UNIVERSITI TEKNOLOGI MARA

LIFE CYCLE ASSESSMENT OF LARGE-SCALE PHOTOVOLTAIC SYSTEM AND END-OF-LIFE POLICY FORMULATION IN MALAYSIA

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Thesis submitted in fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Electrical Engineering)

College of Engineering

September 2022

ABSTRACT

Photovoltaic (PV) system is known as a clean electrification mode considering almost no obvious emissions during its operation. However, when considering its entire life cycle, the PV system still consumes certain amount of primary energy and impacts the environment. Therefore, life cycle assessment (LCA) is used to assess primary energy consumption and environmental impacts of PV systems. Nevertheless, LCA results become unreliable when site-dependent data for appropriate time frame are not considered. In addition, as LCA of different PV module technologies was usually conducted without modifying the inventory of the associated balance-of-system components to meet the specifications of the PV module, the interpretation of results becomes less accurate. In Malaysia, the existing LCA study for large-scale PV system was not conducted using foreground data, thus reducing the representativeness of the results. Moreover, as the number of PV systems is expected to surge in the near future, the PV waste will correspondingly increase, hence presenting a new environmental challenge with the absence of PV end-of-life management policy in Malaysia. Therefore, this study presents the LCA of large-scale PV system and end-of-life policy formulation in Malaysia. The life cycle inventory model of a large-scale PV system in Malaysia was first developed before the primary energy consumption and environmental impacts were quantified. Then, the effect of different PV system configurations on the energy and environmental indicators was evaluated. Later, PV end-of-life policy options were formulated based on life cycle approach. The results showed that the energy payback time and global warming impact of the system are 3.43 years and 30.95 g CO_2-eq/kWh respectively, which are 8.74 times and 19 times lower than system lifetime and Malaysian grid emission factor respectively. When comparing different system configurations, the large-scale PV system using cadmium telluride modules provides better energy and environmental indicators compared to crystalline silicon modules. Apart from that, system using central inverters provides better energy and environmental indicators compared to string inverters. Besides that, when comparing PV end-of-life policy options, regulatory approach yields greater benefits than voluntary approach in terms of quantity of recycled PV modules, environment, primary energy consumption and economic implications. In short, this study highlights the energy and environmental hotspots of the large-scale PV system that could provide insights for PV designers and increase awareness among the PV industry and society. Also, the developed policy options shed light on the future impacts and potentials of PV end-of-life management in Malaysia.

ACKNOWLEDGEMENT

Alhamdulillah all praise to Allah SWT, for the strength, patience and His blessing to complete this study. This research could not have been completed without the help of many parties. I would like to take this opportunity to thank and express my appreciation to all of them.

First and foremost, I would like to express my sincere gratitude and appreciation to my supervisor, Assoc. Prof. Ir. Ts. Dr. Shahril Irwan Sulaiman and my co-supervisor Prof. Dr. Sulaiman Shaari for their excellent guidance, constant support and their continuous encouragement throughout the course of this thesis.

I am sincerely indebted to my beloved husband, Rijalul Fahmi and daughter, Rey Rihanna for their wonderful inspiration. Their presence has definitely given a warm comfort through thick and thin during this journey. My parents, Mohd Nordin Yusoff and Tuan Zainab Tuan Chik, and my parents-in-law, Mustapa Abdul Jalil and Zuraidah Hashim for their prayers, encouragement and endless support during this journey. My family and in-laws for their understanding and words of encouragement. This effort indeed is as much theirs as it is mine.

I would like to express my appreciation to Green Energy Research Centre (GERC) members for their support, motivation and for being good friends. My colleagues in the School of Electrical Engineering, Universiti Teknologi MARA (UiTM) Pasir Gudang for their help with this thesis either directly or indirectly.

I would also like to thank Gading Kencana Development Sdn. Bhd. for providing data used in this study and all the staffs for their assistance with the collection of data.

My special thanks also go to Universiti Teknologi MARA (UiTM) and Ministry of Education (MOE) for providing me the opportunity and scholarship to pursue my Ph.D. study.

Last but not least, I would like to thank all individuals who have involved directly or indirectly in the completion of my study.

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CHAPTER ONE
INTRODUCTION

1.1 Research Background

Photovoltaic (PV) system is a popular mode of electrification that provides relatively cleaner electricity compared to fossil-fuel-based electricity generation technologies. Moreover, PV has played an essential role in achieving a sustainable transition towards clean electricity [1], [2]. Growing exponentially, as of 2020, the total global PV installed capacity was reported to exceed 767 GW, which 145 GW of this total alone was installed in 2020 [3]. Besides the declining cost of PV modules that enable PV systems to become more competitive against conventional electricity generation technologies, various supports in terms of policies, schemes and incentives introduced worldwide have been reported as the key drivers for PV market growth. Examples of such supports are feed-in tariffs (FiT), feed-in premium, direct subsidies, tax credits, 'carbon' taxes, as well as self-consumption and net-metering. These support programs have been implemented for residential, commercial and even utility-scale PV system projects. However, due to relatively larger power capacity, the utility-scale PV systems have shown significant contribution to global PV market growth. Apart from that, the past decade has also witnessed that PV industry transformed from a subsidized into a profitable energy sector [1], [4].

In Malaysia, PV system development is driven by several factors. The hike of national electricity consumption from 53,195 GWh in 1998 to 92,815 GWh in 2008 and subsequently 152,866 GWh in 2018 proves a continuous increase in the country's energy demand [5]. Besides that, although fossil fuel is still dominating the national electricity mix, Malaysia has inked its commitment to the Paris Agreement in mitigating global warming by reducing greenhouse gas emissions. Hence, in coping with the high demand for electricity and at the same time reducing the greenhouse gas emissions, one of the strategies identified is by introducing Renewable Energy (RE)-based electricity generations [6]. In fact, Malaysia has specified RE capacity target of 31% in 2025 and 40% in 2035 to increase the usage of RE in the national electricity mix as one of the efforts to decarbonize the energy sector [7], [8]. One of the common RE used in Malaysia is solar PV.