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ECONOMIC INPUT-OUTPUT LIFE CYCLE ASSESSMENT OF THE MALAYSIAN PALM OIL PRODUCTION

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ABSTRACT

The Malaysian oil palm plantation sector has spurred the development of the country's economy. The contributions of the sector to the national Gross Domestic Product (GDP) grew by a Compound Annual Growth Rate (CAGR) of 1.4% between 2010 and 2020. However, the rapid development of the sector has led to accusations of environmental degradation and deforestation being levelled at businesses in the sector. As a result, this study resolves this issue by providing economic value to the oil palm Life Cycle Assessment (LCA) using Economic Input-Output LCA (EIO-LCA). The highest cost structure for oil palm plantation sector was contributed by the gross value added, mainly attributed by the high operating surplus and employee compensation. Additionally, the Greenhouse Gas (GHG) emissions from the oil palm plantation sector were 0.71%, which was relatively lower than other sectors such as electricity and gas (69.5%), land transport (9.6%), and crude oil and natural gas (6.22%). Notwithstanding the comparatively lower GHG emissions rates, it is imperative for all stakeholders in the oil palm plantation sector to collaborate in addressing issues and challenges related to GHG emissions as such efforts are crucial for gradually reducing these emissions as well as ensuring the sustainability of the oil palm sector.

Introduction

Globally, the demand for oils and fats demand has increased in parallel with the rise in the world's population. The global population currently stands at 8.0 billion people, and this is expected to increase to almost 8.5 billion by 2030, 9.7 billion by 2050, and 10.4 billion people by 2100 (United Nations Department of Economic and Social Affairs, 2022; Worldometer, 2024).

More than 50% of the total world oils and fats production is derived from palm oil (Oil World Annual, 2023). Oil palm production stands as a primary player in the global market of oils and fats, contributing significantly to the economies of the producing countries. Malaysia, one of the foremost producers of palm oil worldwide, plays a key role in influencing the industry's dynamics. Despite its contribution to the national economy, the Malaysian palm oil industry faces global pressure over its sustainability and environmental impact. Researchers have argued that the increase in the production of oils and fats are key drivers of land use changes that have caused or contributed to the adverse environmental impact of palm oil production such as tropical deforestation (Qaim *et al*., 2020) and the loss of biodiversity (Kleijn *et al*., 2009; Oakley & Bicknell, 2022).

To demonstrate its commitment toward forest conservation, Malaysia has pledged at the Earth Summit in 1992 to consistently maintain more than 50% of its landmass as forest (Tuan Man, 2021). In 2019, 54.9% of the total land area of Malaysia was under forest cover. These forests are home to a rich concentration of terrestrial biodiversity, making Malaysia one of the world's mega-diverse countries.

The oil palm sector in Malaysia operates within a complex network, involving cultivation, processing, transportation, and international trade. Being the backbone of the national economy, it is imperative to understand how each link in the supply chain of this industry contributes to both the economic growth and environmental impact. Hence, it is important to analyse its production processes comprehensively that not only evaluate its economic implications but also considers the broader environmental implications. Through a synthesis of economic data, environmental indicators, and Life Cycle Assessments (LCA), this article endeavours to address an understanding of the Malaysian palm oil production life cycle.

LCA is commonly used to evaluate environmental issues such as in to monitor water quality (McAuliffe *et al*., 2022), assessment of vinasse storage dams (Deutsch *et al*., 2022), production of solar technologies (Singh *et al*., 2024), environmental impact of construction industry (Munir *et al*., 2024), and quantify the environmental impact of various activated carbon production from various sources (Vilén *et al*., 2022). It entails a comprehensive analysis of the environmental impacts associated with a product at every stage of its life cycle, from raw material extraction to disposal, with the primary aim of optimising resource efficiency, minimising waste, and reducing environmental and financial liabilities.

LCA is widely used by researchers. According to Butnar (2007), LCA provides an in-depth examination of the environmental impacts linked to a product, process, service, or activity across all phases of its life cycle. This includes the extraction of raw materials, manufacturing, distribution, usage, and the final disposal or recycling, offering a holistic perspective on its environmental footprint. This holistic approach is often referred to as examining the product "from farm to spoon", it involves documenting environmental exchanges, such as emissions and resource consumption, at each stage of the product's life. This comprehensive view of the life cycle, encompassing its associated material and energy flows, is referred to as the "product system". LCA serves as a tool to provide detailed environmental insights into the entire life cycle under study or to assess the potential impacts of modifications within the product system.

Several studies have highlighted that resource availability significantly influences the application of LCA at the regional level, necessitating a comprehensive set of data for the inventory step. Butnar (2007) stated that there is often insufficient information on material and energy flows within a region to overcome this limitation, he recommended the use of alternative databases such as Economic Input-Output Life Cycle Assessment (EIO-LCA). These databases offer more extensive and detailed information on economic and environmental interactions, facilitating more accurate and robust life cycle analyses. Khongprom *et al*. (2020) support this view, indicating that EIO-LCA can offer a cost-effective method for estimating the environmental burdens throughout the life cycle of products at a macro level.

Additionally, Input-Output (IO) tables are important tools because they illustrate the interactions between sectors within a region or country, as well as between different production sectors. The data from a symmetric IO table can be used for a range of economic analyses.

EIO-LCA leverages economic IO tables to analyse and quantify the financial interactions and dependencies between different industries within a national economy. By mapping out these economic relationships, this approach helps in understanding how changes in one sector can affect other interconnected sectors throughout the economy (Suh *et al*., 2004). Leontief developed a general equilibrium model that established the quantitative relationships between industries, forming the basis for IO analysis in economics (Miller & Blair, 2009).

These tables offer a detailed view of monetary transactions among all goods and services across industries and consumers over a year, while also considering intra-industry transactions driven by final demand (Miller

& Blair, 2009). By integrating environmental data such as emissions from each sector into these economic tables, the environmental impact related to final demand for each sector's products can be assessed (Leontief, 1970; in Miller & Blair, 2009). Hendrikson *et al*. (1998) noted that IO-based LCA eliminates the need for boundary selection and avoids "truncation error" by including all industrial sectors in the IO table. However, the assumption of homogeneity within sectors in the linear model may not always reflect reality accurately, making IO-based LCA less suitable for detailed studies (Suh *et al*., 2004).

The urgency of such an investigation is emphasised by the global discourse on sustainable development and the increasing consumer demand for responsibly sourced products. This study aims to contribute not only to the scientific literature but also to the ongoing dialogue shaping corporate responsibility and governmental policies related to palm oil production. Thus, this study aims to address the current gap in available literature by quantifying the economic significance of oil palm LCA through the application of an EIO-LCA, which focuses on the production of the Fresh Fruit Bunches (FFB). Therefore, this study concentrates on the economic assessment of oil palm plantations in Malaysia, with a particular focus on their associated Greenhouse Gas (GHG) emissions.

Literature Review

Palm oil, a versatile and widely utilised vegetable oil holds significant importance in global agro-industrial practices. Studies by Sayer *et al*. (2012) and Fitzherbert *et al*. (2008) have highlighted the economic significance of palm oil, which has contributed substantially to the Gross Domestic Product (GDP) and employment rates in palm oil producing countries.

Over the past five decades, Malaysia's palm oil industry has undergone rapid development, transitioning from a focus on commodity exports to a manufacturing industry that emphasises downstream products (Lai *et al*., 2024). However, the growth of palm oil production has sparked considerable interest due to sustainability concerns related to environmental degradation, deforestation, and socioeconomicimpact (Koh & Wilcove, 2008; Carlson *et al*., 2018). The Malaysian palm oil industry is directly exposed to sustainability risks, including boycotts, reputational damage, and regulatory challenges raised by stakeholders, particularly from European countries. Consequently, the European Union's stance on these issues has also influenced other regions to adopt similar regulatory requirements as part of their corporate responsibility sourcing mandates.

To address the sustainability risk management concerns, LCA methodologies are imperative for evaluating the environmental impact of palm oil production. Significant contributions include the work of Gunarathne *et al*. (2020) that assessed the carbon footprint and Mekonnen and Hoekstra (2012) who looked at water use. While these studies provide valuable insights, traditional LCA approaches may not fully capture the complex economic interdependencies within the palm oil supply chain.

Traditional LCAs often neglect the economic aspects of agro-industrial activities. In contrast, the EIO-LCA methodology has gained recognition for its ability to incorporate both economic and environmental considerations. As emphasised by Lenzen *et al*. (2013), EIO-LCA allows for a comprehensive evaluation by tracing the flow of economic transactions and resource used throughout the entire life cycle.

The concept of Environmental Input-Output (EIO) analysis was originally developed by Professor Wassily Leontief in the late 1930s. This analytical framework, known as Input-Output (IO) analysis is designed to examine and elucidate the intricate interconnections and economic dependencies among different industries within an economy. The EIO model consists of a set of linear equations that detail how an industry's output is distributed across the economy. By including all sectors, these models allow for the calculation of both direct and indirect inputs needed by firms to produce final outputs. Additionally, the EIO model can illustrate the income and output connections between different sectors or industries within a region, usually at the national or provincial level (Miller & Blair, 2009). Bjorn *et al*. (2005) have shown that EIO tables are useful for assessing the overall economic impact of changes in external demands such as exports or local consumer demands.

The IO framework was originally created for macroeconomic system analysis and planning, but it shares numerous methodologies with LCA. The integration of EIO with LCA is facilitated by their similar structure, which connects environmental impact to economic demand, as noted by Mattila (2018).

The EIO-LCA approach presents several advantages. Study by Hendrickson *et al*. (1998) and Joshi (2000) demonstrate that when comprehensive data becomes available or more granular analysis is required, process models can be incorporated. For example, the EIO offers a valuable opportunity to evaluate and compare various LCA strategies for analysing specific supply chains. This comparative analysis not only strengthens confidence in the results but also aids in identifying and rectifying errors. It utilises a comprehensive economic model that eliminates the need for analysts to establish arbitrary boundaries. The analyses can be conducted quickly and cost-effectively, relying solely on publicly available data and standard calculations, ensuring transparency. This approach allows for the direct incorporation of both indirect and feedback interactions among different processes and economic sectors.

Joshi (2000) noted that the EIO-LCA model adopts a top-down approach, considering the entire economy as boundary of analysis. This model is particularly applicable for assessing diverse development plans and evaluating both the direct and indirect effects of public policies (Bjorn *et al*., 2005). Hendrickson *et al*. (2006) reported that the model could trace a range of economic transactions, resource needs, and environmental emissions associated with producing a specific product or service. Kjaer *et al*. (2015) evaluated the advantages and limitations of the EIO approach and its impact on corporate strategies. Their findings indicated that the analysis provided a thorough and holistic perspective on environmental performance, providing a practical basis for strategic planning within a feasible timeframe and budget.

For companies with substantial upstream environmental impacts, this analysis supports the advancement of their sustainability goals by incorporating supply chain effects. Moreover, it helps identify key areas for action to enhance the environmental profile of the analysed system. Numerous studies have shown that an IO analysis can complement the LCA, with several agreeing on its utility (Suh *et al*., 2004; Miller & Theis, 2006; Cicas *et al*., 2007; Norman *et al*., 2007; Ewing *et al*., 2011; Malik *et al*., 2014; Sherwood *et al*., 2017; Wu & Han, 2020).

Notwithstanding the above, the scope of the EIO-LCA is extensive. For instance, Egilmez *et al*. (2013) highlighted that sectors such as manufacturing, utilities, agriculture, construction, transportation, and mining typically have the highest impact across various environmental categories, rather than focusing on just one sector. However, research on Agriculture, Forestry and Fisheries (AFF) sectors have shown that this sector itself has significant environmental impact on AFF products, independent of economic interactions with other sectors. Scholars recommend that future research should integrate foreign production into EIO tables to comprehensively account for imported goods and services in LCA. Moreover, a more detailed breakdown of AFF sectors is needed to better understand the environmental sustainability of agricultural commodities (Yan *et al*., 2013).

Furthermore, the EIO-LCA technique could be useful for demonstrating energy studies by showing how energy inputs in the oil palm sector influence production. For example, Esengun *et al*. (2007) used this technique to determine the amount of IO energy used in dry apricot production in Malatya and Turkey, assessing its energy efficiency and the economics of the production process. The study found the profit-cost ratios were 1.11 and 1.19, with net returns of USD 414.51 per hectare and USD 495.59 per hectare, respectively. These findings could be applied to palm oil cultivation to assess the feasibility based on EIO-LCA analysis and to maintain economic sustainability.

Bekhet and Abdullah (2010) examined the use of resources in agriculture and found that the sector relies more on inputs from the petrol and coal industries compared to others. Additionally, Khongprom *et al*. (2020) used a similar EIO-LCA approach to evaluate the consumption of fuel sources and global warming impact in cement production, revealing that fossil fuels like coal and diesel are major contributors to GHG emissions. Their findings revealed that fossil energy sources, such as coal, diesel, lignite, and electricity, are the primary energy inputs in cement production, with diesel combustion being the largest contributor to total GHG emissions. Furthermore, a study by Omidi-Arjenaki *et al*. (2016) on honey production in Iran found that, except for electricity, all inputs significantly affected production yields. Therefore, the interconnectedness within the entire oil palm sector needs to be further assessed using EIO-LCA to understand the link between fuel inputs and production.

Additionally, the EIO-LCA technique has enabled researchers in examining the impact of energy demand throughout the global financial crisis. For example, a study conducted by Bekhet *et al*. (2016) revealed significant changes to the output multipliers for the manufacturing sectors between 2005 and 2010. The research highlighted that the output multipliers for energy and manufacturing sectors diminished during the global financial crisis, primarily due to a decline in industries reliant on exports. According to MPOB (2024) statistics, palm oil production did not show any significant change during that period, thus proving that external factors also played an important role in productivity.

The EIO-LCA method is also useful for assessing socioeconomic and environmental impacts. For instance, Malik *et al*. (2014) analysed the economic and employment effects of launching a new sugarcane-based biofuel industry in Australia. Using EIO-LCA to model this industry based on the production processes of Brazil's large-scale gas alcohol and alcohol sector, the study predicted a positive effect on employment in the Australian biofuel sector. Similarly, Papong *et al*. (2016) found that exports from China to countries including the United States, Japan, South Korea, Taiwan, and Singapore has notable influence and impact on overall employment in these nations. The palm oil industry, as a major economic force in agriculture, plays a crucial role in enhancing the national socioeconomic landscape by providing employment opportunities in rural areas (Abdul Razak *et al*., 2024). To address environmental impact concerns, palm oil industry players adhere to sustainability practices, particularly via Corporate Social Responsibility (CSR) activities, to protect and minimise risks to the environment. Hence, EIO-LCA is crucial for assessing the linkage between the palm oil industry and its impacts on both socioeconomic conditions and the environment.

Additionally, various studies have applied this method to measure the impact of different products and sectors, including primary and rechargeable batteries (Lankey & McMichael, 2000), conventional and non-traditional fuel vehicles (Lave *et al*., 2000), steel and concrete bridge girders (Horvath & Hendrickson, 1998), plastic and steel gas tanks for cars (Joshi, 2000), reusing exterior wall framing systems (Rios *et al*., 2019), and changes in China's green GDP related to life (Wu & Han, 2020). Most of these studies have found that the EIO-LCA method delivers more comprehensive results.

In summary, the EIO-LCA technique is useful because it can trace the chain of energy use and identify both the direct and indirect impact of that energy use on the economy. Applying this technique to the palm oil industry could similarly comprehensively reveal the environmental and socioeconomic impact of palm oil production. By assessing this impact, stakeholders in the Malaysian palm oil industry can understand and manage sustainability challenges, improve economic outcomes, and enhance the industry's overall sustainability framework.

Materials and Methods

Materials

This research article made use of the Malaysian Input-Output (IO) table for the year 2021, compiled by the Department of Statistics Malaysia (DOSM). The 2021 Malaysian IO table was published to offer an in-depth overview of the flow of goods and services within the economy. The IO table is published by DOSM every five years. These tables illustrate economic performance by emphasising the relationships between producers and consumers and reveal the interdependencies between the different industries. The concepts and definitions employed align with the recommendations of the 2008 System of National Accounts (SNA) by the United Nations. This adherence ensures consistency with internationally accepted accounting principles and provides a robust framework for accurately capturing and analysing economic data.

This study also incorporated specific GHG emissions data from Malaysia's Fourth Biennial Update Report (BUR4), published by the Ministry of Natural Resources, Environment, and Climate Change, Malaysia. The BUR4 was prepared following the guidelines of the United Nations Framework Convention on Climate Change (UNFCCC). It updates the information presented in the Third Biennial Update Report, covering national circumstances, GHG inventory, progress in mitigation policies and actions, as well as support needs and received. Due to the lag in GHG emissions data, the 124 sectors in IO Table 2021 are aggregated into 10 sectors based on related oil palm plantation sector to extend GHG emissions input to the IO analysis Table 1.

Methods

This study employed economic IO analysis, a method introduced by Professor Wassily Leontief in the late 1930s. This approach, as described by Miller and Blair (2009), enables a detailed examination of economic interactions and dependencies within an economy. IO analysis is a widely recognised method in economic studies, capturing the interconnections between various sectors of the economy through

Table 1: Aggregated 10 sectors based on related oil palm plantation sector

Sector
Basic Chemicals
Telecommunications
Oil Palm Plantation
Other Chemicals Products
Communication Equipment and Consumer Electronics
Coke and Refined Petroleum Products
Non-oil Palm Agriculture
Crude Oil and Natural Gas
Land Transport
Electricity and Gas
Others

Source: Department of Statistics Malaysia a set of linear equations. The key part of the model is the intersectoral direct requirements (or technical coefficients) matrix denoted as A. In matrix A, the element A_{ij} signifies the ringgit value of input needed from sector i to produce one-ringgit (RM1.00) worth of output in sector j (where i = 1...n and j = 1...n).

The vector X represents the total outputs of the sectors, while the exogenous change in final demand for these outputs is depicted by vector F. Since the total output of a sector equals the sum of final demand which is donated by F and intermediate demand which is donated by AX (demand as input for the production of other sectors' outputs), the input-output analysis can be expressed as follows:

$$X - AX = F \tag{1}$$

or total final demand for its output can be described as:

$$X = AX + F$$

Solving Equation (1) for obtain the total output X:

$$X = (I - A) F \tag{2}$$

In this context, I denotes the identity matrix, while the matrix $(I - A)^{-1}$ is known as the Leontief inverse, also known as the interdependence coefficients or the total requirements table.

The final equation shows that a change in total output results from multiplying a change in total final demand by $(I-A)^{-1}$. The Leontief matrix emerges from a matrix transformation, which allows for the calculation of multiplier coefficients. These coefficients capture all indirect effects.

Multiplier Analysis

Multiplier analysis is a technique used to evaluate how variations in final demand components contribute to economic growth. It examines both direct and indirect relationships between sectors, capturing how buying and selling interactions influence the broader economy.

$$O = \sum_i^n l_{ij} \tag{3}$$

where:

O_j is output multiplier of sector j

l_{ij} is the element for Leontief inverse matrix

n is the number of sectors

Multiplier Value Added

The value-added multiplier estimates the additional value generated in the economy from goods or services. It can be written:

$$V = B(I - A)^{-1} \tag{4}$$

where:

V is the value-added multiplier

B is the vector of input coefficients of value added

I is the identity matrix

A is the matrix of input coefficients for domestic production

Hypothetical Extracted Method

The Hypothetical Extraction Method (HEM) is a valuable analytical technique used in input-output economics to evaluate the importance of a particular sector within an economy. By simulating the removal or "extraction" of a sector, HEM allows researchers and policymakers to assess the extent of interdependence among industries and to identify key sectors that significantly contribute to economic performance. This study applies the HEM within an input-output framework to assess the economic significance of the oil palm sector in Malaysia. The HEM technique enables the evaluation of both the direct and indirect contributions of the oil palm sector by simulating the economy's structure in the absence of this sector. There are four steps in analysing HEM. The steps are as follows:

Step 1: Construction of the Baseline Model

The standard input-output model is represented by the following equation:

$$X = (I - A)^{-1}F$$

where:

X is the vector of total sector outputs
I is the identity matrix
A is the technical coefficient matrix
F is the final demand

Step 2: Hypothetical Extraction of the Oil Palm Sector

The oil palm sector is “extracted” by adjusting the technical coefficients Matrix A:

- Rows corresponding to the oil palm sector are set to zero to simulate no intermediate supply to other sectors.
- Columns corresponding to the oil palm sector are set to zero to simulate no intermediate demand for inputs from other sectors.

This simulates an economy where the oil palm sector no longer produces outputs or consumes inputs from other sectors.

Step 3: Recalculation of the Adjusted Economy

A new input-output model is solved for the extracted economy:

$$X' = (I - A')^{-1}F$$

where A′ is the adjusted technical coefficient matrix after extraction.

Step 4: Impact Assessment

The economic impact of extracting the oil palm sector is measured by the difference in total outputs:

$$\Delta X = X - X'$$

This difference quantifies the direct and indirect contribution of the oil palm sector to the Malaysian economy.

The output reduction in specific sectors will also be analysed to understand the sectors most dependent on the oil palm industry.

Extended Input-Output (IO)

The IO method can be modified for environmental assessments. Suppose E represents the a k x n matrix of environmental burden coefficients, where r_{kj} denotes the environmental burden k (e.g., carbon monoxide emissions) per dollar of output from sector j, and let e be the vector of total environmental burdens. The total (both direct and indirect) environmental burden across the economy, associated with an external demand vector f, is then given by:

$$E = e\,(I - A)^{-1}\,f \qquad (5)$$

The environmental burden matrix, denoted as e can encompass coefficient vectors for various environmental impact such as energy consumption, non-renewable resource use, and greenhouse gas emissions. To determine the involvement of each industry sector to the overall environmental burden, replace each environmental burden coefficient vector in e with its corresponding diagonal matrix.

Results and Discussions

Technical (Input) Coefficient

The technical coefficient analysis of Malaysian 2021 Input-Output Table reveals the unit cost structure of a commodity. The technical coefficients can be interpreted as inputs required in producing every RM1.00 worth of an output. Table 2 shows inputs required in producing each RM1.00 of FFB in the oil palm plantation. It indicates that 78.4% of the cost structure in oil palm plantation came from gross value added which mainly was attributed by operating surplus and compensation of employees. Meanwhile, the component of intermediate input only represents 10.4% of the total cost structure.

Table 2: Input technical coefficients for oil palm plantation sector

No.	Input	OP Plantation
1	Total intermediate input	0.104
2	Imported commodities	0.112
3	Taxes on products	0.002
4	Subsidies on products	0.003
5	Gross value added	0.784
	Total Inputs	**1.000**

Source: Department of Statistics Malaysia and authors' calculations

Out of total intermediate input use in the production of FFB in the oil palm plantation, "wholesale and retail trade, repair of motor vehicles and motorcycles" represents 1.6% of the total cost structure (Table 3). This is followed by "other agriculture", "coke and refined petroleum products", and "financial institution".

This shows oil palm plantation activities is primarily influenced by operational cost and employment salaries while intermediate inputs have a relatively lower impact. It further highlights the importance of improving efficiency and productivity within the plantation to enhance competitiveness.

Furthermore, oil palm plantation output not only serves as input in producing palm oil but as an input in other intermediate products (Table 4). Soap and detergents, cleaning and polishing agents, perfumes, and toiletries use oil palm plantation output which account for 1.7% of their total cost structure, while oil palm plantation outputs account for 0.09% of the cost ii the wholesale and retail trade sector and 0.08% of the cost n the automotive and other manufacturing sectors, respectively. Thus, in the event of a shock or disruption in the oil palm plantation sector, it could have ripple effects across multiple sectors of the economy.

Output Coefficient

The output coefficient analysis of Malaysian 2021 Input-Output Table assesses the portion of an industry's output that is used as input for other industries within the inter-industry system,

Table 3: Ten major intermediate inputs required in producing every RM1.00 of oil palm plantation output

No.	Input	RM
1	Wholesale and retail trade, repair of motor vehicles and motorcycles	0.016
2	Other agriculture	0.013
3	Coke and refined petroleum products	0.010
4	Financial institution	0.010
5	Motor vehicles	0.009
6	Professional	0.009
7	Other chemicals product	0.006
8	Food and beverage	0.004
9	Basic chemicals	0.004
10	Insurance or takaful and pension funding	0.004

Source: Department of Statistics Malaysia and authors' calculations

Table 4: Oil palm plantation output requirement as input in ten major intermediate products

No.	Input	RM
1	Palm oil	0.426
2	Soap and detergents, cleaning and polishing, perfumes, and toilet preparations	0.017
3	Wholesale and retail trade and motor vehicle	0.009
4	Other manufacturing	0.008
5	Other chemicals products	0.004
6	Soft drinks, mineral waters, and other bottled waters	0.004
7	Real estate	0.003
8	Rental and leasing	0.002
9	Professional	0.001
10	Confectionery	0.001

Source: Department of Statistics Malaysia and authors' calculations

rather than being supplied for final demand. The study reveals that out of 124 sectors in the IO 2021 Table, output of oil palm plantation sector goes to 45 sectors such as palm oil processing, wholesale and retail trade, motor vehicle, and chemicals sectors.

Table 5 shows that 94.1% of every RM1.00 output of oil palm plantation will go to palm oil processing sector. Generally, in the production process of any product, the involvement of various materials from different industries creates interdependencies among them, similar to the oil palm plantation sector (Fatin, 2021). This intricate network of interdependencies highlights the importance of understanding the flow of inputs and outputs within the economy for stakeholders and policymakers alike. Such comprehension is essential to develop resilience strategies and effective risk management.

Partial Income Multiplier

The analysis of partial income multiplier revealed that of every RM1.00 increase in final demand of oil palm plantation products, it generates an income of RM0.868 for the Malaysian economy, of which, RM0.785 is generated by the oil palm industry itself (Table 6). The rest is generated by other industries are created through wholesale

Table 5: Ten major sectors in which oil palm plantation output enters

No.	Input	RM
1.	Palm oil	0.941
2.	Wholesale and retail trade and motor vehicle	0.047
3.	Other chemicals product	0.003
4.	Soap and detergents, cleaning and polishing, perfumes, and toilet preparations	0.002
5.	Coke and refined petroleum products	0.002
6.	Professional	0.002
7.	Real estate	0.002
8.	Other manufacturing	0.001
9.	Soft drinks, mineral waters, and other bottled waters	0.000
10.	Basic chemicals	0.000

Source: Department of Statistics Malaysia and authors' calculations

Table 6: Partial income multiplier of an increase of RM1.00 in final demand for oil palm plantation products

No.	Input	RM
1	Oil palm	0.785
2	Wholesale and retail trade and motor vehicle	0.015
3	Other agriculture	0.010
4	Monetary intermediation	0.009
5	Professional	0.009
6	Crude oil and natural gas	0.005
7	Coke and refined petroleum products	0.005
8	Motor vehicles	0.003
9	Insurance or takaful and pension funding	0.003
10	Forestry and logging (from oil palm trunk)	0.003
11	Other sectors	0.021
	Total Income Arising	**0.868**

Source: Department of Statistics Malaysia and authors' calculations

and retail trade and the automotive sector (RM0.015), other agriculture (RM0.010), and monetary intermediation (RM0.009). Although of the oil palm plantation is connected to the other sectors of the economy, the sector itself remains the core structure.

Output Loses for All Sectors under the Hypothetical Extraction of Oil Palm Sector

As discussed earlier, if one of the core sectors of the country suffers a shock, it can cause a significant impact on the country's economy and vice versa. With this in mind, we simulated a scenario where purchase of oil palm plantation from all other sectors of the economy were hypothetically eliminated (Table 7). As expected, we found that output for all sectors would decrease. Out of 124 sectors in the IO 2021 Table, the highest output losses come from the same sector, which is at 52.4% or RM11.61 million, followed by wholesale and retail trade and motor vehicles at 30.0% or RM6.66 million, crude oil and natural gas at 3.5% or RM0.77

Table 7: Hypothetical extraction of oil palm sector

No.	Sector	GVA Loss (RM million)
1.	Oil palm	11.61
2	Wholesale and retail trade and motor vehicle	6.66
3	Crude oil and natural gas	0.77
4	Coke and refine petroleum products	0.65
5	Finance	0.49
6	Professional	0.47
7	Food and beverage	0.31
8	Telecommunications	0.20
9	Insurance or takaful and pension funding	0.17
10	Motor vehicles, trailers, and semi-trailers	0.15

Source: Department of Statistics Malaysia and authors' calculations

million, coke and refined petroleum products at 2.9% or RM0.65 million and so on. It shows that if the oil palm plantation sector is eliminated, Malaysia's economic structure could take a toll particularly those of smallholding's income. The contribution of palm oil is huge on the nation's socioeconomy.

The Impact of the Malaysian Palm Oil Production on GHG Emissions

As discussed earlier, this study focuses on the economic analysis of oil palm plantations in Malaysia, specifically concerning the levels of GHG emissions.

Figure 1 shows the total greenhouse gasses emissions of 10 selected sectors based on their contribution to oil palm plantations. This would allow for estimation of the direct effect of GHG emissions and environmental impact linked to each economic activity related to oil palm production. The results showed that the largest contributor to GHG emissions in 2021 was the electricity and gas sector.

Every RM1.00 increase in final demand output from the electricity and gas sector led to a 0.00214542 kg CO_2 equivalent increase in GHG emissions. The sector emitted 125.6 times more CO_2 than the oil palm sector. This was followed by the logistics and land transport sector that emitted 40.7 times more GHG than the oil palm sector where every RM1.00 increase in final demand would lead to a 0.00029641 kg CO_2 equivalent increase in GHG emissions. The chemical products sector emitted 7.8 times more GHG than where every RM1.00 increase in final demand would lead to a 0.0001821 kg increase in GHG emissions.

Apart from that, even the communications equipment and consumer electronics sector emitted 4.3 times more GHG emissions where every RM1.00 increase in final demand added 0.0001821 kg of CO_2 to the environment. Even the non-oil palm agriculture sector emitted 3.2 times more GHG than the oil palm sector, coke and refined petroleum products sector accounted for 3.1 times more GHG, while the crude oil and natural gas sector was responsible for 3 times more GHG emissions. However, the telecommunications sector was cleaner than the palm oil sector producing 0.7 times DHB. Finally, the basic chemicals sector emitted 0.3 times less GHG than that of the oil palm sector.

The above finding reveals that, electricity is the high contributor of GHG emissions and is at par with International Energy Agency. According to the report, the energy sector was the leading source of emissions in 2019, contributing 48.8% of the total emissions. Furthermore, Giannakis

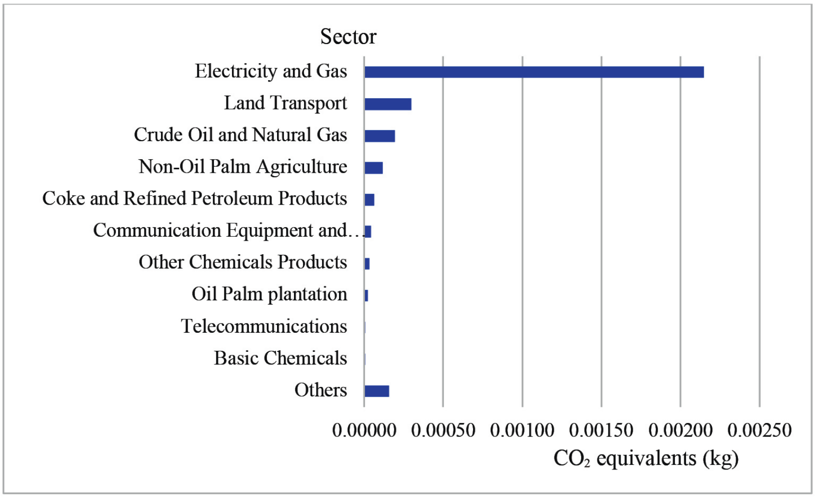

Figure 1: GHG emissions of ten selected sectors

et al. (2020) reported that the land transport sector is also one of the leading emitters of CO_2. Interestingly, a study by Solaymani (2022) demonstrated that there is a relationship between GDP per workers and GHG emissions. The finding suggested that an increase of 1% in GDP per worker in the transport sector could lead to higher CO_2 emissions from the transport sector by 0.57%. This implies that a development in the transportation and logistics sector contributes to a greater and more intense rise in environmental pollutants.

Likewise, a report by Our World In Data also showed that GHG emissions by these sectors in Malaysia for the year 2020 topped that of GHG emissions by the agricultural sectors in that year. By comparison the agriculture sector was only responsible for a slight increase in GHG emissions.

Discussions

The findings of this study demonstrated that the electricity and gas sector is the most significant contributor to GHG emissions among the analysed sectors, contributing emissions approximately 125.6 times higher than the oil palm plantation sector per RM1.00 increase in final demand. This finding aligns with the national emissions inventory presented in Malaysia's Fourth Biennial Update Report (BUR4) to the United Nations Framework Convention on Climate Change (UNFCCC), which attributed approximately 78% of total GHG emissions in Malaysia to the energy sector in 2019 (Ministry of Natural Resources, Environment, and Climate Change Malaysia, 2022).

It is important to note that both this study and the BUR4 employ the same underlying national dataset, thus this consistency primarily indicates methodological coherence rather than independent verification. While this consistency is expected since both analyses are based on the same emissions inventory, it reinforces the internal validity of the EIO-LCA approach adopted herein.

However, this observation is further substantiated by other independent analyses, thus enhancing the robustness of the findings. Solaymani (2022), for instance, explicitly links energy-intensive sectors such as electricity generation and transport directly to rising CO_2 emissions in Malaysia, emphasising the critical relationship between economic activities in these sectors and their associated environmental burdens. Similarly, data from the International Energy Agency (IEA, 2022) supports Malaysia's continued reliance on fossil fuels, particularly coal and natural gas, for electricity production, constituting more than 80% of the national energy mix.

This dependence significantly contributes to the high emission intensity of the electricity and gas sector. Such dependency significantly influences the intensity of sectoral emissions, as consistently noted in global emissions reporting databases (Ritchie & Roser, 2020).

This sectoral emissions profile observed in Malaysia is also consistent with trends reported in other international studies. Giannakis *et al*. (2020), analysing sectoral emissions in various Mediterranean and Asian countries, also identified the energy sector, specifically electricity and transportation, as the largest contributors to national GHG emissions, attributing this predominantly to fossil fuel dependence.

This pronounced dependence on fossil fuels, common in emerging economies has also been observed in other Southeast Asian countries, including Thailand and Indonesia, suggesting that this is a regional trend where energy infrastructure growth often precedes shifts toward cleaner technologies (ADB, 2021).

Furthermore, Khongprom *et al*. (2020) used a similar EIO-LCA methodological framework in their assessment of Thailand's cement industry, identified electricity consumption as a primary contributor to environmental impact due to its high reliance on fossil energy sources. Omidi-Arjenaki *et al*. (2016) examining agricultural systems, similarly reported electricity as an influential environmental burden, emphasising electricity's critical role across different economic sectors and geographical contexts.

Furthermore, Esengun *et al*. (2007) using EIO-LCA analysis for agricultural production in Turkey, demonstrated that energy input, particularly electricity and fuel, substantially drive both economic productivity and associated emissions, further underscoring the consistency of electricity's environmental impact across sectors and geographies.

Given the prominence of the electricity sector emissions identified in this study and corroborated by external literature, it is imperative for Malaysia to pursue alternative energy policies. Malaysia's Renewable Energy Roadmap (MyRER, 2021) outlines strategic national targets for significantly expanding renewable energy, aiming to increase its share to 31% by 2025 and 40% by 2035. These policy objectives align with international sustainability commitments, highlighting Malaysia's proactive stance toward reducing the adverse environmental impact of the energy sector.

Conclusions

This article aims to provide economic value to the oil palm LCA by employing EIO-LCA approach. The study revealed that the high-cost structure in oil palm plantation can be attributed to the compensation of employees and operating surplus of the gross value added. This highlights a key finding, the sector's dependency on labour. In terms of economic contribution, the oil palm plantation sector demonstrates a significant intersectoral relationship.

Output from other sectors are used in oil palm plantation activities, while inputs from oil palm plantations contribute to producing goods in other sectors. This interconnectedness highlights the critical importance of the oil palm industry within the boarders economic landscape. The results indicate that eliminating the oil palm plantation sector would have substantial direct and indirect impacts on Malaysia's GDP and the supply chain reliant on it such as those involving smallholders. The total value-added losses observed in the results emphasise this potential impact.

Consequently, stakeholders and policymakers must be vigilant about the ripple effects of changes that occur within the oil palm plantation sector. Although palm oil production is often linked to environmental degradation, this study found that an increase of RM1.00 in the final demand for oil palm lead to a CO_2 equivalent increase of 0.00002196 kg in GHG emissions. This increase was relatively insignificant compared with GHG emissions from other economic activities in the country.

Moving forward, the industry needs to improve labour efficiency, potentially through mechanisation, which could reduce costs in the long term. Additionally, ensuring sustainability of the oil palm plantation is essential to steer the Malaysian economy. Despite the relatively low GHG emissions from the plantation sector as compared with other sectors, it is crucial for the industry to continuously monitor and reduce GHG emissions over time.

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Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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