DEVELOPMENT OF MARGINAL ABATEMENT COST CURVE (MACC) TO ANALYZE RENEWABLE ENERGY TECHNOLOGY FOR THE PALM OIL INDUSTRY

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MASTER OF MANUFACTURING ENGINEERING (MANUFACTURING SYSTEM ENGINEERING)

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DEDICATION

My loving husband, Ahmad fadhli Bin Munawar, whose unconditional love and unwavering support carried me through the challenges of graduate school. Thank you for being my constant source of encouragement.

My mother, Selamah Binti Ibrahim, who instilled in me the value of higher education and never stopped believing in my abilities. Your guidance has been invaluable.

And to my children, Ahmad Faahim Ibraheem and Ahmad Fahri, who inspire me every day to reach for greatness. May this work serve as an example of what you can accomplish with dedication and perseverance.

Special thanks to Profesor Madya IR. Dr. Lokman Bin Abdullah for his encouragement, guidance and assistance to help me finish this project.

ABSTRACT

The palm oil industry is a significant driver of the global economy, with widespread applications in the food, cosmetic, and biofuel sectors. However, the industry's production processes have substantial environmental impacts, including high greenhouse gas (GHG) emissions, deforestation, and water pollution. As sustainability and climate action become increasingly important global priorities, there is a pressing need to address the environmental footprint of the palm oil industry. Renewable energy technologies offer promising solutions to mitigate these environmental impacts. By integrating clean energy sources, the industry can reduce its reliance on fossil fuels, lower its carbon emissions, and improve its overall sustainability. This master's project explores the potential of renewable energy technologies in the palm oil industry through the development of a marginal abatement cost curve (MACC) analysis.Decision-makers in the palm oil industry often lack comprehensive data and analysis to guide their investments in renewable energy solutions. While some renewable energy options have seen exploration in the industry, a systematic assessment of their cost-effectiveness and barriers to adoption is necessary to inform strategic decision-making and support the industry's transition towards sustainability. This study aims to: 1) identify the renewable energy technologies applicable and viable for the palm oil industry, 2) develop a MACC to analyze the cost-effectiveness of the identified renewable energy options, and 3) assess the economic feasibility and barriers hindering the widespread adoption of these renewable energy technologies in the palm oil sector. The research methodology followed a multi-step approach, including a comprehensive literature review, MACC development, ranking of the renewable energy alternatives based on their cost-effectiveness, sensitivity analysis, and examination of the economic feasibility and barriers.The MACC analysis provided valuable insights for decision-makers in the palm oil industry. The ranking of the renewable energy options based on their cost-effectiveness revealed that certain biomass and biogas technologies are the most promising solutions, with relatively low marginal abatement costs. Solar PV systems were also identified as viable options, though they had higher marginal abatement costs compared to the biomass and biogas alternatives.The sensitivity analysis showed that the discount rate used in the MACC calculations can significantly impact the ranking and perceived cost-effectiveness of renewable energy technologies. This underscores the importance of considering a range of discount rates to ensure robust decision-making.The study identified several key barriers to the widespread adoption of renewable energy technologies in the palm oil industry, including high upfront capital costs, limited access to financing, lack of technical expertise, and unfavorable policy and regulatory frameworks. To address these barriers, the researchers propose the following recommendations: policymakers should implement targeted incentives to support the adoption of cost-effective renewable energy technologies, the palm oil industry should invest in capacity-building programs to enhance technical expertise, further research is needed to refine the MACC analysis and explore innovative financing mechanisms, and the MACC framework should be expanded to other industries and sectors to facilitate the identification and evaluation of cost-effective sustainable solutions. By implementing these recommendations, the palm oil industry can accelerate its transition towards a more sustainable and environmentally friendly future, contributing to global efforts in climate change mitigation and sustainable development.

PEMBANGUNAN KURVA KOS PENGURANGAN MARGINAL (MACC) UNTUK MENGANALISIS TEKNOLOGI TENAGA BOLEH DIPERBAHARUI UNTUK INDUSTRI SAWIT

ABSTRAK

Industri minyak sawit adalah pemacu ekonomi global yang ketara, dengan aplikasi yang meluas dalam sektor makanan, kosmetik, dan bahan api bio. Walau bagaimanapun, proses pengeluaran industri ini mempunyai impak alam sekitar yang besar, termasuk pelepasan gas rumah hijau yang tinggi, penebangan hutan, dan pencemaran air. Dengan kelestarian dan tindakan iklim yang semakin penting sebagai keutamaan global, terdapat keperluan mendesak untuk menangani jejak alam sekitar industri minyak sawit. Teknologi tenaga boleh diperbaharui menawarkan penyelesaian yang menjanjikan untuk mengurangkan impak alam sekitar ini. Dengan mengintegrasikan sumber tenaga bersih, industri ini boleh mengurangkan kebergantungannya pada bahan api fosil, menurunkan pelepasan karbon, dan meningkatkan kelestarian keseluruhan. Projek Sarjana ini meneroka potensi teknologi tenaga boleh diperbaharui dalam industri minyak sawit melalui pembangunan analisis keluk kos pemodalan marginal (MACC). Pembuat keputusan dalam industri minyak sawit sering kekurangan data dan analisis komprehensif untuk memandu pelaburan mereka dalam penyelesaian tenaga boleh diperbaharui. Analisis MACC mengenal pasti bahawa teknologi biojisim dan biogas tertentu adalah penyelesaian tenaga boleh diperbaharui yang paling menjanjikan, dengan kos pemodalan marginal yang agak rendah. Sistem solar PV juga didapati boleh dilaksanakan, walaupun mereka mempunyai kos pemodalan marginal yang lebih tinggi. Kajian ini mengenal pasti beberapa halangan utama kepada penggunaan meluas teknologi tenaga boleh diperbaharui, termasuk kos modal awal yang tinggi, akses terhad kepada pembiayaan, kekurangan kepakaran teknikal, dan rangka kerja dasar dan peraturan yang tidak menguntungkan. Untuk menangani halangan-halangan ini, penyelidik mencadangkan, pembuat dasar harus melaksanakan insentif yang disasarkan untuk menyokong penggunaan teknologi tenaga boleh diperbaharui yang berkesan dari segi kos,industri minyak sawit harus melabur dalam program pembangunan kapasiti untuk meningkatkan kepakaran teknikal kajian lanjut diperlukan untuk memperhalusi analisis MACC dan meneroka mekanisme pembiayaan inovatif, dan rangka kerja MACC harus diperluaskan ke industri dan sektor lain Dengan melaksanakan cadangan-cadangan ini, industri minyak sawit dapat mempercepat peralihan ke arah masa depan yang lebih lestari dan mesra alam, serta menyumbang kepada usaha global dalam mitigasi perubahan iklim dan pembangunan lestari

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UTeM	-	Universiti Teknikal Malaysia Melaka
MACC	-	Marginal Abatement Cost Curve
MAC	-	Marginal Abatement Cost
GHG	-	Greenhouse Gas
CO2	-	Carbon Dioxide
CH4	-	Methane
N2O	-	Nitrous Oxide
CHP	-	Combined Heat and Power
POME	-	Palm Oil Mill Effluent
EFB	-	Empty Fruit Bunches
PKS	-	Palm Kernel Shell
UNFCCC	-	United Nations Framework Convention on Climate Change
IPCC	-	Intergovernmental Panel on Climate Change
CDM	-	Clean Development Mechanism
FiT	-	Feed-in Tariff
NPV	-	Net Present Value
IRR	-	Internal Rate of Return
RES	-	Renewable Energy Sources
CAPEX	-	Capital Expenditure
OPEX	-	Operating Expenditure

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CHAPTER 1

INTRODUCTION

1.1 Background

The palm oil industry has come under intense scrutiny in recent years due to its significant environmental footprint. Large-scale cultivation of oil palms has resulted in vast areas of rainforest being cleared to make way for new plantations. This widespread deforestation releases enormous amounts of carbon dioxide into the atmosphere, contributing to global climate change. It also threatens biodiversity as habitats for endangered species are destroyed. The conversion of forests to agricultural land also removes natural carbon sinks that help offset emissions.

Open burning is also a common low-cost way for smallholders and palm oil businesses to clear land. These fires produce a lot of haze during the dry season in Southeast Asia, which crosses borders and has an impact on neighbouring countries' air quality and public health. If the fresh fruit bunches are not properly handled, the palm oil mills that process them also generate large amounts of contaminated wastewater. If palm oil mill wastewater is dumped directly into waterways, the large levels of organic waste it contains will deteriorate the water quality.

In reaction to the environmental disputes, major markets for palm oil imports, especially the European Union, have imposed stronger sustainability standards and due diligence requirements. Leading brands and consumer goods firms are under increasing pressure to clean up their palm oil supply chains as a result of growing consumer and civil society demand. Environmental non-governmental organisation efforts have brought attention to issues such as deforestation, which could pose a harm to the industry's reputation if the effects are not mitigated. Due to the impending issue of climate change, palm oil producers will probably have to deal with carbon pricing or emission regulations in the future. This strengthens the need for low-carbon and renewable energy-powered enterprises.

Although certification programmes such as the Roundtable on Sustainable Palm Oil (RSPO) have made an effort to tackle sustainability, their effectiveness has not increased. Even now, a sizable amount of palm oil is produced outside of approved supply networks. Major purchasers have responded by making more firm promises to exclusively use palm oil that is produced ethically and without deforestation by predetermined deadlines. Demands for tighter supply chain openness and verification are rising as a result. More rigorous environmental, social, and governance standards are being applied by investors when deciding which palm oil companies to support. Some have simply removed producers connected to unethical forest and community practices off their lists or divested from them.

Governments in developing nations that are major producers of palm oil are also under internal pressure. Policies have been developed by Indonesia and Malaysia to mitigate the negative impacts of growth. Examples of these policies include concession moratoriums in high-carbon stock forests and peatlands. Nonetheless, because smallholder farmers are often associated with deforestation and land fires, the sector continues to be difficult to support and control. Environmental non-governmental organisations' high-profile lobbying campaigns linking popular brands to the devastation of orangutan habitats also keep sustainability at the forefront of public discourse. Younger demographics are becoming more mindful consumers, and palm oil producers need to show that they are ethical in order to win over this market.

Since the growth of the human population is expected to boost world demand by 15-20% by 2050, industrial reform will become even more urgent. This growth makes protecting forests and peatlands as organic carbon sinks even more essential for reducing the effects of climate change. A crucial step in reducing the industry's emissions and promoting energy security in the face of threats to the supply of fossil fuels is the conversion of mills and plantations to renewable energy sources.All things considered, palm oil producers are today under intense pressure to show real sustainability advancement through lower impact methods and pledges to refrain from deforestation.

The palm oil sector in Malaysia contributes significantly to the national economy. With Malaysia being the world's second-largest producer and exporter of palm oil, the industry plays a significant role in the country's agricultural GDP, foreign exchange profits, and rural employment. Over 19 million tonnes of crude palm oil were produced in Malaysia in 2020, making up around 30% of the global output. With about RM77 billion in earnings from exports, palm oil ranks as Malaysia's fourth most important export good. Over 539,000 people are directly employed by this industry, and millions more employment are supported by it. For Malaysia, palm oil is a significant source of income as a major agricultural export, especially for smallholder farmers.

With more than 5.8 million hectares of oil palm plantations, Malaysia has one of the biggest regions in the world dedicated to palm farming. On the island of Borneo, the two main states that produce palm oil are Sabah and Sarawak. Combined, they produce about half of the nation's annual output of palm oil. Negeri Sembilan, Pahang, and Johor are a few other noteworthy states. Malaysia's palm crop sustains a wide supply chain that includes upstream plantation and mill activities as well as downstream refining, processing, and manufacturing industries. The country is the second largest producer and exporter of palm oil in the world.

Palm oil producers face challenges when deciding which low-carbon technology to adopt, despite the obvious opportunities presented by renewable energy. There are several solutions accessible, and depending on the local conditions, each has different economical and technical implications. Without a methodical evaluation process, selecting between options like mini-hydro, solar, biomass, or biogas might be difficult.

The viability and economics of various renewable choices will be impacted by site-specific variables such as the size and processing capacity of individual mills, the resources available for the local climate, the amount of waste generated, and the amount of land that is accessible. Accurate assessments must also be made of the equipment lifespans, reliability, and initial capital costs as well as continuing operation and maintenance expenditures. There may not be much trustworthy information available on technology performance benchmarks in tropical operating settings.

Economic comparisons are further complicated by other factors such as future energy prices and the growth of carbon markets. For palm oil enterprises to properly evaluate the myriad technical aspects and related expenses of every renewable investment option throughout the course of its anticipated lifecycle, a consistent framework is required. Then, and only then, can the best low-carbon alternatives be determined from an economic and environmental standpoint for priority deployment. It's critical that renewable energy investments produce the largest emissions reductions at the most cost-effective rate for specific mill operations, given the limited capital and conflicting demands.

Thus, palm oil farmers would benefit greatly from having a well-established system to methodically assess and prioritise different renewable energy options according to their prices particular to the location and possibilities for avoiding emissions. This is the situation in which a marginal abatement cost curve method might be quite beneficial.

A cost-effective means of fulfilling emissions reduction targets can be greatly aided by a MACC assessment of renewable energy technology. A methodical technique to assessing the cost-effectiveness of different emissions reduction strategies, including renewable energy technology, is offered by the Marginal Abatement Cost Curve (MACC) methodology. Industries can determine and rank the most economical renewable energy solutions for lowering greenhouse gas emissions while hitting emissions reduction targets by performing a MACC assessment.

One study by Huang et al. (2016) demonstrates the application of MACC in comparing different abatement measures, providing valuable insights into the cost-effectiveness of renewable energy technologies for emissions reduction. Additionally, Muangjai et al. (2020) highlight the potential of MACC in visualizing the cost of abatement for specific technologies

The MACC approach has been shown to be effective in a number of situations, including the analysis of CO2 mitigation and energy-saving costs (Zhang et al., 2017), air pollution reduction strategies (Davies et al., 2012), and low-carbon urban water systems (Lam & Hoek, 2020). These applications demonstrate how MACC may be used to evaluate a variety of environmental and economic factors, making it a useful tool for determining how promising renewable energy technologies are for the palm oil sector.

A Marginal Abatement Cost Curve (MACC) must be created in order to analyse renewable energy technology in the palm oil sector. According to Chairat et al. (2023), the MACC technique offers a visual depiction of the cost of abatement and the possibility for mitigating CO2 emissions for particular technologies. It is a crucial tool for calculating CO2 reduction choices since it makes comparing abatement strategies and their cost-effectiveness possible (Chairat et al., 2023). Moreover, MACC can be utilised to evaluate the cost-effectiveness and abatement potential of different palm oil sector prospects, covering both utility and broader options (Chairat et al., 2023).

Policymakers and industry stakeholders can evaluate the cost-effectiveness of various renewable energy solutions by using the MACC. Making decisions regarding which technologies to invest in can be aided by this. The most economical strategies to lower greenhouse gas emissions from the oil palm sector can be found with the aid of the MACC. This can guarantee that scarce resources are utilised effectively. A clear and impartial foundation for decision-making is offered by the MACC. This can contribute to increasing confidence and trust in the sector's dedication to sustainability.

1.2 Problem Statement

The major problem facing Malaysia's palm oil sector is lowering greenhouse gas (GHG) emissions and moving towards sustainable energy methods. The necessity to find and rank cost-effective ways to lessen environmental impact is increasing due to the industry's large contribution to CO2 emissions. Research has shown how significant greenhouse gas emissions are linked to palm oil energy chains that are built on once natural peatlands or rainforests, underscoring the significance of addressing the repercussions of land use change.

Furthermore, the production of palm oil, a versatile vegetable oil utilised in a variety of goods like food, cosmetics, and biofuels, makes the palm oil business a significant global industry. But the sector also has to deal with serious problems including social unrest, environmental degradation, and deforestation. Over 50% of packaged food goods worldwide are thought to include palm oil, which makes up around 35% of all vegetable oil produced worldwide. Approximately 85% of the world's palm oil production is produced in Indonesia and Malaysia, the two largest producers. Deforestation is mostly caused by the growth of oil palm plantations, especially in Southeast Asia. This increases greenhouse gas emissions, habitat loss, and biodiversity reduction.

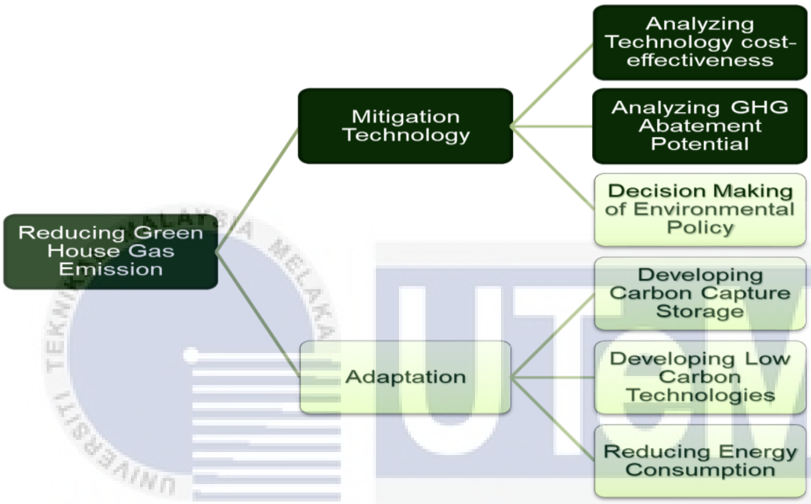

Figure 1. 1 Hierarchy of problem statement

This increases greenhouse gas emissions, habitat loss, and biodiversity reduction. Carbon dioxide is one of the main greenhouse gases released when peatlands are converted to oil palm plantations. The use of pesticides, fertilisers, and palm oil mill effluent during the production process of palm oil can contaminate water and the air. Growing oil palm plantations may cause land conflicts with neighbouring populations, especially indigenous tribes who can lose access to their ancestral lands and means of subsistence. Child labour and forced labour are just two examples of the human rights violations and labour exploitation that have been reported from this industry. High palm oil consumption has been connected to a number of health issues, including cancer, heart disease, and obesity.

In spite of these initiatives, the industry continues to confront formidable obstacles in its pursuit of sustainability. More stakeholder participation, enhanced openness, and stricter enforcement of the law are all necessary. Nonetheless, there exist prospects for the sector to enhance its ecological and societal efficacy. This include funding sustainable technology research and development, assisting smallholder farmers, and working with NGOs and other stakeholders.

In light of the intricate issue of managing both cost-effectiveness and greenhouse gas (GHG) emissions, the Marginal Abatement Cost Curves (MACC) have been suggested as a potent instrument for well-informed decision-making. MACCs provide a thorough and illustrative breakdown of the costs and benefits associated with different alternatives for reducing greenhouse gas emissions.

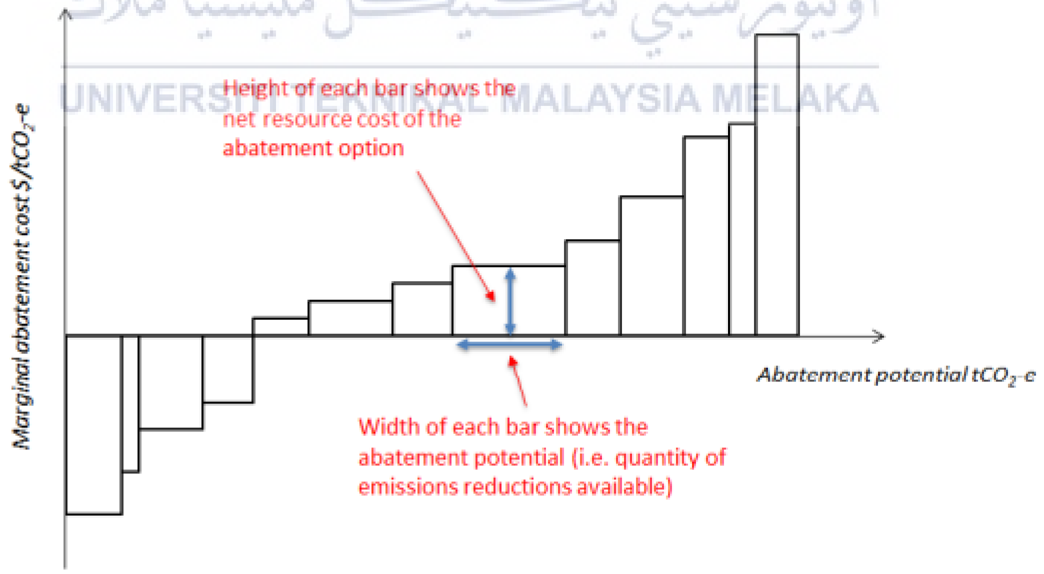

Figure 1. 2 Example of MACC Graph

Source: Marginal abatement cost curves analysis for New Zealand: Potential greenhouse gas mitigation options and their costs

Creative solutions are needed to address the twin challenges of controlling expenses and lowering GHG emissions. A useful tool for evaluating and ranking emission reduction alternatives according to their cost-effectiveness is the Marginal Abatement Cost Curve (MACC). Governments, corporations, and individuals can all work together to create a cleaner, more sustainable future by implementing MACC into decision-making processes.

Therefore, the development of a Marginal Abatement Cost Curve (MACC) for renewable technology in the palm oil industry in Malaysia is crucial for evaluating the cost-effectiveness of renewable energy technologies and guiding investment decisions towards achieving emissions reduction targets in a cost-effective manner.

1.3 Research Question

The development of a marginal abatement cost curve (MACC) for renewable technology in the palm oil industry in Malaysia is a multifaceted challenge that requires a comprehensive understanding of sustainability, environmental impact, and economic viability. The palm oil industry in Malaysia is a significant contributor to greenhouse gas (GHG) emissions, and there is a growing need to identify and prioritize cost-effective measures for reducing these emissions. The study by Chairat et al. (2023) emphasizes the importance of facilitating greenhouse gas emission reduction in the palm oil sector using MACC methodology, highlighting the industry's need for a systematic approach to evaluate the cost-effectiveness of renewable energy technologies.

Additionally, the investigation of the environmental sustainability of palm biomass supply chains by Zahraee et al. (2019) underscores the complexity of assessing the environmental impact of palm biomass supply chains, further emphasizing the need for a systematic evaluation framework such as a MACC. Furthermore, the study by Goh & Potter (2022) highlights the potential of integrating waste management with the production of high-value bioenergy and biomaterials, indicating the need for a comprehensive assessment of the economic and environmental implications of such integration within the palm oil industry.

Therefore, the development of a MACC for renewable technology in the palm oil industry in Malaysia is crucial for evaluating the cost-effectiveness of renewable energy technologies, addressing environmental sustainability, and guiding investment decisions towards achieving emissions reduction targets in a cost-effective and sustainable manner.

Marginal Abatement Cost Curves (MACCs) have emerged as a promising tool for addressing climate change by providing a framework for analyzing and prioritizing greenhouse gas (GHG) emission reduction options based on their cost-effectiveness. While MACCs offer several potential benefits, their effectiveness in informing decision-making remains under investigation. This research aims to critically evaluate the effectiveness of MACCs in guiding decision-making for GHG emission reductions and cost-effectiveness.

a. How effective are MACCs in guiding decision-making for GHG emission reductions and cost-effectiveness?

b. What are the limitations of MACCs and how can they be addressed?