Faculty of Manufacturing Engineering

MANAGING SUPPLY CHAIN FOR THE END-OF-LIFE SOLAR PANELS IN MALAYSIA

Muliati Binti Mohd Romli

Master of Manufacturing Engineering
(Industrial Engineering)

2023

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MULIATI BINTI MOHD ROMLI

A project report submitted
in fulfillment of the requirements for the degree of
Master of Manufacturing Engineering (Industrial Engineering)

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2023

DECLARATION

I declare that this project entitled "Managing Supply Chain for the End-of-Life Solar Panels in Malaysia" is the result of my research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature : .....

Name : Muliati Binti Mohd Romli

Date : 10/02/2023

APPROVAL

I hereby declare that I have read this report and in my opinion this report is sufficient in terms of scope and quality as partial fulfillment of the Master of Manufacturing Engineering (Industrial Engineering).

Signature : .....

TS DR AL AMIN BIN HJ MOHAMED SULTAN
PENSYARAH KANAN/SENIOR LECTURER
FAKULTI KEJURUTERAAN PEMBUATAN
UNIVERSITI TEKNIKAL MALAYSIA MELAKA
HANG TUAH JAYA 76100 MELAKA

Name : Ts. Dr. Al Amin Bin Mohamed Sultan

Date : 16 February 2023

DEDICATION

I dedicated my study to my loving parents, Mohd Romli Marto and Masriyah Hasan, that be my most significant source of inspiration. This work is also dedicated as an aspiration to my one and only brother, Muhammad Kasim Mohd Romli, to continue his master in the future further. Thank you, Ts. Dr. Al Amin, my supervisor who guided me in this process, and the committee who kept me on track. Lastly, my friends, colleagues, and classmates who had always listened to my rant and together with me to finish the writing. May Allah, Subhanahu Wa Ta'ala, grant all your kindness to Jannah Firdaus. Amen.

ABSTRACT

Solar energy is one of the renewable energy sources that aims to convert solar energy into electricity. The usage of PV solar panel has rapidly increased in Malaysia as this country have a strategic geographical area and receives high solar irradiation throughout the year. In the upcoming 25–30 years, the globe could face up to 78 million tonnes of solar panel waste by 2050, this including waste from Asia. Currently, in Malaysia, no recycling facilities are available, and there is no preparation towards managing the first batch of solar waste. In terms of analysis, still a lack of studies discussing managing solar panel waste, specifically in Malaysia. This project determined the total volume and distribution of waste generated by used solar panels at the End-of-Life (EoL). Then, this report studied the potential recycling facility centres using the centre-of-gravity method to determine the midpoints. Besides, this project also presented the most appropriate sites for recycling centres that possess low complexity of the supply chain and the most negligible greenhouse gas emissions from transportation using the supply chain complexity method and the weighted sum method. This report focuses on the usage of PV panels at the Large Solar Scale (LSS) in Malaysia. 115 LSS farm data in Malaysia were collected for this study. Using the centre of gravity approach, the central point for the potential recycling centre was identified based on the current LSS farm location (longitude and latitude). The result of the supply chain complexity measurement shows alternative A, with a value of 1.937, having the lowest value for the supply chain complexity. Then the weighted sum calculation was used to re-check the result. The weight sum calculation shows alternative D, with a value of 0.010, was the lowest value indicating this alternative has the most inadequate greenhouse emissions. From the project, the study concluded alternative A with one recycling centre having the least supply chain complexity. Still, it poses high greenhouse emissions as it requires more travel distance from each LSS to the one recycling centre. On the other side, alternative D, with the 14 recycling centre, show minor greenhouse emission through transportation. This is due to the less distance from LSS to its state recycling centre. The initiative and preparation towards managing future solar panel waste are required. More studies focusing on the details process and the cost of the recycling centre were recommended for the future.

MENGURUSKAN RANTAI BEKALAN UNTUK AKHIR HAYAT PANEL SOLAR DI MALAYSIA

ABSTRAK

Tenaga suria merupakan salah satu sumber tenaga boleh diperbaharui yang bertujuan untuk menukar tenaga suria kepada tenaga elektrik. Penggunaan panel solar PV telah meningkat dengan pesat di Malaysia kerana negara ini mempunyai kawasan geografi yang strategik dan menerima penyinaran suria yang tinggi sepanjang tahun. Dalam 25–30 tahun akan datang, dunia akan berhadapan sehingga 78 juta tan sisa panel solar menjelang 2050, ini termasuk sisa dari Asia. Pada masa ini, di Malaysia, tiada kemudahan kitar semula tersedia, dan tiada persediaan untuk menguruskan kumpulan pertama sisa solar. Dari segi analisis, masih kurang kajian yang membincangkan pengurusan sisa panel solar, khususnya di Malaysia. Projek ini menentukan jumlah isipadu dan pengagihan sisa yang dijana oleh panel solar terpakai di End-of-Life (EoL). Kemudian, laporan ini mengkaji pusat kemudahan kitar semula yang berpotensi menggunakan kaedah pusat graviti untuk menentukan titik tengah. Selain itu, projek ini juga membentangkan tapak yang paling sesuai untuk pusat kitar semula yang mempunyai kerumitan rendah rantaian bekalan dan pelepasan gas rumah hijau yang paling boleh diabaikan daripada pengangkutan menggunakan kaedah kerumitan rantaian bekalan dan kaedah jumlah berwajaran. Laporan ini memberi tumpuan kepada penggunaan panel PV pada Skala Suria Besar (LSS) di Malaysia. 115 data ladang LSS di Malaysia telah dikumpul untuk kajian ini. Menggunakan pendekatan pusat graviti, titik pusat untuk pusat kitar semula yang berpotensi dikenal pasti berdasarkan lokasi ladang LSS semasa (longitud dan latitud). Hasil pengukuran kerumitan rantaian bekalan menunjukkan alternatif A, dengan nilai 1.937, mempunyai nilai terendah untuk kerumitan rantaian bekalan. Kemudian pengiraan jumlah wajaran digunakan untuk menyemak semula keputusan. Pengiraan jumlah berat menunjukkan alternatif D, dengan nilai 0.010, adalah nilai terendah yang menunjukkan alternatif ini mempunyai pelepasan rumah hijau yang paling tidak mencukupi. Daripada projek itu, kajian menyimpulkan alternatif A dengan satu pusat kitar semula yang mempunyai kerumitan rantaian bekalan paling sedikit. Namun, ia menimbulkan pelepasan rumah hijau yang tinggi kerana ia memerlukan lebih banyak jarak perjalanan dari setiap LSS ke satu pusat kitar semula. Sebaliknya, alternatif D, dengan 14 pusat kitar semula, menunjukkan pelepasan rumah hijau kecil melalui pengangkutan. Ini disebabkan oleh jarak yang kurang dari LSS ke pusat kitar semula negerinya. Inisiatif dan persediaan ke arah menguruskan sisa panel solar masa depan diperlukan. Lebih banyak kajian yang memberi tumpuan kepada proses perincian dan kos pusat kitar semula disyorkan untuk masa hadapan.

ACKNOWLEDGEMENTS

In the Name of Allah S.W.T, the Most Gracious, the Most Merciful.

Firstly, Alhamdulillah, my greatest thankful to Allah for being able to complete the Master Project. Then, I would like to convey my sincere gratitude to my parents, *Mohd Romli Marto* and *Masriah Hassan,* for their continuous support from the first semester of my master's studies at Universiti Teknikal Malaysia Melaka (UTeM). Using this chance, I would like to sincerely thank my supervisor, Ts Dr. Al Amin bin Mohamed Sultan ffrom the Faculty of Manufacturing UTeM, fot his essential supervision, precious guidance & support throughout this report.

I would also extend my gratitude to my departmental managers for all their support and understanding through my master's degree journey.

Apart from that, special appreciation to all my friends from the Faculty of Manufacturing, UTeM, for their motivational support. Thank you very much.

Muliati Binti Mohd Romli

February 2023

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EoL	-	End-of-Life
EVA	-	Ethylene Vinyl Acetate
IRENA	-	International Renewable Energy Agency
kW	-	Kilowatts
LSS	-	Large Solar Scale
MW	-	Megawatts
PET	-	Polyethylene Terephthalate
PV	-	Photovoltaic
SEDA	-	Sustainable Energy Development Authority
SWAP	-	Solar Waste Action Plan
SEDA	-	Sustainable Energy Development Authority
TCF	-	Total Carbon Footprint
TTD	-	Total Transportation Distance
US	-	United States
WSM	-	Weighted Sum Method

CHAPTER ONE

INTRODUCTION

1.1 Research Background

In the past decade, the usage of alternative energy sources, particularly renewable energy, has increased globally (Bundschuh et al., 2021). Alternative energy sources, particularly renewable energy, have increased globally in the past decade. Renewable energy sources include wind, biomass, hydro, geothermal, and solar energy. Among all these energy sources, solar energy technology is currently the third most widely used renewable energy source in the world, trailing behind hydropower and wind power, which are first and second, respectively (Chowdhury et al., 2020).

In the current context, conventional energy sources such as oil, coal, and gas satisfy the energy requirement. However, when fossil fuels are utilised to generate power, pollution and greenhouse gas emissions grow (Rathore et al., 2021). Using fossil fuels to create energy results in increased pollutants and greenhouse gases, which causes environmental difficulties (Rathore et al., 2021). This is where renewable energy plays a vital role in overcoming this issue.

In Malaysia, the only renewable energy source that has expanded in installed capacity between 2014 and 2019 is solar, which has seen a tremendous 432% increase over this time (Nguyen, 2021). Malaysia benefits from its equatorial location in terms of creating solar energy. It is blessed with a natural tropical environment with an average daily solar radiation of 4500 kWh m–2 and abundant sunshine for roughly 12 hours daily (Abd. Aziz et al., 2016).

However, because Malaysia has a tropical environment and receives a lot of sunlight, solar energy has become more adaptable to be used here over time. Malaysia's average daily temperature ranges from 21°C to 32°C (Climate, 2022). As per reported by (Average monthly hours, 2022), the average number of sun hours in a year is 2220.

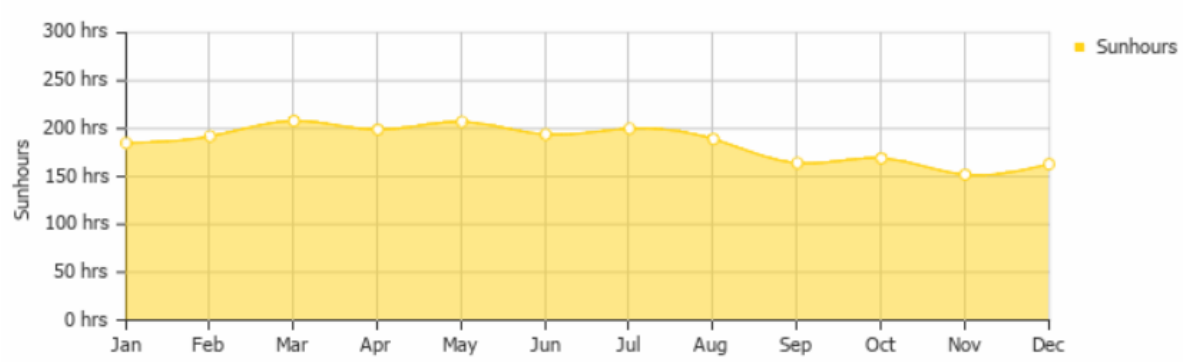

Figure 1.1: The total number of sun hours in Kuala Lumpur, Malaysia, during the year. (Average monthly hours, 2022).

Photovoltaic technology has a bright future to meet the world's future energy needs because solar power is safe, efficient, non-polluting, and reliable (Chowdhury et al., 2020). According to (Kusch & Alsheyab, 2017). Other than that, PV technology is one of the greenest and most promising energy-generation technologies since it generates electricity directly from the sun, avoiding the usage of fossil fuels and the emission of greenhouse gases (GHG) during system operation. In addition, car Photovoltaic (PV) panels have a reasonably long active (Tao & Yu, 2015) life, often ranging from 20 to 30 years.

The increasing production of solar PV panels, whose End-of-Life (EoL) waste is expected to reach millions of tonnes by the middle of this century, poses a threat to the social and environmental surroundings. (Daniela-Abigail et al., 2022). Globally, beginning in 2020, EoL solar photovoltaic (PV) panels will be a fast-growing hazardous waste (Kusch & Alsheyab, 2017). An international organisation called the International Renewable Energy Agency (IRENA) predicted that by the year 2050, there will be enough solar panels that have reached the end of their useful lives to weigh up to 78 million metric tonnes collectively (Nguyen, 2021). This is equivalent to the weight of more than 10.4 million mature elephants. In the future, it will become a mass problem if no action plan is taken to properly manage the solar panel's EoL. According to (Papamichael et al., 2022), to most significant amounts of solar waste are anticipated to be produced in Asia (3.5 Mt), Europe (3 Mt), and the United States (1 Mt). And finally, between 2030 and 2050, a 60-89 Mt global buildup is anticipated.

The EoL phase has been neglected or ignored for the most part during the majority of the study, primarily due to the low number of panels that have reached the disposal stage yet and the absence of data regarding their EoL characteristics (Latunussa et al., 2016). With increasing renewable energy penetration to the relatively increasingly effective use of PV, there is currently insufficient or perhaps no infrastructure for recycling solar panels, demonstrating a disregard for future demands concerning solar panels' recycling potential (Papamichael et al., 2022). According to (Vekony A., 2021), in 2050, Malaysia is predicted to produce 190,000 tonnes of solar panel waste.

1.2 Problem Statement

Solar energy is one of the renewable energy sources globally trending. Its usage to replace the use of fossil fuel are environmentally friendly. While solar energy is a clean energy source in and of itself, managing the expected EoL solar panel waste is likely to be a huge challenge that calls for preparation and foresight. Throughout the years, the usage of solar panels has been increasing. However, as the life span only can stand for 20 to 30 years, it will need to be replaced and become waste. Solar panels contain various materials such as glass, aluminium, silicon, and other hazardous materials. As that, a proper EoL is required to handle this upcoming waste.

In Malaysia, solar energy is a clean energy resource in and of itself. Nevertheless, the disposal of the waste generated when solar panels reach the end of their useful lives is expected to provide a tremendous management challenge that demands forethought and planning. Unfortunately, however, currently, there is still limited research discussing solar panel management in Malaysia. Currently, the first batch of total volume and distribution of waste generated by used solar panels in Malaysia at the end of their EoLis still unknown. The predicted volume produced by the solar panel needs to be identified as this will play an essential factor in managing its supply chain complexity later in transportation.

Other than that, globally, many countries have begun preparing to manage the EoL of solar panels. Nevertheless, a still limited study has been explicitly conducted to study Malaysia's potential recycling or remanufacturing facility centres. Parallel to that, less study towards Malaysia's preparation for the first EoL solar panel batch. Then no analysis of the most appropriate sites for recycling centres that possess low complexity of the supply chain and the most negligible greenhouse gas emissions from transportation, specifically in Malaysia.

When these facilities are ready in Malaysia, the end-of-life panel will be more manageable. Besides that, no study had been done to evaluate Malaysia's most suitable solar panel recycling centre with the most negligible environmental impact.

1.3 Research Objectives

The objectives of the study are:

i. To determine the total volume and distribution of waste generated by used solar panels at the End-of-Life (EoL).

ii. To study potential recycling or remanufacturing facility centres using the centre-of-gravity method.

iii. To identify the most appropriate sites for recycling centres that possess low complexity of the supply chain and the most negligible greenhouse gas emissions from transportation.

1.4 Scope of the Study

The study was conducted according to the following scopes;

(i) Solar farm using PV panel

As stated before, this study will focus on solar energy. However, the scope will be focused on PV panel usage in Malaysia.

(ii) Solar Farms in Malaysia

As the cost of recycling is very high and non-profitable for the small quantity of recycling, this study will focus on the LSS. LSS is intended to facilitate the deployment of utility-scale solar PV systems with capacities ranging from 1 to 100 MW in Malaysia. This study plan was conducted based on the current LSS in Malaysia (Johor, Melaka, Negeri Sembilan, Selangor, Pahang, Terengganu, Kelantan, Perak, Kedah, Perlis, Sabah and Sarawak)

(iii) Photovoltaic Solar Panel Waste

Solar panels are made from crystalline silicon, with approximately 70% being glass, 15% being aluminium for frames, 10% being plastic, and only 3-5 per cent being silicon. The waste calculated included overall waste from the solar panel as the recycling centre proposed will be managing the separating process of the solar waste. The waste is estimated and then used in supply chain complexity analysis. It needed to achieve the objective study to ensure the location was the most strategic. In this study, the transportation complexity will also focus on reducing the greenhouse effect through waste transportation from the solar farm to the recycling facilities.

1.5 Significant or Importance of Study

Managing solar panel waste may not be a common topic discussed. However, managing and recycling this solar panel waste in a few more years will be challenging as no strategic preparations are planned. PV solar panels are complex parts consisting of different types of material in one part. Thus, the EoL management needed a few details before the material could be sent out for the following recycling process. This is one of the new potential future industries. By using the central f gravity method, the central recycling centre proposed will be responsible for disassembling the module panel into a few material categories. This will reduce the complexity recycling process. Supply chain complexity and the weighted sum method to evaluate the best alternative or cluster for the recycling centre.

1.6 Organization of the Report

To achieve the objective study based o the previously provided, this report is divided into five chapters, the contents of which are summarised as follows:

- Chapter 1: Introduction

This chapter introduces the project's subject and provides a synopsis of the study for the reader. This chapter includes the project's introduction, problem statement, objective, scope, and significant or important findings.

- Chapter 2: Literature review

A thorough and critical analysis of the literature on the subject of the Master Project report is provided in this part. It serves as the foundation for the paper's experimental and theoretical sections.

- Chapter 3: Methodology

The project's methodology to achieve the objective is covered in this chapter. It gives an explanation of the theoretical approaches and concept creation process used to accomplish the objectives of the study.