm oil mill effluent (POME) and livestock manure where a total capacity of 4.45 MW was under construction with the potentials of producing 410 MW by 2028.

Municipal solid waste (*MSW*): The total annual solid-waste production of Malaysia was 7 million tonnes in 2010, and the GDP growth rate of the country was 5.5% by 2011 which means a remarkable increase in solid-wastes production. Malaysia generated 5.5 MW of electricity from MSW in August 2009 and it is expected that, the total installations will rise to 360 MW by 2022.

Small and mini-hydro: The total hydroelectric capacity of Malaysia is around 18,500 MW which is about 20% of the total energy provided by Tenaga Nasional Berhad (TNB). The total mini-hydro installations in Malaysia were 30.3 MW by July 2009 and the expected potential is 490 MW by 2020.

Wind energy: Although Malaysia's wind energy potential is not as high as in Europe, wind energy is a promising way of generating electricity using on-shore and off-shore power systems. There are two wind-turbine units already installed in Pulau Perhentian, Terengganu and Pulau Layang–layang in Sabah with a total capacity of 250 kW.

Geothermal power: The Tawau geothermal program is planned to install a total capacity of 67 MW of geothermal power systems with RM1.5 million has been allocated in the 10th Malaysia Plan for research on geothermal power generation in Sabah.

The Annual Power Generation (in MWh) for Malaysia from the already commissioned Renewable Energy Resources as per 2014 updates as shown in Table 1.1. Although the generated energy seems to be unstable and slightly decreasing for most of the resources, efforts have been made by the Sustainable Energy Development Board (SEDA) to overcome the situation and meeting the targeted energy mix.

Table 1.1: Annual Power Generation in MWh of Commissioned RE resources. Online source from http://seda.gov.my

Year	Biogas		Biomass		Small Hydro	Solar PV
	Landfill/ Agri Waste	Others	Solid Waste	Others		
2014	27702.9	19538.29	4347.83	192983.97	64453.49	177216.31
2013	9477.59	12217.15	11144.25	209407.59	73032.12	48628.83
2012	7465.4	98.11	3234.52	101309.87	25629.78	4714.01

By the FiT scheme, cummulative value of renewable energy are expected to achieve up to 11.5 GW by 2050 where 9GW is expected to come from solar PV as shown below in Figure 1.1:

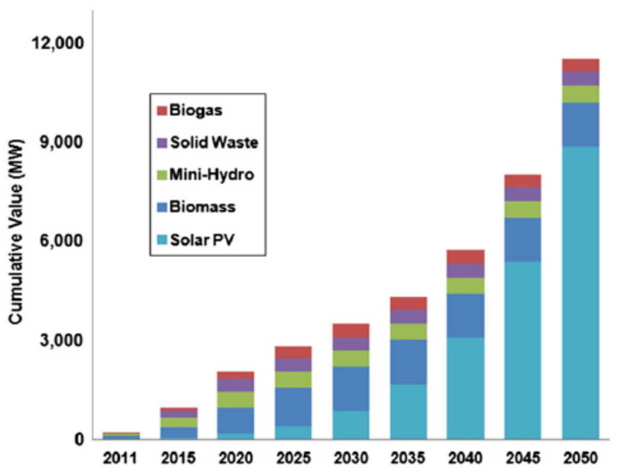

Figure 1.1: Cummulative value of renewable energy in Malaysia 2011 to 2050. (*F. Muhammad-Sukki et al., 2012)*

Renewable energy sources, can be a significant role in Malaysia. In general, renewable energy gives benefits to the environment including avoiding carbon emissions (CO_2), improving economics of renewable energy technology and lowest-cost option by avoiding fuel cost (Aslan Alper and Ocal Oguz, 2016).

1.2 Research background

Electricity generation in Malaysia is fully dependent on fossil fuel, mainly from natural gas and coal. Nevertheless, in sustaining the increasing energy demand, Malaysia need to shift using an alternative energy resources. Energy source can be divided into two categories which is non-renewable energy resources such as coal, petroleum and natural gas and renewable energy resources including energy generated from solar, wind, wave, biomass, geothermal and hydro. Under the Tenth Malaysia Plan (RM-10), Malaysia introduced the Renewable Energy (RE) Action Plan with Feed-in-Tariff (FiT) schemes which spelled out in detail the way forward to increase the market share of RE in the generation mix of the country based on the renewable energy policies and initiatives for a sustainable energy future. The continuously decreasing market price in solar PV technologies are highlighted with strong effort by Malaysian Government through Renewable Energy (RE) policy and National Key Economy Area (NKEA).According to Hashim (2011), solar PV technologies will become the most significant green energy resources towards Malaysia energy mix by the year 2020. Solar PV can be designed to suit the application and operational requirement (Ong HC, Mahlia TMI, Masjuki HH, 2011). Solar energy or solar photovoltaic (PV) electricity generation is clean, non-depleting and does not emit greenhouse gas (GHGs). Figure 1.2 shown the decreasing market trend with advance technology in developing PV cells and cheaper pricing in the world market.

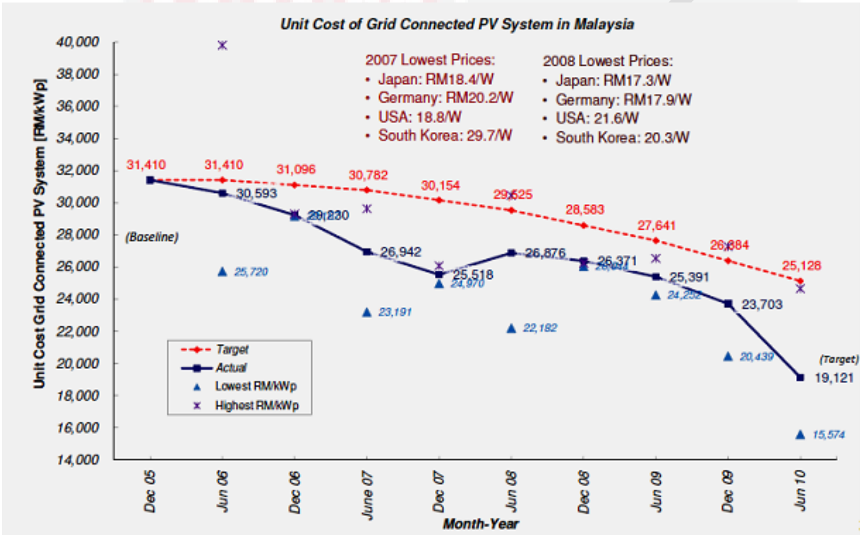

Figure 1.2: The decreasing trend of solar PV cost with the effect of increasing demand in Malaysian market. *(Haris, 2008)*

The final commercial energy sector demand in Malaysia as reported in the Ninth Malaysia Plan, has increased almost 80% from 1243.7 PJ (*petajoules*) in 2000 to 2217.9 PJ in 2010. The transportation and industrial sectors continued merging as the major energy consumers, as compared to the agricultural and forestry sector which consumes only 0.8%. Table 1.2 shows the final commercial energy demand by sector in Malaysia from 2000 to 2010.

Table 1.2: Commercial energy demand by sector in Malaysia (2000 to 2010)

Source	Petajoules (PJ)						Average annual growth rate (%)	
	2000		2005		2010		Eighth Malaysia Plan	Ninth Malaysia Plan
Industrial[a]	477.6	(38.4%)	630.7	(38.6%)	859.9	(38.8%)	5.7	6.4
Transport	505.5	(40.6%)	661.3	(40.5%)	911.7	(41.1%)	5.5	6.6
Residential and commercial	162.0	(13.0%)	213.0	(13.1%)	284.9	(12.8%)	5.6	6.0
Non-energy[b]	94.2	(7.6%)	118.7	(7.3%)	144.7	(6.5%)	4.7	4.0
Agricultural and forestry	4.4	(0.4%)	8.0	(0.5%)	16.7	(0.8%)	12.9	15.9
Total	1243.7	(100.0%)	1613.7	(100.0%)	2217.9	(100.0%)	5.6	6.3

[a] Includes manufacturing, construction and mining.
[b] Includes natural gas, bitumen, asphalt, lubricants, industrial feedstock and grease.

In July 2009, the current Prime Minister of Malaysia, launched the new National Green Technology Policy with specific objectives of (i) to minimise the growth of energy consumption but enhance economic development; (ii) to encourage growth of Green Technology industry; (iii) to increase national capability and capacity in Green Technology development; (iv) to ensure sustainable development and protect the environment; (v) to enhance public education and awareness on Green Technology.

Feed-in Tariff is the most effective renewable energy policy mechanism in promoting and sustaining renewable energy growth. This FiT scheme was introduced in Malaysia by the Parliament approval of Renewable Energy Act (REA) in April, 2011. REA is to establish and implement a special tariff scheme of FiT to catalyse the generation of renewable energy from 2011 onwords. The FiT scheme will be administered and implemented by the Sustainable Energy Development Authority (SEDA). The Malaysia FiT scheme Table 1.3 shows the rate for the electricity generated using solar PV ranging from RM0.85 to RM1.23/kWh, depending on the capacity installed. Malaysia aims solar PV capacity can reach up to 399 MW by the year 2025. It is shown as in Figure 1.3 which Malaysia cumulative solar PV capacity (MW) from 2013 to 2015.

Table 1.3: Malaysia FiT rate for solar PV (F. Muhammad Sukki et al.,2012)

Renewable resource	Description of qualifying renewable energy installation	Feed-in Tariff Rate (MYR/kW h)	Effective Period -commencing from the feed-in tariff commencement date (year)	Annual degression rate (%)
Solar photovoltaic	(a) Renewable energy installation having an installed capacity of:	Basic feed-in tariff rate		
	(i) up to and including 4 kW	1.23	21	8.0
	(ii) above 4 kW, and up to and including 24 kW	1.20	21	8.0
	(iii) above 24 kW, and up to and including 72 kW	1.18	21	8.0
	(iv) above 72 kW, and up to and including 1 MW	1.14	21	8.0
	(v) above 1 MW, and up to and including 10 MW	0.95	21	8.0
	(vi) above 10 MW, and up to and including 30 MW	0.85	21	8.0
	(b) Renewable energy installation having any one or more of the following criteria in addition to (a) above:	Bonus feed-in tariff rate in addition to basic feed-in tariff rate		
	(i) use as installations in buildings or building structures	+0.26	21	8.0
	(ii) use as building materials	+0.25	21	8.0
	(iii) use of locally manufactured or assembled solar photovoltaic modules	+0.03	21	8.0
	(iv) use of locally manufactured or assembled solar inverters	+0.01	21	8.0

Figure 1.3: Total cumulative PV installed in Malaysia reached up to 225 MW in 2015

Currently, the Photovoltaic materials and solar-based technologies is growing at a fast pace as well as other related industries. However, traditional PV technologies need to be more future-oriented by improving the design and their cost effective installation. Most of the solar PV farm installation implies the fix structure PV panel with a certain tilted angle attached to aluminum frames and the space under this structure is not utilized at all. In Malaysia, urban land is a crucial factor operating agricultural activities which is the same issue for solar PV installations. A few example of solar installation project in Malaysia as shown below:

Location/ State	**Plant Capacity**	**Area**	**Investment**
Rembia Industrial Area	5 MWp	7,248.43 ha	RM46 million
Hang Tuah Jaya, Melaka	8 MWp	6.83 ha	RM84 million
Puchong, Selangor	2 MWp	7.5 acre	RM17 million

Based on C. Dupraz et al. (2011), the concept of agrivoltaics in the U.S are presented by developing the same area of land for both PV production and conventional agriculture production or in simple terms the combination of energy and crops production. In other study, Dinesh and J. M Pearce (2015) claimed that this concept increases food production demand and energy demand over 30% in economic value thus minimizes crop yield losses and maintain crop price stability.

The trend for cash crops and decreasing market price in solar PV technologies are highlighted with strong effort by Malaysian Government through Renewable Energy Policy and National Key Economy Area (NKEA). Herbal remedies has capture a strong economical catalyst and provides substantial benefits in the area of pharmaceutical health care, supplementary food and eco-tourism in most of the ASEAN country especially in

Malaysia. In conjunction with the Economic Transformation Program (ETP), the government of Malaysia outlined a number of strategic thrusts to boost economic growth especially in the agriculture sector. Under the Entry Point Projects 1 (EPP1), herbal products have been given sufficient room for extension. There are 11 types of selected commercialize High Value Herbal crops (HVHc) including *Orthosiphon Stamineus* or Java Tea, *Androghaphis Paniculata* or The King of Bitter, *Euphorbia Tirucalli* or Tetulang and *Hibiscus Sabdariffa* or Roselle.

A field evaluation for four types of herbal plants with different physiological characteristics have been selected to suit this study, in addition to their good economical, uniqueness and medicinal properties aspects. This research work also highlights field measurement to identify the plant growth and its sustainability under solar PV arrays in Malaysia tropical weather condition specifically in Universiti Putra Malaysia. From the morphological analysis of herbal plants, *Orthosiphon Stamineus* known as Java Tea are chosen to be deployed under solar PV arrays for utilising the unused space, based on its growth and high potential market value. *Eurycoma Longifolia* or Tongkat Ali are not selected due to the plant height can reach up to 18 meter, is not suitable for this condition which will affect the solar PV system operation. This slow-growing plant takes about 25 years for complete maturation and the roots are harvested after takes 4 years cultivation (Bhat and Karim, 2010). Kacip Fatimah (*Labisia Pumila*) which is also listed under the EPP herbs is a very sensitive plant especially when expose to increasing heat plus limited availability of the seedling. Open sunlight or even partial shade could threaten the establishment and growth of kacip Fatimah (Diyana Jamaluddin et al., 2015).

Temperature plays a significant role in Solar PV technology and herbal growth. Skoplaki and Palyvos (2009a) and Kim et al. (2011) explains that approximately 0.5 % electricity from PV generators are reduce based on 1°C increase of the PV module temperature. This statement proves that a significant amount of electricity generated from the PV system will be reduce or disperse as heat energy due to the increasing module temperature. This condition shows inversely proportional relationship with decreasing of PV conversion efficiency. Cooling of PV panels is the critical issue of PV technology where based on Haitham M.S Bahaidarah et al. (2016), high cell temperature and non-uniform temperature on the surface of PV panel has a major impact on the PV performance due to the reduction of PV conversion efficiency which could lead to permanent structural damage. Simple design of cooling method keeps the cell temperature at its optimum condition. Figure 1.4 shown a typical uniform cooling techniques for cooling PV cell and electronics devices and one of the commonly used is phase change material (PCM).

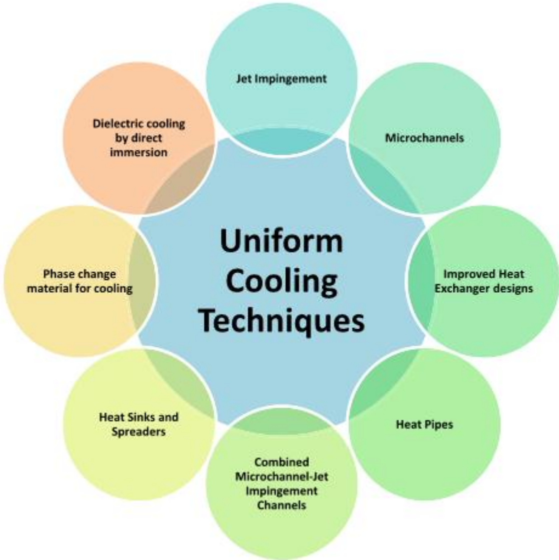

Figure 1.4: A typical uniform cooling techniques

Heat sink concept generally absorbs or transfer the heat generated by the PV conversion process thru means of active cooling such as conventional glazing or passive cooling such as heat exchanger via natural air, forced air, Phase Change Materials (PCM), etc (Browne, Norton, & McCormack, 2015; Do, Kim, Han, Choi, & Kim, 2012; Du, Darkwa, & Kokogiannakis, 2013). Typical example of commonly applied heat sinks in Fixed Flat Solar PV applications are shown in Figure 1.5

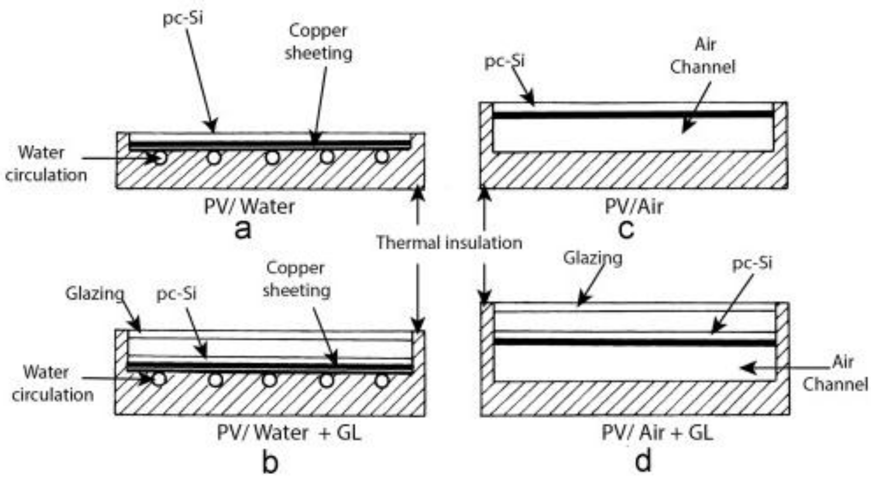

Figure 1.5: Typical concept of Heat sink mechanism to reduce PV module temperature.(Browne et al., 2015)

Green plants has great potential and contribution to urban green infrastructure (Wang, Bakker, de Groot, & Wörtche, 2014)(Emmanuel & Loconsole, 2015) thus, the cooling effect by herbal plots under Solar PV array are suggested. The cooling mechanism provides financial benefits to the project via herbal plots integration as the heat sink. This hypothesis can be proven by means of measured temperature within herbal plant surroundings which are comparatively lower as compared to the mid-air temperature under the solar PV array. This condition is considered acceptable based on recent study in the field of green infrastructure which concludes that strategic positioning of plants could reduce domestic buildings' heat energy consumption by 20 – 40 %. Electricity generation via solar PV modules are also suggested to be embedded with this green infrastructure as to absorb the heat energy discharged (Cameron et al., 2012, Norton et al., 2015). The findings of this work are justified with financial analysis of CBA (Cost Benefit Analysis), NPV (Net Present Value) and IRR (Internal Rate of Return) to analyses the profitability and suitability of the approach.

1.3 Problem statement

During the Third Global Bio-Herbs Economic Forum, 2009, Malaysia government under the Malaysian economic policies and development plans has highlighted many programs and funding to support local herbal industry. Nowadays, people have realized the huge potential and the benefits of using herbs. The demand of herbal products especially in herbal supplement, health functional food, herbs-based energy drink and cosmetics have shown increasing trend which support economical growth (Farizah Ahmad et al., 2015). As a result, in early 2011, the governance of the Ministry of Agriculture and Agro-based Industries Malaysia, has planned and executed Economic Transformation Programme (ETP) as one of the entry point project (EPP). Since then, there were continuous efforts and financial support from Malaysian government to develop herbal industry to improve competitiveness of herbal industry and to be able contribute to higher share within in agriculture sector and the GDP of Malaysia.

The East Coast Economic Region (ECER) of Malaysia approved by the government, plays a significant role as the regional hub for innovation in herbs and biotech product which have developed herbal integrated cluster focused on herbs such as Hempedu Bumi or The King of Bitter (*Andrographis paniculata*), Misai Kucing (*Orthosiphon stamineus*) and Roselle (*Hibiscus sabdariffa*). This herbal park covered about 407 hectares of land in Pasir Raja, Terengganu to ensure the availability of ready source of raw material for the production of nutraceuticals and botanical drugs. Herbal fund of RM533 million from the public funding, under the NKEA Agri EPP1 initiatives, has been established including R & D grant was allocated to develop the project to increase the value chain and support the growth of herbal industry towards high value herbal products (PEMANDU Annual Report, 2011).

The increasing demand of high value herbal crops and solar PV technologies especially in Malaysia creates a green economic opportunity for the integration of agriculture and renewable energy resources. The adaptation of solar PV technologies in large scale high value herbal crops cultivation for tropical country like Malaysia, requires in-depth research work. The unused space under each 1 kWp solar PV arrays is one crucial factor to be investigated which covers about 9 square meter of potential land. If this value is projected for 1 MWp solar PV system, the available space can reach up to 2.2 acres. Many solar PV farm projects currently in operation such as the 8 MWp Hang Tuah Jaya, Melaka, 5 MWp Sepang etc. are some of the examples of potential projects for agro-PV integration.

According to S. M Shafei et al. (2011), in the year 2009, 94.5% of electricity is generated from fossil fuel from which Malaysia remains an exporter as present. Recently, renewable energy resources becomes an attractive pathway for sustainable energy development in Malaysia, as to mitigate concerns about the issues of energy security, the fluctuate of crude oil price and the global climate change. The government of Malaysia estimated to have 9 GW of solar PV installation by year 2050 as anticipated by F. Muhammad Sukki (2012), following the introduction of the FiT policy to encourage public and business enterprises to invest in solar PV projects.

Increasing module temperature decreases directly the electricity generation in PV systems which requires heat sink to cool down the process. Adaptation of herbal plots under PV structures as an effective cooling mechanism are suggested for system enhancement despite the significance of carbon reduction. The concept of agro-PV integrations are the main elements of this work and are supported with economical justifications. The unused area under Solar PV arrays in Universiti Putra Malaysia are planted with *Orthosiphon Stamineus (Java Tea)* as the chosen High Value Herbal crops (HVHc). The integration of these two elements would eventually projects high demand of herbal product outcomes within eco-friendly facilities.

1.4 Research aim and objectives

The aim of the study is to evaluate the feasibility of herbal plots under solar PV arrays as the cooling mechanism. The objectives of this research are as follows:

a) Conduct field measurement to identify and choose the most suitable herbal crops under solar PV arrays in Malaysia tropical weather condition.
b) To determine and estimate cost and benefits elements involved in using herbs for utilizing the unused space under solar PV arrays.
c) To conduct economic feasibility assessment on agro-PV project using the Monte Carlo method in NPV model.

Thus, the hypothesis in this research work is the adaptation of herbal plots as an effective cooling mechanism in solar PV farm is technically sound and economically feasible

1.5 Significance of study

A strong justification of the significance of this study can be described by the integration of herbal plots under solar PV array to optimize the potential land under this unique condition. Furthermore, the concept of green plants as cooling mechanism is also proposed to resolve issues of decreasing electricity generation due to increasing PV module temperature during the energy conversion process.

1.6 Scope of work and research contributions

This study cultivates four types of herbal as the recommended high value herbal crops for Malaysia green economics. The scope of work to be carried out involves two main elements which is conducting field test for herbal sustainability under solar PV arrays as means of utilizing the unused space. Secondly, installing temperature sensors to determine the cooling effect from the herbal plots. The project is located at the existing 10kWp PV pilot plant in Universiti Putra Malaysia (UPM). Data monitoring system with real-time features are used for the field test arrangement in the tropical ground condition.

The validity and justifications of this study can be appreciated with actual measurement of 3,470 data points for the temperature measurement with correlation factor of 0.94. The academic contributions in this study can be described by the field justification of Java Tea as the most sustainable herbal crops planted under solar PV arrays and the economical evaluation of utilizing the unused space and the cooling mechanism. Thus, the information obtained from this study can fills the information gaps providing field measurement and insights to policy makers and stakeholders for better decision in agro-pv industry.

1.7 Thesis organization

The thesis is written using the alternative format where chapter 1 - 3 remain as per conventional and the remaining 4 - 6 chapters reflect the body of the thesis from which two chapters were already published/ approved for publication in high impact ISI journals. Chapter 2 refers to the literature reviews on the research scope with emphasize on Malaysian efforts towards green economics, integration of renewable energy resources in agriculture with highlights on Solar PV technologies as the drying tools. Chapter 3 covers the methodology and field setup. The monitoring system capture measurement from multiple input sources and analyze visually in real-time and synchronize mode which is the crucial aspect for rapid fluctuating data flow.

Chapter 4 addresses some practical approach of PV farming based on morphological analysis on four types of Malaysian Herbs namely *Orthosiphon Stamineus* or Java Tea, *Andrographis Paniculata* or The King of Bitter, *Euphorbia Tirucalli* and *Hibiscus Sabdariffa* or Roselle. The selections of these herbs are mainly based on the uniqueness and physical difference to suit this study in addition to their good economical and medicinal properties aspects. Chapter 5 presents Java Tea *Orthosiphon Stamineus* as the High-Value Herbal crops (HVHc) chosen to be deployed under PV arrays based on its sustainability and potential market value. The financial analysis is based on 3-months harvesting cycle with reference to the harvesting coefficient p_c and realistic cash flow. The crucial findings of this work are explained in Chapter 6 where the cooling approach via herbal plots is expected to increase the annual Solar PV energy generation up to 2.77 % which initiates handsome monetary benefits of RM156k/ year. The Agro-PV concept produces sufficient IRR value of 13.51% with a reduction of one year for ROI.

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