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Geospatial Visualization for Second-Generation Renewable Diesel Feedstock from Palm Oil Value Chain

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Abstract

The demand for biofuels has begun to shift from first-generation biofuels to second-generation biofuels. One of the biofuels already planned in the government's roadmap is renewable diesel from the hydrotreatment of palm oil. By 2040, the share of renewable diesel is projected to reach 1.4 million kL per year, contributing to 9% of the biofuel blend program. As the world's largest palm oil producer and consumer, Indonesia has the opportunity to achieve a circular economy in the palm oil value chain by utilizing its waste and byproducts for biofuel production. However, there is a lack of a top-down perspective to assess second-generation renewable diesel potential from the palm oil sector in Indonesia. This study is intended to fill such gap by providing practical and comprehensive tools to develop the roadmap for second-generation renewable diesel in Indonesia, comprising of a conversion diagram and geospatial visualization method. Based on the results of this study, there are around 1,200 points of source (palm oil mills, refineries, and others) for palm oil-based waste in Indonesia with an approximate total of 1.4 million kL per year renewable diesel production capacity potential. Applicable waste-based feedstock from upstream and midstream palm oil sectors are palm oil mill effluent (POME) oil, spent bleaching earth oil (SBEO), and palm fatty acid distillates (PFAD). These are concentrated in the regions of Sumatra, Kalimantan, and Java to a lesser extent.

Keywords:
second-generation biofuels, palm oil value chain, renewable diesel, geospatial visualization

1. Introduction

1.1 Renewable Diesel and Its Development Status in Indonesia

The global demand for clean fuel continues to rise due to growing concerns over environmental sustainability where lessening dependency on fossil fuels is a necessity. Hence, many countries are seeking greener alternatives to traditional energy sources in the form of biofuels. Based on its feedstock source, biofuel can be categorized into four generations, as explained in Table 1.

The use of blending first-generation biodiesel in diesel fuel is not sufficient to replace the dependence on fossil fuels. Additionally, first-generation biodiesel has several disadvantages, such as lower energy content compared to an equivalent amount of diesel fuel, lack of oxidation stability, and the presence of microbes that can sometimes affect engines (Mahdi et al., 2021). Considering these factors, the development of alternative fuels to replace fossil fuels is necessary. One promising type of biofuel is renewable diesel.

Table 1. Generations of biofuel (Alalwan et al., 2019).

Biofuel generation	Definitions
First-generation	Biofuel sourced from feedstock that competes with food use or food cropland (e.g., crude palm oil, soybean oil).
Second-generation	Biofuel sourced from feedstock that does not compete with food use or food cropland (waste or residue e.g., used cooking oil, animal fats, POME oil, tall oil, distillers corn oil).
Third-generation	Biofuel sourced from microalgae and macroalgae.
Fourth-generation	Biofuel sourced from genetically modified microorganisms (microalgae, yeast, fungi, and cyanobacteria).

Renewable diesel is a biofuel that is chemically similar to petroleum diesel but with improved properties. It has a high calorific value, lower corrosivity, higher energy density, and better oxidation stability compared to biodiesel and petroleum diesel. Due to its high cetane number, renewable diesel can be directly used in diesel engines without the need for blending with petroleum diesel or engine modifications. Additionally, renewable diesel utilizes non-edible oil as a feedstock. Based on its characteristics that surpass biodiesel and petroleum diesel, renewable diesel can be considered as an alternative to replace petroleum diesel in Indonesia. The comparison between different types of diesels can be seen in Table 2.

Table 2. Comparison between different types of diesels (Mahdi et al., 202; Sennder team, 2021).

	Petroleum Diesel	Biodiesel	Renewable Diesel
Constituents	Hydrocarbons (alkanes)	Methyl esters (FAME)	Hydrocarbons (alkanes)
Processing	Mainly from crude oil distillation	Esterification process with methanol as reactant	Hydrodeoxygenation + isomerization process with hydrogen as reactant
Byproducts	Fuel gas, propane, butane, naphtha	Glycerol	Fuel gas, propane, naphtha
Carbon (wt%)	86.8	76.2	84.9
Hydrogen (wt%)	13.2	12.6	15.1
Oxygen (wt%)	0	11.2	0
Specific Gravity	0.84	0.88	0.78
Cetane Number (CN)	40–67	45–65	70–90
LHV (MJ/kg)	42.34–43.1	37.2–38	43.7–44.5
Density at 15 °C (kg/m^3)	796–841	880	770–790
Sulfur Content (ppm)	< 10	< 1	< 1
Flash Point (°C)	54–148	100–180	59–138
Viscosity at 40 °C (mm^2/s)	1.9–4.1	2.9–11	2.0–4.0
Emission reduction (%)	0	60	90

Second-generation biofuels, also known as advanced biofuels, are fuels sourced from feedstock that do not compete with food use or food cropland. This type of biofuel is developed to address concerns regarding food security caused by the use of food crops for the production of first-generation biofuels. The use of edible food biomass for the production of biofuels could result in competition with food and land uses for food crops. The purpose of second-generation biofuel is to increase the availability of biofuel that can be produced sustainably by using biomass from waste, byproducts, or residual non-food parts of current crops, such as stems, leaves, husks, and surplus seeds that are left behind once the food crop has been extracted, as well as other plants that are not used for food purposes (non-food crops), such as jatropha, and also industry or consumer waste such as woodchips, skins and pulp from fruit pressing, used cooking oil, etc. The use of second-generation biofuel also facilitates a circular economy that is aligned with sustainability goals.

Unlike biodiesel (B100), currently, there is no official mandate to use first or second-generation renewable diesel (D100) in Indonesia, but the Ministry of Energy and Mineral Resources (Kementerian ESDM) has included them in Indonesia biofuel mix roadmap where they are projected to fulfill around 9% of 15.2 million kL biofuel mix in 2040 (Misna, 2021). Groundwork to include renewable diesel into the biofuel mix has been prepared, such as the renewable diesel specification stipulated in *Keputusan Direktur Jenderal Energi Baru, Terbarukan dan Konservasi Energi Nomor 95.K/EK.05/DJE/2022* which is based on Indonesian standard specification of renewable diesel, the SNI 8968:2021. Indonesian standard specification of vegetable oil feedstock for renewable diesel production is stipulated in SNI 8875:2020.

Pertamina is a major pioneer of renewable diesel development in Indonesia with various strategic national programs (Umah, 2020). As of 2023, Pertamina is able to produce renewable diesel and related biofuels (biogasoline, biojet) from the refinery units in Dumai (1,000 bpsd) and Cilacap (3,000 bpsd), with planned expansions in Cilacap (6,000 bpsd) and Plaju (20,000 bpsd). Domestic capability to produce catalysts for the process will be possible through the Katalis Merah Putih manufacturing plant in Kujang Cikampek Industrial Park, which is expected to be online in 2023 (Pupuk Kujang, 2022). Field tests of D100 and B30+D10 fuel usage on cars were successfully conducted in 2020 (Kementerian ESDM, 2020) and 2022 (Lemigas, 2023), respectively. All of these are proof of substantial and serious efforts by Indonesia to incorporate renewable diesel into the national biofuel mix.

1.2 Research Background and Objective

Indonesia, as the world's largest producer of palm oil, has an advantage in securing both first and second-generation feedstock for biodiesels and renewable diesels (Ditjenbun, 2022). In the palm oil industry, several types of waste are generated, which can be categorized as second-generation feedstock for renewable diesel production (Chew, 2019). In addition, using the palm oil value chain will play a vital role in promoting a circular economy. Prominent waste types from the upstream to midstream palm oil value chain are palm oil mill effluent (POME) oil, palm fatty acid distillate (PFAD), and spent bleaching earth oil (SBEO). The extensive palm oil processing and plantation activities in Indonesia, combined with the large quantities available, provide an advantage for Indonesia to become a supplier of second-generation renewable diesel feedstock. However, on the other hand, the mapping of palm oil plantations and processing facilities is not thoroughly developed, requiring clear data to further utilize this feedstock.

Therefore, the main objective of this paper is to provide tools for developing a roadmap to understand second-generation renewable diesel feedstock sources from the palm oil value chain in Indonesia. These tools come in the form of a conversion diagram based on estimates of palm oil waste yield from various sources, as well as geospatial visualizations illustrating the distribution of palm-based second-generation feedstock across Indonesia. Both tools will become the basis of an empirical framework that enables stakeholders to identify and evaluate potential feedstock sources, understand the conversion estimates, and visualize the geographical distribution of these sources. By providing these tools, the paper seeks to facilitate strategic decision-making and promote the development of a sustainable and efficient biofuel industry in Indonesia.

The two key deliverables of this paper (the conversion diagram and geospatial visualization) will be briefly explained. The term 'conversion diagram' in this paper is defined as a block flow diagram (BFD) of the palm oil value chain, which is supplemented with a simple mass balance or yields for the reader to understand what materials are involved and how many material outputs can be produced from their inputs. The conversion diagram covers all stages of a palm oil value chain, starting from the upstream (plantation and mills) until the downstream processing sector. This is why a block flow diagram is selected as the type of diagram to simplify the drawing of the entire process flow and enable a quick overview of the basic structure of the system. Along the value chain diagram, the materials that are eligible to be used as second-generation feedstock will be highlighted.

Geospatial visualization involves displaying data on a map, focusing on particular locations. In this situation, the data pertains to the positions of palm oil processing facilities (mills, refineries, oleochemical plants). The provided dataset precisely identifies where these factories are in relation to provinces. It establishes a link between these location details and the waste production capacity of each individual facility. This visualization allows for the observation of patterns and the layout within a specific area, contributing to an enhanced comprehension of connections between places and the amount of waste capacity.

The tools offer practical benefits for potential investors, policymakers, and industrial executives by giving a quantitative sense to determine the capacity of second-generation renewable diesel production facilities, as well as considerations for location, logistics, and access, such as ports and roads. This will help to optimize decision-making, resource allocations, and formulation of plans or roadmaps regarding the development of renewable diesel production in Indonesia.

2. Materials and Methods

This section describes the methods taken to obtain the study results. Detailed explanations are provided regarding the steps taken, techniques applied, as well as tools utilized in the data collection and analysis process. All of these are aimed at providing a comprehensive understanding of the study, result collection, and analysis process. The method flowchart of this research is presented in Figure 1.

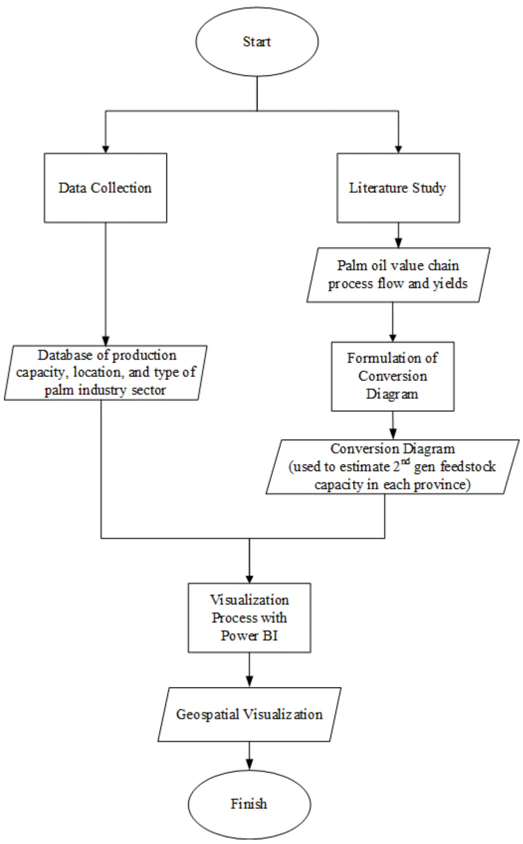

Figure 1. Research flowchart.

This research employs a comprehensive methodology to explore and visualize second-generation renewable diesel feedstock derived from Indonesia's palm oil value chain. The study initiates with simultaneous data collection and literature study, culminating in the creation of a database containing production specifics and insights into the value chain process. These outputs synergize to construct a conversion diagram that visually portrays the feedstock conversion process. This diagram facilitates the estimation of feedstock capacity across various provinces. Subsequently, Power BI is harnessed for geospatial visualization, producing interactive maps that vividly illustrate waste capacity across provinces, with the added functionality of sector-based filtering. Additionally, Power BI's analytical capabilities unveil capacity trends over time. This comprehensive approach within the method section provides a clear outline of the steps involved in analyzing and visually presenting second-generation renewable diesel feedstock potentials within Indonesia's palm oil value chain.

2.1 Data Collection

An extensive data collection process was conducted to examine the distribution of the palm oil industry in Indonesia. This involved gathering information on mills, oleochemical plants, and refineries, aiming to understand their geographical spread and production capacity. The specific focus was on identifying the key companies and regions responsible for producing palm oil products.

To ensure the accuracy and reliability of the findings, data was obtained from the Ministry of Agriculture, a trusted source in the agricultural sector. This data encompasses important details such as production capacity, as well as the primary types of palm oil products generated by the industry. By relying on this information, valuable insights are obtained regarding the production locations and the specific companies involved in the palm oil industry.

Through a meticulous data collection process, a comprehensive understanding of the distribution of the palm oil industry in Indonesia was gained. This information enables the analysis of the dynamics of the industry and its impact on various regions. By identifying the key players and production centers, this study contributes to a deeper insight into the palm oil sector in Indonesia. These data were processed and summarized by three types of palm industry (oleochemical plant, palm oil mill, and palm oil refinery) with the number of companies and production capacity stated in kilo ton per annum (kTPA), which can be observed in APPENDIX.

The data search was initiated through contact with the Ministry of Agriculture in April. After multiple discussions with the Ministry, the palm industry sector data for 2022 was obtained in May. This data is the latest data gathered by the Ministry, and the choice of this year aims to keep the data relevant to the current industry conditions. The data obtained from the Ministry was verified for its accuracy by comparing it with roundtable on sustainable palm oil (RSPO) and unified mill list (UML) data, which indicate the operational status of palm oil sector facilities. One of the encountered limitations was the inability to crosscheck this data with data from the Ministry of Industry and the Ministry of Home Affairs due to the difficulty in accessing such information.

2.2 Literature Study

Through a comprehensive review of existing literature on the palm oil industry, a diverse range of products within the industry have been identified, and the conversion processes from upstream to downstream stages are mapped. This analysis enhances the understanding of the industry's value chain and economic implications. The literature sources are from scientific papers received from scientific databases such as Global Yield Gap Atlas, Sustinere, Social Science Research Network, NCBI, and Wiley Online Library, as well as publications from companies, associations, and government organizations. The specific topics or phrases and references found are presented in Table 3.

Table 3. Topics or phrases used in the literature search along with found references.

Topics/phrases	Key Words	References
Fresh fruit bunch yield	'Fresh' NOT 'Empty' AND 'Fruit' AND 'Bunch' AND 'Yield'	Global Yield Gap Atlas
Palm oil mill mass balance	'Palm' AND 'Oil' AND 'Mill' AND 'Mass Balance'	Faisal and Taleb, 2013; Azis et al., 2014; Kramanandita et al., 2014
Bioethanol yield from empty fruit bunch	'Bioethanol' AND 'Yield' AND 'Empty' AND 'Fruit' AND 'Bunch'	Chuenbubpar et al., 2018
POME oil recovery	'POME Oil' AND 'PAO' AND 'Recovery'	Alfa Laval, 2022
Biogas yield from POME	'Biogas' NOT 'Biomass' AND 'Yield' AND 'POME'	Shahidul et al., 2018
Bleaching earth consumption, spent bleaching earth quantity, and spent bleaching earth oil (SBEO) recovery	'Bleaching' AND 'Earth' AND 'Consumption' AND 'Spent Bleaching Earth' AND 'SBEO' AND 'Recovery'	Abdelbasir et al., 2022
Palm oil refinery yield	'Palm' AND 'Oil' AND 'Palm Oil' AND 'Yield'	Ishak and Michael, 2020
Palm fatty acid distillate (PFAD) yield	'PFAD' AND 'Palm Fatty Acid Distillate' AND 'Yield'	Top, 2010
Palm oil downstream sectors	'Palm' AND 'Oil' AND 'Palm Oil' AND 'Downstream'	Gabungan Pengusaha Kelapa Sawit Indonesia (GAPKI) in Ahdiat, 2023 and Widi, 2023; Ministry of Trade (Kementerian Perdagangan) in Jelita, 2022

Additionally, the literature study enables the exploration of waste materials generated during palm oil production and their potential for utilization. By examining relevant literature, the types of waste produced, and yield rates can be known. This knowledge can help to determine which waste materials can be utilized as second-generation renewable diesel feedstock, contributing to the development of sustainable practices within the industry.

2.3 Formulation of Process Flow & Mass Balances for the Conversion Diagram

Based on a literature study on the palm oil industry, the processes, and the typical yields on each stage of the palm oil value chain were compiled with 100 ton crude palm oil (CPO) as the basis. The yield data from the literature study are used for a spreadsheet calculation for the simple mass balance of each process based on 100 ton CPO.

2.4 Visualization Software

The analysis of second-generation feedstock potential within Indonesia's palm industry sector employs a structured methodology encompassing data collection, processing, and visualization. The dataset obtained from Kementan includes critical attributes such as location, industry classification, and production capacity. The initial phase involves processing the production capacity data to calculate waste capacity per factory (conversion diagram), facilitating a more comprehensive understanding of potential feedstock generation.

To effectively convey these insights, Microsoft Power BI, a robust visualization software, serves as a central tool. Power BI's geospatial visualization features accurately map waste capacity and types onto geographic coordinates. This visual representation offers a comprehensive overview of feedstock potential trends across diverse provinces, mills, oleochemical plants, and refineries. A notable capability of Power BI's geospatial visualization lies in its interactive filtering. By utilizing filters such as province and industry type (mill, oleochemical, and refinery), users can dynamically explore the data. While not real-time, Power BI's seamless data integration ensures the accuracy and relevance of visualizations. This feature supports informed decision-making as strategies related to second-generation feedstock continue to evolve.

3. Results and Discussions

The following are the results obtained from this research, which were achieved through data collection, literature study, and data visualization.

3.1 Data Validation

The data in APPENDIX indicates that the potential of the palm oil industry in Indonesia is relatively significant. The data obtained from the Ministry of Agriculture (Kementerian Pertanian) amounts to approximately 1,200, which has been placed in APPENDIX as a summary. All forms of visualization and calculations are based on this data and are limited to this data. Errors are possible as the data period was from the year 2022, which may change slightly over one year. The data obtained from the Ministry of Agriculture can potentially yield an error with a margin of 6%. This is because the data collected is from the year 2022, while the projection from BPDPKS indicates a 6% increase in the year 2023, which can be seen in Figure 2. However, the calculations in this journal remain grounded in the Ministry of Agriculture's 2022 data. Observable from the flowchart in Figure 1, this database containing total plant, provincial, and product capacity will be employed to create a conversion diagram. This marks the initial steps, coupled with a literature study, in achieving the objective of this journal: to provide tools for developing a roadmap to understand second-generation renewable diesel feedstock sources from the palm oil value chain in Indonesia.

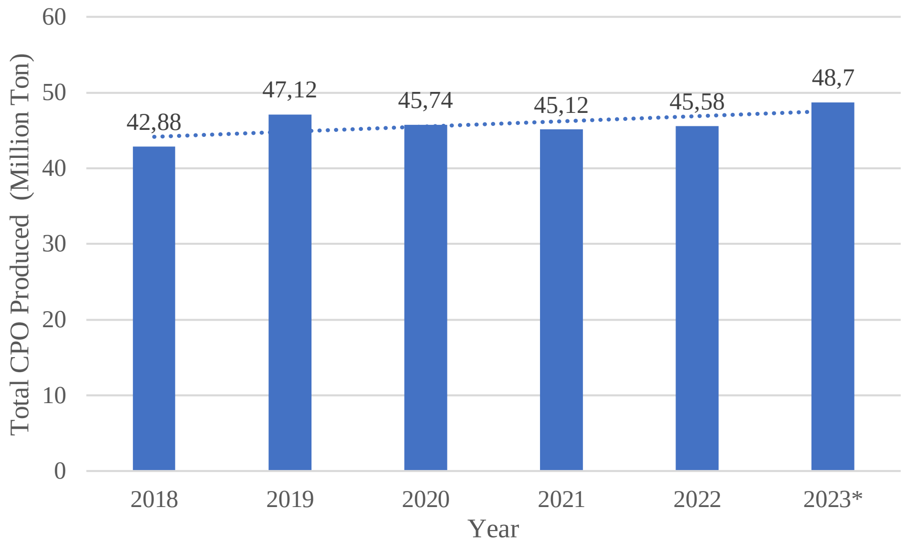

Figure 2. Indonesia CPO production 2018-2023 (BPDPKS, 2023; BPS, 2023).

3.2 Conversion Diagram

The conversion diagram is a significant output that can serve as one of the tools for developing a roadmap to understand second-generation renewable diesel feedstock. Disseminated data from the palm oil industry typically involves finished production data. With the presence of a conversion diagram, it's possible to gain an overview of the various waste products generated from a specific palm oil factory's production capacity, along with the quantity of such waste. This information becomes essential for taking further steps in purchasing or utilizing such feedstock.

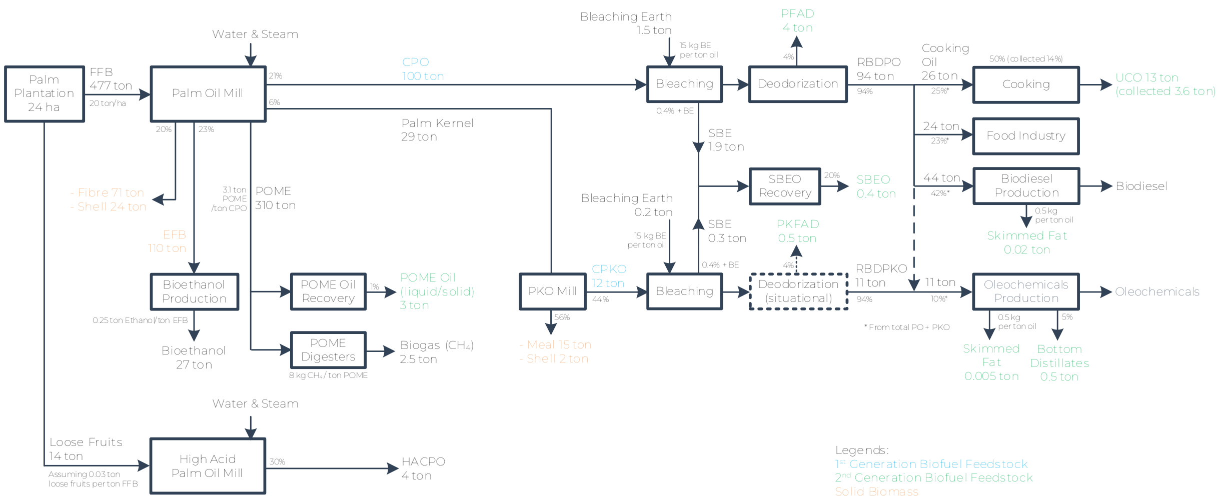

Figure 3. Palm oil value chain conversion diagram.

Figure 3 shows that with a base of 100 tons of CPO, various types of waste will be generated depending on the industry in which this CPO is used and whether it becomes a product or a feed. The percentage usage in the following sentence will refer to the basis. In the palm oil mill, around 1-3 tons POME oil may be recovered for each 100-ton CPO produced. Additionally, loose fruits from palm plantations are usually collected to produce non-food grade, high-acid crude palm oil (HACPO), but it is not officially recognized as a second-generation biofuel feedstock.

Table 4. Palm oil mill waste conversion.

Waste Type	Ton / Ton CPO Product
POME Oil	0.03

For the palm oil refinery industry, CPO is treated to become refined, bleached, and deodorized palm oil (RBDPO), which is further processed as cooking oil as well as an ingredient in the food industry and biodiesel. Assuming CPO basis at 100 tons, the bleaching and deodorization processes in the production of RBDPO will respectively generate Spent Bleaching Earth Oil (SBEO) amounting to 0.4 tons (0.4%) and PFAD amounting to 4 tons (4%).

Table 5. Palm oil refinery waste conversion.

Waste Type	Ton / Ton CPO Feed
SBEO	0.004
PFAD	0.04

In the oleochemical industry, with a base of 12 tons of crude palm kernel oil (CPKO) as feed, it will produce waste as a second-generation renewable diesel feedstock in the form of palm kernel fatty acid distillate (PKFAD), amounting to 0.5 tons (4%) during the production of refined, bleached, and deodorized palm kernel oil (RBDPKO). RBDPKO, as the product, will generate skimmed fat, amounting to 0.005 tons (0.2%), and bottom distillates, amounting to 0.5 tons (4%) during the process of becoming the finished product.

Table 6. Oleochemical industry waste conversion.

Waste Type	Ton / Ton CPKO Feed
PKFAD	0.04
Skimmed fat	0.002
Bottom distillate	0.04

3.3 Geospatial Visualization

After obtaining data on production capacities in each region from the Ministry of Agriculture and conversion values of second-generation renewable diesel feedstock from the palm oil sector, visualizing the potential supplier regions becomes crucial. This assists in developing a roadmap to understand second-generation renewable feedstock in terms of distance, cost, logistic access, ports, and roads. This is where Power BI with mapping features was utilized, as mentioned in the "Method and Materials" chapter. This mapping for feedstock will be referred to as "Geospatial Visualization of Palm Oil Value Chain Second-Generation Renewable Diesel Feedstock." This visualization will be limited to five types of waste, excluding skimmed fat, because its conversion value and waste are relatively small compared to other waste.

Figure 4. Geospatial visualization of palm oil mill in Indonesia (per province) with bubble as an indication of the capacity concentration (Kementan, 2022).

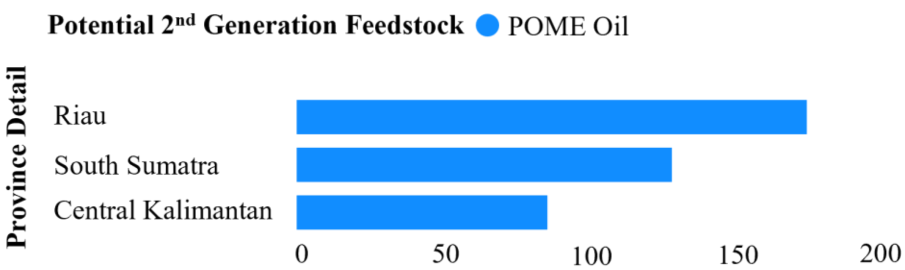

Figure 5. Bar chart of palm oil mill potential second-generation renewable diesel feedstock from top 3 largest provincial capacities in Indonesia (kTPA) (Kementan, 2022).

The geospatial visualization in Figure 4 shows the distribution of palm oil mills across provinces in Indonesia. This is depicted by bubbles in the provinces, where the size of the bubble represents the production capacity in that province. The larger the bubble, the greater the capacity in that province. Figure 5 above indicates that the three provinces with the largest capacities are Riau, South Sumatra, and Central Kalimantan. With the obtained conversion estimates, the total waste (POME oil) that can be seen in Figure 5 in Riau is 174 kTPA, in South Sumatra is 128 kTPA, and in Kalimantan is 85 kTPA.

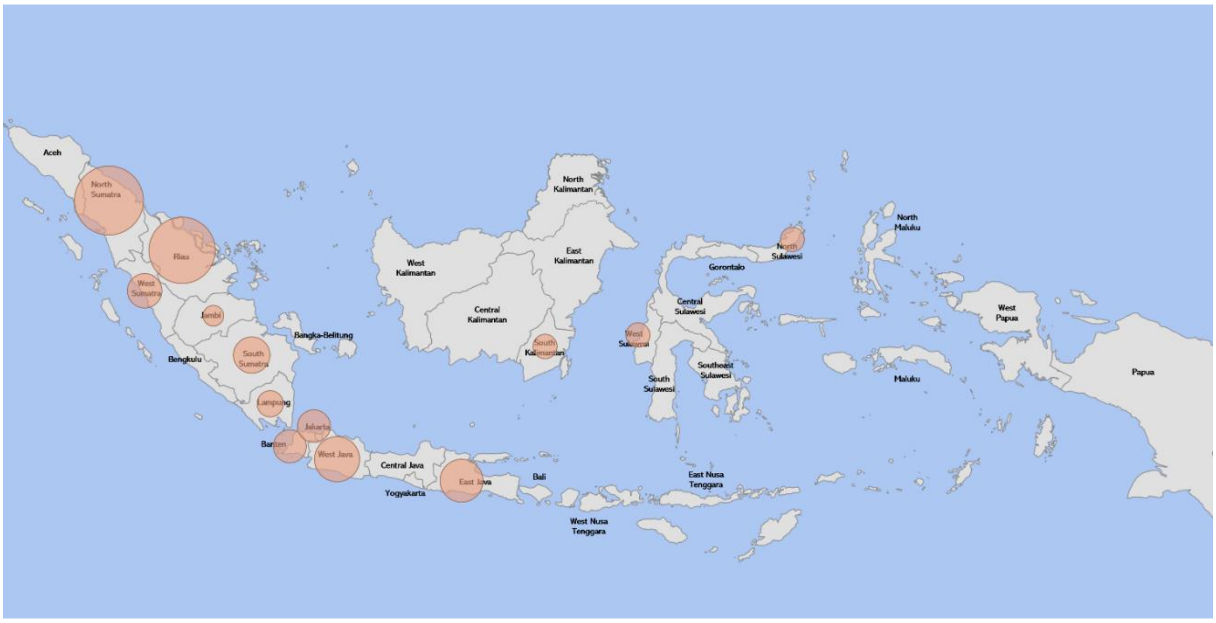

Figure 6. Geospatial visualization of palm oil refineries in Indonesia (per province) with bubble as indication of capacity concentration (Kementan, 2022).

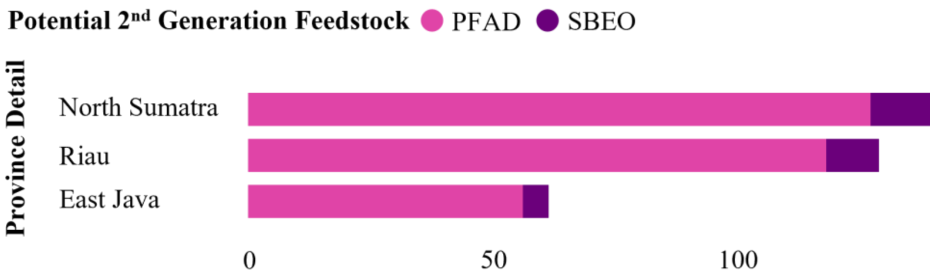

Figure 7. Bar chart of palm oil refineries potential second-generation renewable diesel feedstock from top 3 largest provincial capacities in Indonesia (kTPA) (Kementan, 2022).

The geospatial visualization in Figure 6 shows the capacities of palm oil refineries spread throughout Indonesia. This is represented by bubbles indicating the provinces where palm oil refineries are located, and the size of the bubble corresponds to the production capacity in that province. The larger the bubble, the greater the production capacity in that province. It appears that the three provinces with the largest production capacities are North Sumatra, Riau, and East Java, in descending order from largest to smallest. Since this paper already has estimates of the conversion rate for products from palm oil refineries, the waste generation rates can be predicted from palm oil refineries in the three provinces with the largest capacities. This can be done by multiplying the production capacity of palm oil refineries by the waste generation rate. The total waste (PFAD + SBEO) generated by palm oil refineries in Figure 7 in North Sumatra is 138 kTPA, in Riau is 129 kTPA, and in East Java is 61 kTPA.

The geospatial visualization in Figure 8 shows the distribution of oleochemical plants across provinces in Indonesia. This is depicted by bubbles in the provinces, where the size of the bubble represents the production capacity in that province. The larger the bubble, the greater the capacity in that province.

Figure 9 indicates that the three provinces with the largest capacities are North Sumatra, Riau, and East Java. With the previously obtained conversion estimates, the total waste that can be seen in Figure 9 (BD, PKFAD, and SBEO) in North Sumatra is 142 kTPA, in Riau is 58 kTPA, and in East Java is 47 kTPA.

Figure 8. Geospatial visualization of oleochemical plants in Indonesia (per province) with bubble as indication of capacity concentration (Kementan, 2022).

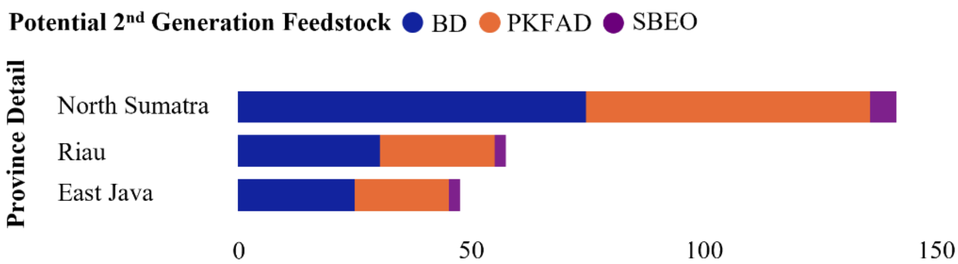

Figure 9. Bar chart of oleochemical plants potential second-generation renewable diesel feedstock from top 3 largest provincial capacities in Indonesia (kTPA) (Kementan, 2022).

Table 7. Top 5 provinces of second-generation renewable diesel feedstock capacity.

Province	Second-Generation Renewable Diesel Feedstock Capacity (kTPA)
Riau	361
North Sumatra	341
South Sumatra	181
East Java	108
Central Kalimantan	85

From the geospatial visualizations and bar charts depicting the distribution of waste for the three provinces with the largest capacities in each industry, a table was compiled to identify the provinces with significant second-generation renewable diesel feedstock capacity. Several types of waste in each province can be combined since what matters for second-generation renewable diesel feedstock is the oil derived from waste, regardless of its origin. Typically, the pre-treatment process in HVO production allows for the mixing of various types of feedstocks, which can then be further processed through hydrodeoxygenation and isomerization. Of the three provinces with the largest capacities in each industry, it is found that Riau has the highest capacity of 361 kTPA of second-generation renewable diesel feedstock, as seen in Table 7.

Table 8. Feedstock type total capacities and top 3 provinces.

Feedstock Type	Capacity (kTPA)	Top 3 Provinces in Capacity	Identified Capacity
POME oil	867	Riau, South Sumatra, Central Kalimantan	Large
PFAD	506	North Sumatra, Riau, East Java	Large
BD	147	North Sumatra, Riau, East Java	Medium
PKFAD	117	North Sumatra, Riau, East Java	Medium
SBEO	59	North Sumatra, Riau, East Java	Small
Skimmed fat	2	North Sumatra, Riau, East Java	Small

The capacity data of five waste types from each province have shown that the two largest waste types are POME oil and PFAD, so it can be concluded that these waste types are the most promising sources of second-generation renewable diesel feedstock in Indonesia. POME oil, the waste generated during palm oil milling, boasts a capacity of 867 kTPA, although its industrial sales remain uncertain, and the increasing effectiveness of crude palm oil extraction rate means that the production of POME oil is expected to decrease. Meanwhile, PFAD, a byproduct of palm oil refining, already demonstrates significant potential with a capacity of 506 kTPA and established industrial sales. The reported total capacities of all types of waste are ranging from 2 kTPA to 867 kTPA, categorized into common distribution as small (0–100 kTPA), medium (100–500 kTPA), and large (>500 kTPA). The utilization of POME oil and PFAD can make a substantial contribution to the production of renewable diesel, but ensuring reliable and sustainable feedstock supply necessitates extensive validation efforts.

Site surveys are crucial to be conducted for the validation of the above data and to delve deeper into sourcing feedstock. Site surveys within the palm oil industry involve a multifaceted approach accompanied by distinct challenges. Reaching remote locations, managing data inconsistencies, and maintaining uniform methodologies present significant obstacles. Effective communication and collaboration are crucial to securing industry stakeholders' cooperation. The survey process involves meticulous planning, scheduling, and physical visits. Direct observations, interviews, and measurements of production processes are conducted, often supported by GPS technology and geospatial tools. The collected data is cross-referenced for validation, leading to accurate insights. Despite the time investment, site surveys yield numerous benefits. They ensure data accuracy, enabling informed decisions and policy formulation. Identifying operational inefficiencies enhances productivity, while data validation fosters trust and compliance. Moreover, surveys evaluate environmental impact, promoting sustainable practices within the industry.

3.4 Share of Second-generation Renewable Diesel from Palm Oil Value Chain in Indonesia

Based on Table 8, the collection of all second-generation biofuel feedstock from the Indonesian palm oil value chain will result in 1.6 million tons per year of feedstock capacity. This equates to 1.4 million kL per year of renewable diesel, which can completely meet the demand of 1.4 million kL renewable diesel in 2040 based on the Kementerian ESDM projection. This number represents 9% of the biofuel mix in that year.

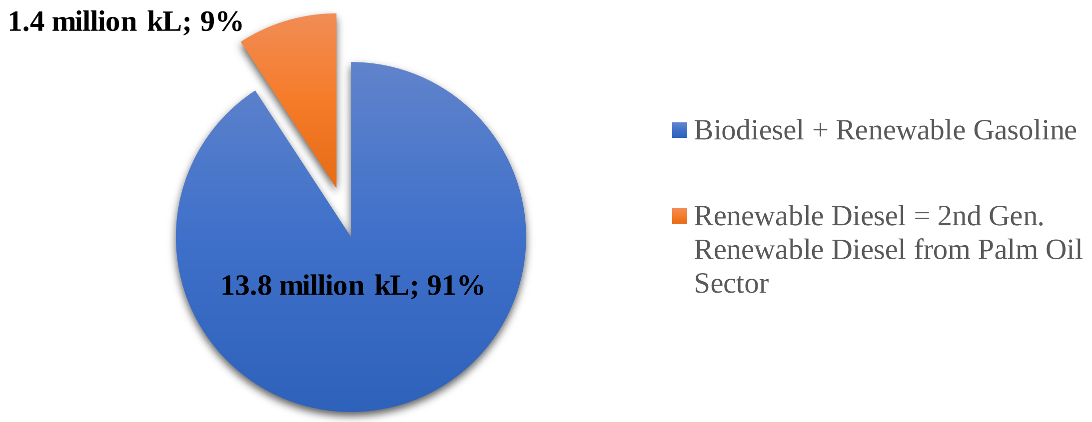

Figure 10. Share of second-generation renewable diesel potential in Indonesia based on 2040 biofuel mix (Misna, 2021).

3.5 Implications and Significance of Findings

The geospatial visualization of potential second-generation renewable diesel feedstock distribution in tandem with the estimated conversion diagram elucidates crucial factors for the successful development of this sector in Indonesia. These insights hold implications for various aspects of biofuel production. Strategically, visualization aids in identifying optimal regions for establishing production facilities, ensuring proximity to feedstock sources while minimizing logistical complexities. This is particularly important since feedstock cost takes around 80% of the production cost (O'Connor, 2018). Hence, there will be an advantage if the production facility is built very near the feedstock sources.

Here are a few examples of the decision-making process that can be accelerated through the information presented in this paper. Stakeholders who are interested in building a second-generation renewable diesel plant as near as possible to the feedstock source without relying on tanker shipping may consider a production capacity between 100–300 kTPA in either Riau or North Sumatra province, 50–150 kTPA in South Sumatra, and so on. Stakeholders who want to construct their plant in Sumatra will mainly rely on POME oil and PFAD, while smaller capacity plants (30–60 kTPA) may be established in Java using all kinds of second-generation feedstock except for POME oil due to the relative absence of palm oil mill in Java.

Nevertheless, realizing the potential of second-generation renewable diesel feedstock is not without challenges. Regulatory frameworks, technological advancements, and market dynamics present hurdles that must be addressed for industry growth. Furthermore, the broader impact of these findings is notable. By leveraging available resources efficiently and reducing waste through optimized conversion processes, the biofuel industry can align with circular economy principles, minimizing its environmental footprint. This shift not only contributes to Indonesia's sustainable energy goals but also showcases the role of biofuels in transitioning towards greener energy alternatives. These findings provide a foundation for strategic planning and innovation in the biofuel sector, inviting collaboration among stakeholders to navigate challenges and seize opportunities, ultimately propelling sustainable development in Indonesia's energy landscape.

4. Conclusion

The conversion diagram illustrates the waste output from the palm oil industry, depicting conversion rates and providing insights into Indonesia's substantial palm oil waste capacity. Geospatial visualization highlights the availability of waste materials from palm oil mills, palm oil refineries, and oleochemical plants, resulting in the production of second-generation renewable diesel feedstock.

Various feedstocks are available, including POME oil, PFAD, SBE oil, BD, and PKFAD, with promising provinces such as Riau, East Java, North Sumatra, South Sumatra, and Central Kalimantan. POME oil and PFAD emerge as standout feedstock types due to their significant capacities, with approximately 867 kTPA and 506 kTPA, respectively. These capacities may not only address waste management challenges but also promote environmentally friendly energy generation. Conducting site surveys is crucial for gaining deeper insights. The combination of geospatial visualization and conversion diagrams will facilitate the development of a roadmap for second-generation biofuel. However, it is important to acknowledge and navigate challenges such as regulatory constraints, technological considerations, and market dynamics to ensure sustained success. The successful implementation of these strategies can significantly contribute to Indonesia's sustainable energy goals and serve as a model for the pivotal role of biofuels in transitioning towards alternative energy sources.

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