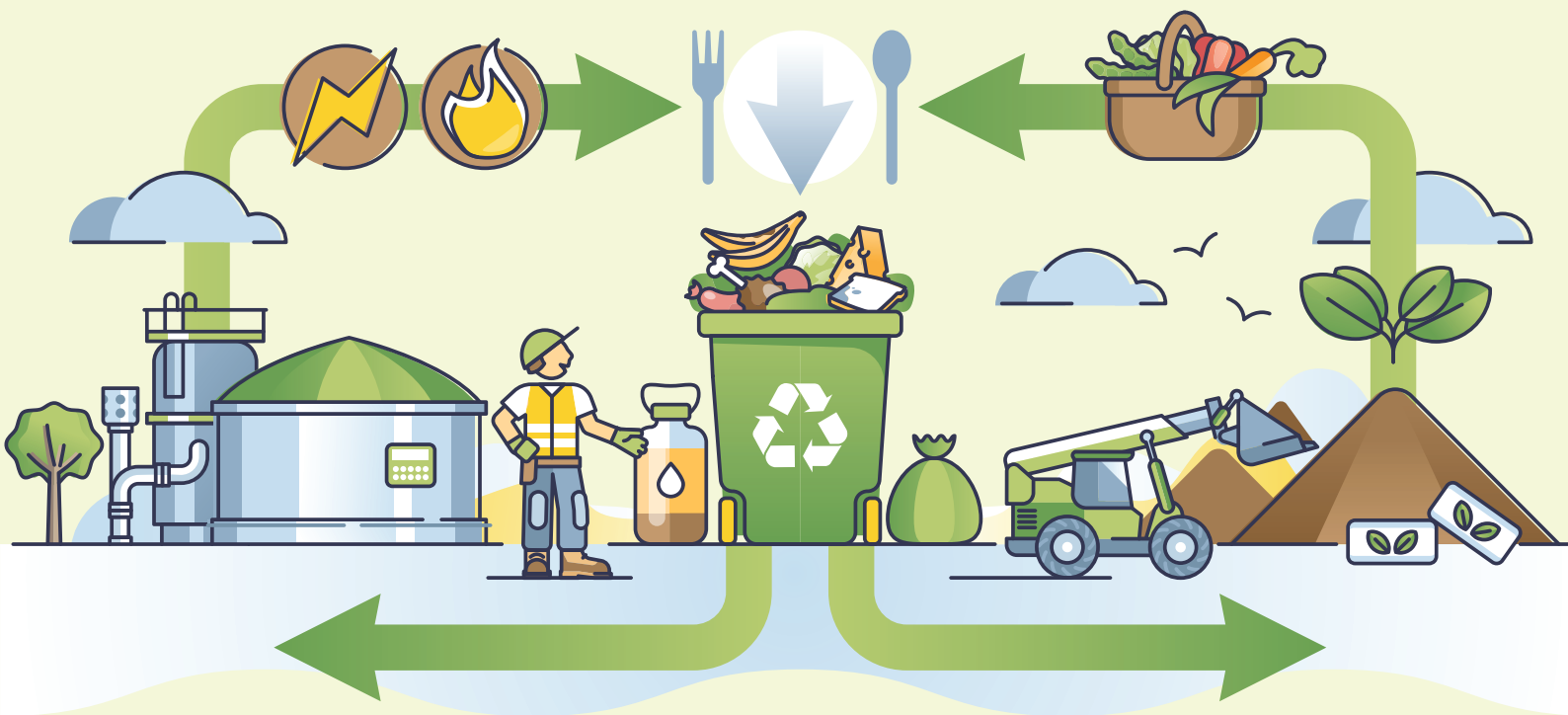


Green and Inclusive Economic Recovery through Circular Economy in Food & Beverages Related Sectors





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Organization



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Introduction

The work project of “**Green and Inclusive Economic Recovery through Circular Economy in Food & Beverages Related Sectors**” was proposed to support stakeholders with a set of policy recommendation regarding the green and inclusive economic recovery through circular economy in the food and beverages industry sectors. This document is one of two reports produced by two main activities of the projects:

- 1) **Quick/Rapid Assessment** on Food & Beverage (F&B) value chains that contribute most significantly to green economic recovery in the context of LCDI and the identification of circular economy potential– as the basis for value chain selection; and
- 2) **Resource Efficiency Potential Assessment** in F&B Sector, including in-depth assessment on Waste & CO₂ Reduction potential in Food & Beverage sub-sectors.

In this report on **Quick/Rapid Assessment**, we present in three parts the progress results of two corresponding studies:

- 1) **Part 1: Quick Assessments**, to assess quickly the most significant food & beverage sub-sectors; and
- 2) **Part 2: System Dynamics Modeling**, to assess the most significant value chains of the selected sub-sectors.
- 3) **Part 3: Waste & CO₂ Reduction Life Cycle Assessment**, to elaborate available WCR systems/technologies promoting circular economy implementation in five value chain potential.



PART 1

Quick Assessment

Table of Contents

1. Background and Objective of Quick Assessments	1
2. Methodology for Quick Assessments	2
3. Determining the Criteria and Indicators for Potential Sub-sectors Selection	3
3.1 Literature review	3
3.2 Long-list Criteria and Indicators Generation	6
3.3 Expert Candidates Selection and Their Contacts	8
3.4 Survey Data Collection	8
3.5 Survey Data Analysis	9
3.6 Final Indicators	20
4. Data of Indicators Collection for F&B Sub-Sectors	22
4.1 Data Collection from BPS and from SIINAS Ministry of Industry	22
4.2 Data Assessment and Selection	23
4.3 Data Preprocessing	24
5. Assessing and Ranking Sub-Sectors	27
5.1 Scenario development for scoring method and input	27
5.2 Scoring and Ranking of Each Sub-Sector Based on Each Scenario	28
6. Analyzing the Result and Making Recommendation for Selected Sub-Sector	37
References	38
Appendix 1: Questionnaire Draft	39
First Iteration	39
Second Iteration	44
Third Iteration	47
Fourth Iteration	51
Fifth Iteration	54
Sixth / Final Iteration	56
Appendix 2: List of Experts Invited in the Survey	58
Appendix 3: Indicators Importance Score	61



1. Background and Objective of Quick Assessments

The government has set one approach to the post-COVID-19 green economic recovery efforts through Building Back Better with Low Carbon Development Initiative or B3-Low Carbon. A recent joint study by Bappenas, UNDP, and The Government of Denmark (2021) has identified five sectors which have large potentials for creating benefits in terms of economic, social, and environment in the context of circular economy. Those five sectors are: (i) food and beverages (ii) textiles (iii) construction (iv) wholesale and retail trade, and (v) electrical and electronic equipment. Those five sectors, as they are main economic sectors in Indonesia, are quite diverse.

The food and beverage sector accounted for 9.3 percent of the total GDP in 2019 and was the largest sub-sector of the manufacturing sector, which itself was the largest industry sector in Indonesia. Thus, the need for a circular economy transformation in this sector is urgent. As the circular economy approach that will be taken by Gol has been set according to set of activities focused on the 5Rs: Reduce, Reuse, Recycle, Refurbish, and Renew; the government’s qualitative assessment results and opportunities in the F&B secincludedeudes Reduce and Recycle approaches.

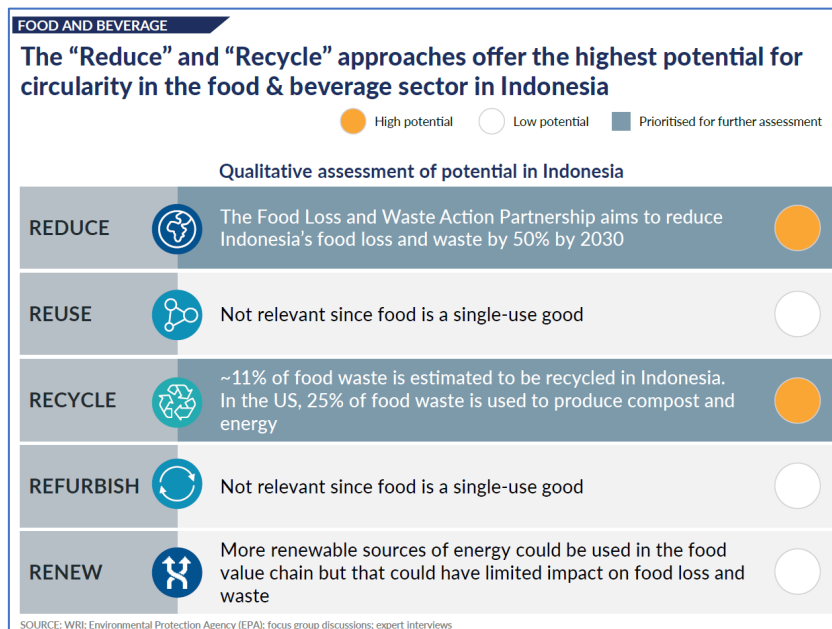


Figure 1 Results of qualitative assessment of potential in Indonesia for F&B

Given that the selected food and beverage sector has various stakeholders from production to post-consumption who can contribute to the government’s initiative, an assessment of potentials along its value chain will be needed. This quick assessment is the part of the study with the objective to assess quickly the food & beverage sub-sectors that contribute most significantly to green economic recovery in the context of LCDI and identification of CE potential. Also, given the different operation and business processes of different sub-sectors, vast amount of time and resources will be needed to identify and describe these potentials. Hence a quick or rapid assessment is used to identify the most prominent sub-sector, especially in the food and beverage sector in Indonesia.

2. Methodology for Quick Assessments

The methodology of quick assessments for selecting indicator and sub-sector is presented in Figure 1. The methodology adopted from grey-delphi method, superiority linguistic ratings, entropy weighting method, and fuzzy-VIKOR. The first step is to conduct decision group with relevant experts. Based on the decision group, benefit evaluation index will be created with grey-delphi method and collect the objective evaluation of sub-criteria values. Then, an aggregate weight of evaluation of sub criteria will be conducted based on distributed superiority linguistic rating to all alternatives of sub-criteria. The last step is to evaluate comprehensive benefit with using fuzzy-VIKOR method.

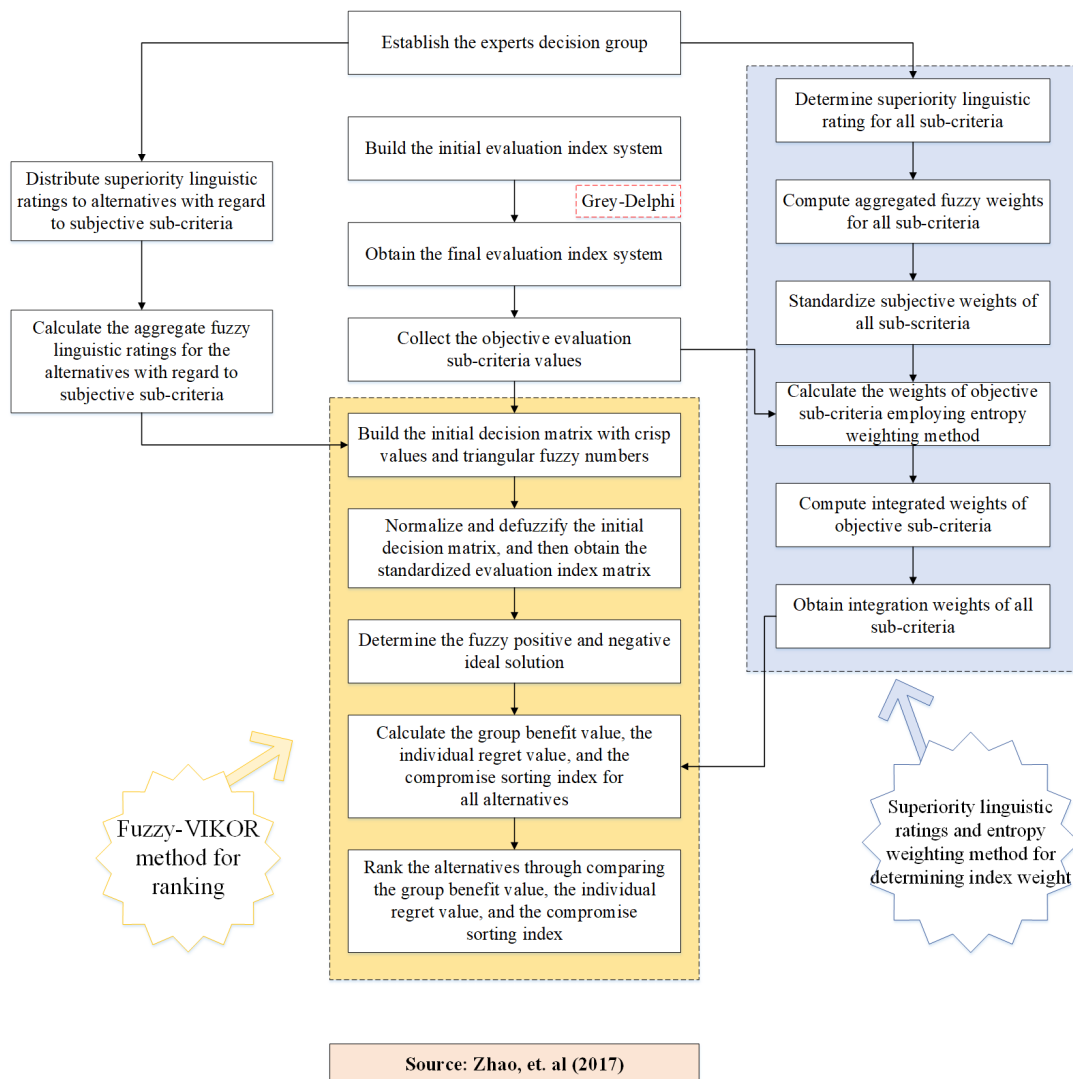


Figure 2 Methodology for quick assessment

From Figure 2, we can divide the quick assessment process into four stages:

- **Stage 1:** Determining the criteria and indicators for potential sub-sectors selection;
- **Stage 2:** Collecting data and calculating indicators scores for each F&B sub-sector;
- **Stage 3:** Assessing and ranking of F&B sub-sectors; and
- **Stage 4:** Analyzing the result and making recommendation for selected sub-sector.

3. Determining the Criteria and Indicators for Potential Sub-sectors Selection

This stage objective is to generate a short list of criteria and indicators to be used for selecting the most potential F&B sub-sector to implement low carbon development (LCD) and circular economy (CE). This stage can be divided into several steps:

- **Step 1:** Conduct a literature review to build an inventory of criteria and indicators of CE and LCD
- **Step 2:** Build a long-list of criteria and indicators of CE and LCD and the questionnaire based on this long list
- **Step 3:** Identify the experts on CE and LCD to weigh the importance of the criteria and indicators in the long-list
- **Step 4:** Collect the data through questionnaire survey
- **Step 5:** Process the survey data
- **Step 6:** Finalize the short-list criteria and indicators

These steps will be elaborated in the next sub-sections.

3.1 Literature review

The researchers reviewed some journals related to Multi-Criteria Decision Making (MCDM). There were three main papers that were reviewed in order to collect potential indicators:

- 1) *How Industrialization Stage Moderates the Impact of China’s Low-Carbon Pilot Policy* (Sun, et.al., 2020);
- 2) *Evaluating the Comprehensive Benefit of Eco-Industrial Parks by Employing Multi-Criteria Decision Making Approach for Circular Economy* (Zhao, Zhao, & Guo, 2016); and
- 3) *Circular Economy Indicators as a Supporting Tool for European Regional Development Policies* (Avdiuschenko & Zajac, 2019).

From these three papers, the researchers found 88 indicators from 18 criteria. Table 1 shows the list of the potential indicators and its criteria.

Table 1 List of potential indicators

Criteria	Indicator	Reference
Economic	Economic Annual average growth rate of industrial added value	Zhao, Zhao, & Guo (2016)
	Per capital industrial added value	
	Industrial assets	
	The proportion of research and development input value in GDP	
	The proportion of high-tech output value in gross industrial output value	
Social	Contribution rate of scientific and technological progress to GDP	
	Social Government revenue	
Environmental	Employment increase promoting degree	

Criteria	Indicator	Reference
	Environmental Comprehensive energy consumption per unit of industrial added value	
	Fresh water consumption per unit of industrial added value	
	Industrial water recycling rate	
	Reclaimed water reuse rate	
	Recycling rate of industrial solid waste	
	Repeated utilization ratio of raw material	
	Energy recycling rate	
	The substitution of raw material source	
	Gross industrial output value per unit of industrial land	
	The COD emissions of per unit of industrial added value	
	The solid waste emissions of per unit of industrial added value	
	The CO2 emissions of per unit of industrial added value	
	Centralized sewage treatment rate	
	Hazardous waste disposal rate	
	Harmless disposal rate of garbage	
	Waste chain perfection	
	Waste treatment facilities	
	Toxic and hazardous waste emissions of per unit of industrial added value	
Ecology industry construction	Ecology industry construction Network degree of information system	
	Perfection of environmental management system	
Management	Network degree of water and energy systems	
	Per capita public green space	
	Coverage rate of green space in the park	
	Correlation degree of enterprises	
	The formulation of internal management system of the park	
	The implementation of internal management system of the park	
	The formulation of enterprises management system	
	The implementation of enterprises management system	
	The parks' changing monitoring capacity	
	ISO14001 certification number of enterprises in the park	
	Eco-industrial training	
Macro System	Total Energy Consumption of Industrial Enterprises (A1)	Sun, et.al., (2020)
	Total carbon emissions of industrial enterprises (A2)	
	Carbon emissions per unit of industrial value-added (A3)	
Energy System	Coal consumption as a percentage of total fossil energy consumption (B1)	
	Natural gas consumption as a proportion of fossil energy consumption (B2)	
	Energy consumption reduction rate per unit of GDP (B3)	
	power consumption reduction rate per unit of GDP (B4)	
	water consumption reduction rate per unit of GDP (B5)	

Criteria	Indicator	Reference
Industrial System	The proportion of tertiary industry to GDP (C1)	Avdiuschenko & Zajac (2019)
	The proportion of industrial added value to GDP (C2)	
	Energy consumption reduction rate per unit of industrial added-value (C3)	
Environmental system	PM10 annual average concentration (D1)	
	Industrial sulfur dioxide emissions per unit of industrial value-added (D2)	
	Industrial wastewater discharged per unit of industrial added-value (D3)	
	Sewage treatment rate (D4)	
Land System	Green area per capita (E1)	
	The green coverage rate of urban built-up area (E2)	
	Forest coverage (E3)	
	Rate of decline in construction area per unit of GDP (E4)	
Living system	Annual per capita production of urban household waste (F1)	
	Urban water consumption per capita (F2)	
	Annual electricity consumption per capita for urban residents (F3)	
	Urban per capita living construction area (F4)	
	Number of buses owned by ten thousand people (F5)	
Economic prosperity economy	GDP	
	Average life expectancy at birth for men	
	Registered unemployment rate	
	At-risk-of-poverty rate	
Zero-waste economy	Municipal waste collected selectively in relation to the total amount of municipal waste collected	
	Municipal waste collected per one inhabitant	
	Industrial and municipal wastewater purified in wastewater requiring treatment	
	Outlays on fixed assets serving environmental protection and water management related to recycling and utilization of waste	
Innovative economy	Expenditures on research and development activities	
	Average share of innovative enterprises in the total number of enterprises	
	Adults participating in education and training	
	Patent applications for 1 million inhabitants	
Energy-efficient and renewable energy-based economy	Share of renewable energy sources in total production of electricity	
	Outlays on fixed assets serving environmental protection and water management related to electricity saving	
	Electricity consumption	
Low carbon economy	Carbon dioxide emission from plants especially noxious to air purity	
	Emission of particulates	
	Passenger cars	

Criteria	Indicator	Reference
	Pollutants retained or neutralized in pollutant reduction systems in total pollutants generated from plants especially noxious to air purity	
	Outlays on fixed assets serving environmental protection and water management related to protection of air and climate	
Smart economy	Households with personal computer with broadband connection to Internet	
	enterprises with access to the Internet via a broadband connection	
Spatially effective economy	Forest cover indicator	
	Street greenery and share of parks, lawns and green areas of the housing estate areas in the total area	
	Urbanization rate	

3.2 Long-list Criteria and Indicators Generation

After collecting the list of many potential criteria and indicators, the researchers conducted reduction. The potential indicators were reduced based on these evaluation criteria:

I. Relevancy to the topic and research location (Indonesia)

The three papers context range from local industrial park up to regional (Europe) in terms of scope. Criteria like ecology industry construction, management, and living system are considered irrelevant to this study, hence these criteria are eliminated. On the other hand, there are indicators that are not in consulted literature but have been used in previous studies in Indonesia (Bappenas, 2021; Bappenas, UNDP, and The Government of Denmark, 2021).

II. Measurement difficulty, while can be replaced by proxy

In the context of industrial park, it might be possible to measure the indicators in factory levels and the data can be generated regularly. For example, pollutants retained or neutralized in pollutant reduction systems in total pollutants generated from plants especially noxious to air purity might be collected from the plants in a certain industrial complex. However, this data in the national level might be unavailable considering the complexity of different industries and different locations. This indicator can be represented by particulate emission as a proxy of air pollutants.

III. Redundancy

Different criteria from different studies basically measure similar indicators. For example, CO2 emissions per industry added value under the Environmental criterion in Zhao, Zhao, and Guo (2016) is similar to total carbon emissions under Macrosystems criterion in Sun et al. (2020).

The researchers searched for these issues in each criterion and indicator and then decided to perform these actions on each criterion and indicator, including:

- Delete the irrelevant criteria and indicators
- Change the wording (renaming or modifying) of the criteria and indicators considering the context
- Merging similar criteria and indicators into one criterion or indicator

- Adding relevant criteria from previous BAPPENAS CE and LCDI studies

The process of the evaluation was conducted iteratively. The details of each iteration are explained in Appendix 1: Questionnaire Draft. Table 2 shows the short-list of the indicators as much as 42 indicators which were divided into eight criteria as included in the questionnaire.

Table 2 Long list of selected indicators

No	Criteria	Indicator
1	Economy	Economic annual average growth rate of sub-sector added value
2		Potential to increase employment
3		Research and development input value in the sub-sector
4		Gross sub-sector output value per unit of land
5	Social	Potential to educate or to increase awareness on environment issues
6		Social intangible benefit potential
7		Potential to reduce poverty
8		Potential to increase women employment rate
9		Potential to increase household saving
10	Circularity Potential	Industrial water recycling rate
11		Reclaimed water reuse rate
12		Recycling rate of industrial solid waste
13		Repeated utilization ratio of raw material
14		Energy recycling rate
15		The substitution of raw material source with recycled material
16	Energy System	Current coal consumption
17		Current natural gas consumption
18		Current power consumption
19		Potential power consumption reduction rate per unit sub-sector output
20		Potential energy consumption reduction rate per unit sub-sector output
21		Potential use of renewable energy sources
22	Environmental System	PM10 (particulate matter in the air with a diameter of 10 micrometers or less) emission annual average concentration
23		Potential industrial sulfur dioxide emissions reduction
24		Potential industrial wastewater discharged reduction
25		Sewage treatment rate
26		The COD (chemical oxygen demand) emissions of per unit of industrial added value
27		The solid waste emissions of per unit of industrial added value
28		Potentially hazardous waste disposal reduction
29		Potential harmless disposal rate of garbage reduction
30		Waste treatment facilities
31		Potential toxic and hazardous waste emissions reduction
32		Fresh water consumption per unit of industrial added value
33	Low Carbon Initiatives	Potential carbon dioxide emission reduction
34		Potential other GHG emission reduction
35		Potential to capture carbon emission/to absorb carbon

No	Criteria	Indicator
36	Investment or outlays needed to promote CE & LCDI	Investment or outlays needed on fixed assets related to environmental protection
37		Investment or outlays needed on fixed assets related to energy saving
38		Investment or outlays needed in pollutant reduction systems
39		Investment or outlays needed related to carbon reducing system
40	Stakeholder Involvement	Government priority
41		Potential of private sector involvement
42		Potential of international support

3.3 Expert Candidates Selection and Their Contacts

Based on the quick assessment methodology (Figure 2), in this study the the the researchers used Grey-Delphi method. In Delphi method, the researchers need expert judgements from experts from relevant fields which is in this case are about CE and LCDI. Therefore, the researchers distributed the questionnaire to CE and LCDI experts. To determine which experts that will be contacted, the researchers assessed their qualification by their activities in CE and LCDI events in Indonesia. A person will be considered to be an expert if she or he has ever been a speaker in a seminar or talk-show about CE and LCDI or have publication(s) about CE and LCDI. This searching process was conducted using Google, Youtube, and LinkedIn searches as well as researchers' professional networks. To assure that the experts represented all points of view on CE and LCDI, we made sure that there were representatives of experts from:

- 1) Government bodies
- 2) Academics
- 3) Business sectors
- 4) NGO and international institutions

After the researchers determined the list of the expert candidates to be invited to fill our questionnaire, the researchers searched their contact(s) such as e-mail or phone number from their LinkedIn, Google Scholar, or available publication. Then, the researchers re-evaluated each candidates' background to make sure that they were the right people to fill the questionnaire. Finally, after conducted a discussion and finalized the expert candidates list, the researchers distributed the questionnaire via e-mail, WhatsApp, or LinkedIn with the cover letter from UNDP as an attachment.

3.4 Survey Data Collection

The data collection process is classified into two stages, namely the construction of the online questionnaire and the questionnaire distribution. The questionnaire was made to assess the importance of the criteria and indicators regarding to CE and LCDI. The questionnaire was created on Google Form since the data collection process would be conducted online. The questionnaire was consisted of five sections, namely:

- 1) **Introduction:** brief description of the research;
- 2) **Personal data of respondents:** questions about the name, job position, and the length of time the expert worked on the job position;

- 3) **The assessment of the criteria and indicators:** uses the final criteria and indicators from the criteria and indicators selection process with five-scale of importance, namely *very unimportant* (1), *unimportant* (2), *moderately important* (3), *important* (4), and *very important* (5);
- 4) **The suggestion of criteria and indicator** which has not been included in questionnaire;
- 5) **Closing:** the appreciation notes for the participation in the study.

After the online questionnaire has been constructed, the next process was to gather the data by distributing the questionnaire to the selected respondents. The distributions were conducted by multiple approaches; such as by e-mail, WhatsApp, and LinkedIn; regarding to the available contact of the expert. There are 44 experts that can be contacted. The list of these experts is provided in Appendix 2: List of Experts Invited in the Survey.

The link of the online questionnaire was distributed from November, 26th 2021. After 19 days of distribution (November, 26th – December, 17th 2021), including a reminder message, there were 27 responses received. Hence the response rate is 61 per cent, which is a very good response rate since more than half of the respondents responded. Table 3 shows the distribution of the experts' responses. The distribution of the respondents leans to think-tank/international organization and academia. Of the 27 responses, only 24 responses are further processed. Responses which are too uniform and not complete are excluded for further analyses. Hence, the final ratio of processed responses compared to the number of experts contacted is 55 per cent.

Table 3 Distribution of respondents

Category	Number of Respondents
Academia	9
Industry	4
Government	3
Think Tank / International Organization	11
Grand Total	27

3.5 Survey Data Analysis

3.5.1 Data Analysis Using Grey Clustering Methodology

From literature study and preliminary evaluation, it has been identified 8 criteria and 42 indicators that potentially can be used for evaluating sub-sectors of food and beverage sector. Grey Delphi method is an application of grey system theory mixed with Delphi's method which uses the grey whitening weight function to evaluate and select indicators from a long-list indicators into short-listed indicators (Ma et al., 2011). The grey-Delphi method has advantages on ensuring accuracy with less and limited data or information. Specifically, this research uses the variable weight grey clustering. The steps on data analysis with grey clustering to short-list criteria and indicators is described below (Liu et al., 2016; Ma et al., 2011).

- **Step 1: Determine the possibility function and the turning point.**

First, we need to decide which possibility function and the turning points that construct it. There are 4 types of possibility function in the variable weight grey clustering method as listed on Table 4. In this step, we also need to determine the k grey class.

- **Step 2: Transform the questionnaire result to the possibility function and calculate the weight of the criterions.**

The questionnaire result will be translated into the possibility function. Next, the basic value will be calculated to determine the weight of indicator j th on each k grey class. The transformation of questionnaire result and basic value calculation can follow the formula on Table 5. The weight calculation of the j th criterion of the k th subclass follows the equation below.

$$\eta_j^k = \lambda_j^k / \sum_{j=1}^m \lambda_j^k$$

- **Step 3: Calculate clustering coefficient.**

The next step is calculating the clustering coefficient for j th criterion of each the k th subclass.

$$\sigma_j^k = \sum_{i=1}^m f_{i,j}^k(x) \eta_j^i$$

- **Step 4: Analyze the decision vector.**

The decision vector is analyzed with determine the maximum value of the clustering coefficient for each criterion. Then, find the k th class where the maximum value belongs to. If the maximum value belongs to 4th or 5th class (in case of 5 subclass), the criterion should be retained. However, if it belongs to 1st, 2nd, or 3rd class, it should be deleted since it's not important.

$$\max_{1 \leq k \leq s} \{\sigma_j^k\} = \sigma_j^{k^*}$$

Table 4 Type of possibility function

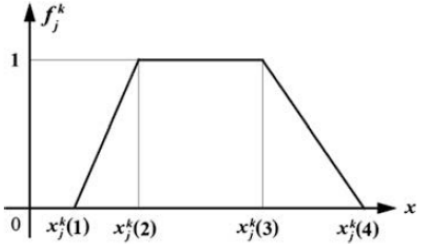
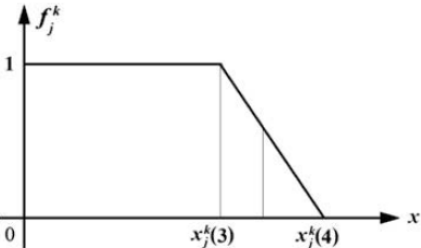
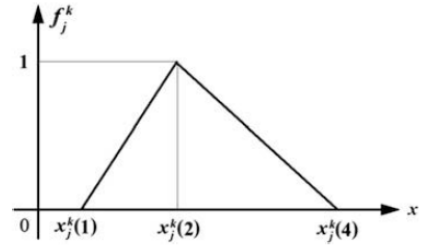
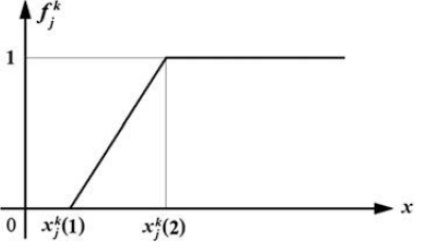
Probability Function	Basic figure	Notation
Typical form		$f_j^k [x_j^k (1), x_j^k (2), x_j^k (3), x_j^k (4)]$
Lower measure		$f_j^k [- , - , x_j^k (3), x_j^k (4)]$
Moderate measure		$f_j^k [x_j^k (1), x_j^k (2), - , x_j^k (4)]$
Upper measure		$f_j^k [x_j^k (1), x_j^k (2), - , -]$

Table 5 Possibility function and basic value formula

Type	Probability Function	Basic value
Typical form	$f_j^k(x) = \begin{cases} 0 & x \notin [x_j^k(1), x_j^k(4)] \\ \frac{x - x_j^k(1)}{x_j^k(2) - x_j^k(1)} & x \in [x_j^k(1), x_j^k(2)] \\ 1 & x \in [x_j^k(2), x_j^k(3)] \\ \frac{x_j^k(4) - x}{x_j^k(4) - x_j^k(3)} & x \in [x_j^k(3), x_j^k(4)] \end{cases}$	$\lambda_j^k = \frac{1}{2}([x_j^k(2) + x_j^k(3)])$
Lower measure	$f_j^k(x) = \begin{cases} 0 & x \notin [0, x_j^k(4)] \\ 1 & x \in [0, x_j^k(3)] \\ \frac{x_j^k(4) - x}{x_j^k(4) - x_j^k(3)} & x \in [x_j^k(3), x_j^k(4)] \end{cases}$	$\lambda_j^k = x_j^k(3)$

Moderate measure	$f_j^k(x) = \begin{cases} 0 & x \notin [x_j^k(1), x_j^k(4)] \\ \frac{x-x_j^k(1)}{x_j^k(2)-x_j^k(1)} & x \in [x_j^k(1), x_j^k(2)] \\ \frac{x_j^k(4)-x}{x_j^k(4)-x_j^k(3)} & x \in [x_j^k(2), x_j^k(4)] \end{cases}$	$\lambda_j^k = x_j^k(2)$
Upper measure	$f_j^k(x) = \begin{cases} 0 & x < x_j^k(1) \\ \frac{x-x_j^k(1)}{x_j^k(2)-x_j^k(1)} & x \in [x_j^k(1), x_j^k(2)] \\ 1 & x \geq x_j^k(2) \end{cases}$	$\lambda_j^k = x_j^k(2)$

To begin the processing data, the researchers need to determine the grey classes that will be used. Table 6 shows the grey classes with the probability function and the turning point that will be used in this research.

Table 6 Grey classes

Grey Classes	Probability Function	Basic value
k=1 (Lower measure)	$f_j^1(x) = \begin{cases} 0 & x \notin [0, 5] \\ 1 & x \in [0, 4] \\ 5 - xx & x \in [4, 5] \end{cases}$	$\lambda_j^1 = 4$
k=2 (Moderate measure)	$f_j^2(x) = \begin{cases} 0 & x \notin [2, 4.5] \\ \frac{x-2}{2} & x \in [2, 4] \\ \frac{4.5-x}{4.5} & x \in [4, 4.5] \end{cases}$	$\lambda_j^2 = 4$
k=3 (Typical form)	$f_j^3(x) = \begin{cases} 0 & x \notin [4, 5] \\ 4x - 8 & x \in [4, 4.25] \\ 1 & x \in [4.75, 5] \\ 20 - 4x & x \in [4.75, 5] \end{cases}$	$\lambda_j^3 = 4.5$
k=4 (Moderate measure)	$f_j^4(x) = \begin{cases} 0 & x \notin [4.5, 5] \\ 4x - 18 & x \in [4.5, 4.75] \\ 1 - \frac{x}{5} & x \in [4.75, 5] \end{cases}$	$\lambda_j^4 = 4.75$
k=5 (Upper measure)	$f_j^5(x) = \begin{cases} 0 & x < 4.5 \\ 2x - 9 & x \in [4.5, 5] \\ 1 & x \geq 5 \end{cases}$	$\lambda_j^5 = 5$

Based on Table 6, we need to determine the weight of each criterion and subclasses. Table 7 shows the weight value of each criterion and subclasses.

Table 7 The weight value of each criterion and subclasses.

Grey Classes	Basic Value	Weight
k=1	$\lambda_j^1 = 4$	$\eta_j^1 = 0.18$
k=2	$\lambda_j^2 = 4$	$\eta_j^2 = 0.18$
k=3	$\lambda_j^3 = 4.5$	$\eta_j^3 = 0.20$
k=4	$\lambda_j^4 = 4.75$	$\eta_j^4 = 0.21$
k=5	$\lambda_j^5 = 5$	$\eta_j^4 = 0.22$

After determine the grey classes and with the calculation of weight value, now clustering coefficient will be calculated based on step 3 formula and will be determine which criteria and indicators will be retained or deleted. Table 9 is the summary of clustering coefficient and the decision of each criterion. Based on grey-delphi methods, 10 indicators will be deleted and

30 indicators will be retained. For assessment criterion, all criterion will be retained. Table 8 is the list for deleted indicators.

Table 8 Deleted indicators

Notation	Deleted Indicators
X1	Economy [Economic annual average growth rate of sub-sector added value]
X3	Economy [Research and development input value in the sub-sector]
X4	Economy [Gross sub-sector output value per unit of land]
X6	Social [Social intangible benefit potential]
X8	Social [Potential to increase women employment rate]
X17	Energy System[Current natural gas consumption]
X22	Environmental System [PM10 (particulate matter in the air with a diameter of 10 micrometers or less) emission annual average concentration]
X25	Environmental System [Sewage treatment rate]
X26	Environmental System [The COD (chemical oxygen demand) emissions of per unit of industrial added value]
X42	Stakeholder Involvement [Potential of international support]

Table 9a Grey-Delphi results for Indicators

Notation	Description	σ_1^j	σ_2^j	σ_3^j	σ_4^j	σ_5^j	Max σ_j^k	Decision
X1	Economy [Economic annual average growth rate of sub-sector added value]	3,24	2,61	0,00	0,00	2,02	1	Deleted
X2	Economy [Potential to increase employment]	2,52	2,34	0,00	0,00	2,92	5	Retained
X3	Economy [Research and development input value in the sub-sector]	3,96	3,24	0,00	0,00	1,12	1	Deleted
X4	Economy [Gross sub-sector output value per unit of land]	3,42	2,52	0,00	0,00	1,80	1	Deleted
X5	Social [Potential to educate or to increase awareness on environment issues]	1,80	1,71	0,00	0,00	3,82	5	Retained
X6	Social [Social intangible benefit potential]	2,88	2,34	0,00	0,00	2,47	1	Deleted
X7	Social [Potential to reduce poverty]	2,16	2,07	0,00	0,00	3,37	5	Retained
X8	Social [Potential to increase women employment rate]	3,42	2,79	0,00	0,00	1,80	1	Deleted
X9	Social [Potential to increase household saving]	2,70	1,89	0,00	0,00	2,70	5	Retained
X10	Circularity Potential [Industrial water recycling rate]	1,44	1,35	0,00	0,00	4,27	5	Retained
X11	Circularity Potential [Reclaimed water reuse rate]	2,70	2,70	0,00	0,00	2,70	5	Retained
X12	Circularity Potential [Recycling rate of industrial solid waste]	1,62	1,53	0,00	0,00	4,04	5	Retained
X13	Circularity Potential [Repeated utilization ratio of raw material]	2,16	2,16	0,00	0,00	3,37	5	Retained
X14	Circularity Potential [Energy recycling rate]	1,44	1,35	0,00	0,00	4,27	5	Retained
X15	Circularity Potential [The substitution of raw material source with recycled material]	1,44	1,35	0,00	0,00	4,27	5	Retained
X16	Energy System[Current coal consumption]	2,52	1,89	0,00	0,00	2,92	5	Retained
X17	Energy System[Current natural gas consumption]	2,88	2,07	0,00	0,00	2,47	1	Deleted
X18	Energy System[Current power consumption]	2,34	2,16	0,00	0,00	3,15	5	Retained
X19	Energy System[Potential power consumption reduction rate per unit sub-sector output]	2,34	2,25	0,00	0,00	3,15	5	Retained
X20	Energy System[Potential energy consumption reduction rate per unit sub-sector output]	2,34	2,34	0,00	0,00	3,15	5	Retained
X21	Energy System[Potential use of renewable energy sources]	1,98	1,80	0,00	0,00	3,60	5	Retained
X22	Environmental System [PM10 (particulate matter in the air with a diameter of 10 micrometers or less) emission annual average concentration]	3,42	2,97	0,00	0,00	1,80	1	Deleted
X23	Environmental System [Potential industrial sulfur dioxide emissions reduction]	2,52	2,25	0,00	0,00	2,92	5	Retained
X24	Environmental System [Potential industrial wastewater discharged reduction]	2,34	2,25	0,00	0,00	3,15	5	Retained
X25	Environmental System [Sewage treatment rate]	3,06	2,88	0,00	0,00	2,25	1	Deleted
X26	Environmental System [The COD (chemical oxygen demand) emissions of per unit of industrial added value]	3,60	3,24	0,00	0,00	1,57	1	Deleted
X27	Environmental System [The solid waste emissions of per unit of industrial added value]	2,70	2,52	0,00	0,00	2,70	5	Retained
X28	Environmental System [Potential hazardous waste disposal reduction]	1,80	1,71	0,00	0,00	3,82	5	Retained
X29	Environmental System [Potential harmless disposal rate of garbage reduction]	2,52	2,16	0,00	0,00	2,92	5	Retained

Notation	Description	σ_j^1	σ_j^2	σ_j^3	σ_j^4	σ_j^5	Max σ_j^k	Decision
X30	Environmental System [Waste treatment facilities]	2,16	2,16	0,00	0,00	3,37	5	Retained
X31	Environmental System [Potential toxic and hazardous waste emissions reduction]	1,80	1,80	0,00	0,00	3,82	5	Retained
X32	Environmental System [Fresh water consumption per unit of industrial added value]	2,16	2,07	0,00	0,00	3,37	5	Retained
X33	Low Carbon Initiatives [Potential carbon dioxide emission reduction]	2,16	2,07	0,00	0,00	3,37	5	Retained
X34	Low Carbon Initiatives [Potential other GHG emission reduction]	1,80	1,53	0,00	0,00	3,82	5	Retained
X35	Low Carbon Initiatives [Potential to capture carbon emission/to absorb carbon]	2,34	2,07	0,00	0,00	3,15	5	Retained
X36	Investment or outlays needed to promote CE & LCDI [Investment or outlays needed on fixed assets related to environmental protection]	2,16	1,71	0,00	0,00	3,37	5	Retained
X37	Investment or outlays needed to promote CE & LCDI [Investment or outlays needed on fixed assets related to energy saving]	2,16	2,07	0,00	0,00	3,37	5	Retained
X38	Investment or outlays needed to promote CE & LCDI [Investment or outlays needed in pollutant reduction systems]	2,34	2,16	0,00	0,00	3,15	5	Retained
X39	Investment or outlays needed to promote CE & LCDI [Investment or outlays needed related to carbon reducing system]	1,98	1,71	0,00	0,00	3,60	5	Retained
X40	Stakeholder Involvement [Government priority]	1,26	1,08	0,00	0,00	4,49	5	Retained
X41	Stakeholder Involvement [Potential of private sector involvement]	0,90	0,90	0,00	0,00	4,94	5	Retained
X42	Stakeholder Involvement [Potential of international support]	2,88	2,61	0,00	0,00	2,47	1	Deleted

Table 10b Grey-Delphi results for Criteria

Notation	Description	σ_j^1	σ_j^2	σ_j^3	σ_j^4	σ_j^5	Max σ_j^k	Decision
X43	Criterion: Economy	2,34	2,07	0,00	0,00	3,15	5	Retained
X44	Criterion: Social	1,98	1,89	0,00	0,00	3,60	5	Retained
X45	Criterion: Circularity Potential	2,16	2,16	0,00	0,00	3,37	5	Retained
X46	Criterion: Energy System	1,98	1,98	0,00	0,00	3,60	5	Retained
X47	Criterion: Environmental System	1,98	1,98	0,00	0,00	3,60	5	Retained
X48	Criterion: Low Carbon Initiatives	2,16	1,98	0,00	0,00	3,37	5	Retained
X49	Criterion: Investment or outlays needed to promote CE & LCDI	2,70	2,43	0,00	0,00	2,70	5	Retained
X50	Criterion: Stakeholder Involvement	2,52	2,34	0,00	0,00	2,92	5	Retained

3.5.2 Data Analysis Using Simple Group Uniform Weight Indicator Importance

Up to this point, the initial 88 indicators has been reduced into 32 indicators using grey clustering method. This method resulted with 32 indicators from 42 indicators retained since they were deemed important or very important, according grey clusters of indicators importance. Because the number of retained indicators is still too large and infeasible for the next QA study stage of sub-sector scoring process, then the 32 indicators are ranked based on their average importance scores.

The average importance score for each indicator is obtained by averaging importance scores given by the respondents. First, the responses are grouped based on the respondent groups, namely academia, government, industry, and think-tank/international organization. Second, the responses in each group are averaged, resulted in group averages. Third, group averages are then averaged again to come up with a grand average as the final indicator importance. Here, each group is given the same weight, regardless the number of experts in each group. The list of final indicator importance scores is given in Appendix 3: Indicators Importance Score.

There are two aspects considered in selecting final indicators:

- Each criterion should be represented by final indicators; and
- The number of indicators should be small enough (not more than 20).

Based on the considerations above it is then decided to select top two indicators in each criterion. Exception by letting three indicators is given to criteria that their top 3 indicators are still ranked higher than rank 10 in total rank of indicators. Table 11-18 below shows the ranking (criterion rank and overall rank) for each indicator in each criterion.

1) Criterion: Economy

Table 11 Indicators ranking (Criterion: Economy)

No	Indicator	Criterion Rank	Overall Rank
1	Economic annual average growth rate of sub-sector added value	2	27
2	Potential to increase employment	1	18
3	Research and development input value in the sub-sector	4	41
4	Gross sub-sector output value per unit of land	3	38

Although the second most important indicator in this criterion has a quite low rank in overall rank (below median), and considering economic added growth is closely related to GDP, then this indicator is included in the final indicator list.

2) Criterion: Social

Table 12 Indicators ranking (Criterion: Social)

No	Indicator	Criterion Rank	Overall Rank
1	Potential to educate or to increase awareness on environment issues	2	8
2	Social intangible benefit potential	3	36
3	Potential to reduce poverty	1	20
4	Potential to increase women employment rate	5	42
5	Potential to increase household saving	4	40

The two highest ranked indicators are very relevant, and the rest of indicators have very low overall rank. In addition, potential to increase women employment rate and potential in increase household saving can be reflected by potential to reduce poverty.

3) Criterion: Circularity

Table 13 Indicators ranking (Criterion: Circularity)

No	Indicator	Criterion Rank	Overall Rank
1	Industrial water recycling rate	2.5	4
2	Reclaimed water reuse rate	6	24
3	Recycling rate of industrial solid waste	4	7
4	Repeated utilization ratio of raw material	5	11
5	Energy recycling rate	1	1
6	The substitution of raw material source with recycled material	2.5	3

This criterion has very highly ranked indicators. The first four highest ranked indicators even are ranked in the top ten of overall rank. However, to keep the number of indicators for each criterion more balanced, the recycling rate of industrial solid waste is dropped. This indicator to some extent can be reflected also by Indicator 6: the substitution of raw material sources with recycled material.

4) Criterion: Energy System

Table 14 Indicators ranking (Criterion: Energy System)

No	Indicator	Criterion Rank	Overall Rank
1	Current coal consumption	5	33
2	Current natural gas consumption	6	35
3	Current power consumption	4	22
4	Potential power consumption reduction rate per unit sub-sector output	2	16
5	Potential energy consumption reduction rate per unit sub-sector output	1	13
6	Potential use of renewable energy sources	3	19

The indicator of potential use of renewable energy sources is included although it is ranked number 3 because the importance is still higher than the median and using the other more highly ranked indicators still cannot provide complete situation.

5) Criterion: Environmental System

Table 15 Indicators ranking (Criterion: Environmental System)

No	Indicator	Criterion Rank	Overall Rank
1	PM10 emission annual average concentration	11	39
2	Potential industrial sulfur dioxide emission sreduction	8	32
3	Potential industrial waste water discharged reduction	5	25
4	Sewage treatment rate	9	34
5	The COD emissions of per unit of industrial added value	10	37
6	The solid waste emissions of per unit of industrial added value	6	28
7	Potentially hazardous waste disposal reduction	3	14
8	Potential harmless disposal rate of garbage reduction	7	29
9	Waste treatment facilities	2	10
10	Potential toxic and hazardous waste emissions reduction	1	5
11	Fresh water consumption per unit of industrial added value	4	23

Although this criterion has the most potential indicators, only two indicators: waste treatment facilities and potential toxic and hazardous waste emission reduction have overall rank in the top ten. Additionally, the third rank indicator, potentially hazardous waste disposal reduction is closely related to potential toxic and hazardous waste emission reduction.

6) Criterion: Low Carbon Initiatives

Table 16 Indicators ranking (Criterion: Low Carbon Initiatives)

No	Indicator	Criterion Rank	Overall Rank
1	Potential carbondioxide emission reduction	1	9
2	Potential other GHG emission reduction	2	12
3	Potential to capture carbon emission/to absorb carbon	3	21

The third ranked indicator, potential to capture carbon emission is quite significantly lower in importance than the second ranked indicator. Moreover, in near future, the carbon capture technology is still not mature and costly as well as is still difficult to be implemented in Indonesia especially for SME.

7) Criterion: Investment or Outlays Needed

Table 17 Indicators ranking (Criterion: Investment or Outlays Needed)

No	Indicator	Criterion Rank	Overall Rank
1	Investment or outlays needed on fixed assets related to environmental protection	3	26
2	Investment or outlays needed on fixed assets related to energy saving	1	6
3	Investment or outlays needed in pollutant reduction systems	4	30
4	Investment or outlays needed related to carbon reducing system	2	15

The third and fourth ranked indicators have low importance score, hence only the top two are retained.

8) Criterion: Stakeholder Involvement

Table 18 Indicators ranking (Criterion: Stakeholder Involvement)

No	Indicator	Criterion Rank	Overall Rank
1	Government priority	2	17
2	Potential of private sector involvement	1	2
3	Potential of international support	3	31

The third ranked indicator has a low importance score. It also may reflect the thoughts of the experts the initiatives should not be dependent on international support.

Based on evaluation on each criterion indicators ranking, Table 19 sums up the short-listed indicators.

Table 19 Short-listed indicators

Criterion	Indicator	Numbering
Economy	Economic annual average growth rate of sub-sector added value	1
	Potential to increase employment	2
Social	Potential to educate or to increase awareness on environment issues	3
	Potential to reduce poverty	4
Circularity	Industrial water recycling rate	5
	Energy recycling rate	6
	The substitution of raw material source with recycled material	7
Energy System	Potential power consumption reduction rate per unit sub-sector output	8
	Potential energy consumption reduction rate per unit sub-sector output	9
	Potential use of renewable energy sources	10
Environment System	Waste treatment facilities	11

Criterion	Indicator	Numbering
	Potential toxic and hazardous waste emissions reduction	12
Low Carbon Development	Potential carbon dioxide emission reduction	13
	Potential other GHG emission reduction	14
Investment or Outlays Needed	Investment or outlays needed on fixed assets related to energy saving	15
	Investment or outlays needed related to carbon reducing system	16
Stakeholder Involvement	Government priority	17
	Potential of private sector involvement	18

3.6 Final Indicators

Based on further focus group discussion with representatives from Ministry of Industry and Bappenas, the number of indicators in the short list are still considered too large and expected to be reduced further under 10 indicators. Hence, further selection process is conducted using two considerations: (i) the indicators can be evaluated based on data and not subjective judgment, i.e., based on quantitative data (ii) the indicators that can be related to other indicators can be represented by the other indicator(s).

The result of final indicators is presented in Table 20 and the eliminated indicators from final indicators is presented in Table 21.

Table 20 List of final indicators

No	Indicator	Data / Proxy Data	Potential Data Source
1	Economic annual average growth rate of sub-sector added value	GDP/value added	BPS/SIINAS
2	Potential to increase employment	Number of employees	BPS/SIINAS
3	Industrial water recycling rate	Water consumption	BPS/SIINAS
4	Potential energy consumption reduction rate per unit sub-sector output	Energy consumption	BPS/SIINAS
5	Potential power consumption reduction rate per unit sub-sector output	Power consumption	BPS/SIINAS
6	Waste treatment facilities	Number of Waste Facility	BPS/SIINAS
7	Potential toxic and hazardous waste emissions reduction	Toxic emission (B3)	Estimated from Energy/Power Consumption
8	Potential carbon dioxide emission reduction	CO2 emission	Estimated from Energy/Power Consumption
9	Potential other GHG emission reduction	Other GHG emission	Estimated from Energy/Power Consumption

Table 21 Excluded short-listed indicators from the final indicators

No.	Indicator	Remark	Consideration/assumption
1	Potential to educate or to increase awareness on environment issues	Qualitative	Need subjective expert judgment
2	Potential to reduce poverty	Related to GDP and employment	The higher GDP and number of employments the higher the potential to reduce poverty
3	Energy recycling rate	Related to energy consumption	The higher current energy consumption the higher potential to recycle energy
4	The substitution of raw material source with recycled material	Qualitative/expert	Need expert judgment to identify raw material related to food and beverage to be recycled
5	Potential use of renewable energy sources	Related to energy consumption	The higher current energy consumption the higher potential to use renewables
6	Investment or outlays needed on fixed assets related to energy saving	Related to energy consumption	The higher current energy consumption the higher investment needed
7	Investment or outlays needed related to carbon reducing system	Related to CO2 emission	The higher CO2 emission the higher investment needed
8	Government priority	Qualitative	Need subjective expert judgment
9	Potential of private sector involvement	Qualitative	Need subjective expert judgment

4. Data of Indicators Collection for F&B Sub-Sectors

After the indicators are finalized, the next stage of this study is the data collection of these indicators for all food and beverage sub-sectors. Based on Klasifikasi Baku Lapangan Industri (Standard Classification of Industry Sectors) or KBLI, there are 38 four-digits sub-sector classifications of the food and beverage sector.

This data collection and processing stage consists of three steps:

- **Step 1:** Data collection from BPS and from SIINAS, Ministry of Industry
- **Step 2:** Data assessment and selection
- **Step 3:** Data preprocessing: data imputation and indicator estimation (proxies calculation)

4.1 Data Collection from BPS and from SIINAS Ministry of Industry

There are two main data sources that can be used to make prioritization of the food and beverage subsectors. The first data source is BPS (Badan Pusat Statistik or Statistics Indonesia) and the second data source is Indonesian Ministry of Industry's database (SIINAS or Sistem Informasi Industri Nasional). The availability of the data from these two sources is presented in Table 22.

Table 22 Data availability comparison

Indicators	Data (Proxy)	BPS	SIINAS
Economic annual average growth rate of sub-sector added value	GDP (value-added)	available	not available
Potential to increase employment	Number of employees	available	available
Industrial water recycling rate	Water consumption	not available	available
Energy recycling rate	Energy consumption	available	available
Potential power consumption reduction rate per unit sub-sector output	Power consumption	available	available
Waste treatment facilities	Volume	not available	estimated
Potential toxic and hazardous waste emissions reduction	Toxic emission (B3)	estimated	estimated
Potential carbon dioxide emission reduction	CO2 emission	estimated	estimated
Potential other GHG emission reduction	Other GHG emission	estimated	estimated

Specifically, data available from BPS are the number of establishment (unit); production workers (people); total generated and purchased electricity (kWh); fuel and lubricant used, namely gasoline (litre), diesel fuel (litre), coal (kg), coal briquettes (kg), gas (m³), LPG (litre), and lubricant oil (litre); and value added at factor cost (Rp). Data from SIINAS available are The Indonesia Ministry of Industry's database (SIINAS) is used to complete the information provided by BPS. The information extracted from the Indonesian Ministry of Industry are number of workers, electricity consumed (kWh), energy consumed (gasoline, solar, coal, gas, lpg), lubricants, water consumption (m³), toxic byproduct, and liquid waste production (m³).

Both data from BPS and SIINAS are based on sampling. Published data from BPS is already presented as estimates for national level. However, data from SIINAS is only averages of data from companies sampled. Hence, we multiple the averages from sampled SIINAS data with the number of companies in Indonesia from BPS to result in national estimates based on SIINAS data. Next, we compare and assess data from both sources.

4.2 Data Assessment and Selection

Our assesment on data available from BPS and SIINAS showed that none of both sources provide complete indicators data. Furthermore, each BPS and SIINAS data are based on survey with different companies sampled. This results in discrepancies on some indicators data which available on both BPS and SIINAS. Tabel xxx show examples of these discrepancies on on Solar Fuel Consumption (in liter) data.

Table 23 Example of Discrepancies on Solar Fuel Consumption (in liter) based on BPS and SIINAS Data

KLBI	BPS	SIINAS*	Dicrepancy	Discrepancy Percentage
1013	628.611	1.523.928	895.317	142%
1021	21.806.496	28.226.680	6.420.184	29%
1022	1.910.762	6.685.872	4.775.110	250%
1029	4.167.612	2.320.992	1.846.620	44%
1041	650.797	8.746.700	8.095.903	1244%
1042	10.186.372	2.555.787	7.630.585	75%
1043	229.096.872	717.057.673	487.960.801	213%
1051	1.218.882	1.752.911	534.029	44%

Another issue is that not all indicators can be determined directly from the available data. For example, there is no carbon dioxide or other greenhouse gases emissions recorded by BPS and SIINAS. However, this issue can be solved by calculating the emissions using consumption of each fuel type with a constant, representing the amount of emission per unit fuel type, from the literature. We will explain this process in detail in the next subsection.

Finally, there is missing values issue. There are many missing data in some variables. The problem with missing values is they can make the analysis bias, especially in this study we use VIKOR methodology which using relative score. If each missing value for subsectors is replaced by zero, it can severely affect the VIKOR score for the subsector and bias the result if in reality the missing value has a value significantly higher than zero. Hence, we can not replace the missing values directly with zero. Instead, we need to impute the missing values with some values. These imputed values can be determined using two approaches: (i) imputation using minimum values (ii) imputation using average values from other subsectors whose data on this indicator are not missing. However, these two methods can result in significantly different numbers. So, it needs to be simulated the effect of Sthese two different imputation methods on final selection of subsectors. Furthermore, since BPS and SIINAS data shows significant discrepancies, the imputation process should use values from the same source of data (no cross source of data imputation process).

4.3 Data Preprocessing

The data collected from Manufacturing Statistics Indonesia (BPS) and Indonesian Ministry of Industry still contain some blank data. Data from BPS although does not contain missing value for most cases, they still contain several missing values, especially for the fuel and power consumption data. In addition, there is around 32% missing value for water consumption and water treatment capacity (liquid waste production) indicator from provided data by Indonesian Ministry of Industry. The blank data or missing value can cause the bias on the result of data processing/analysis and will lead to invalid conclusions or policy. To prevent the bias, we conduct imputation method to fill the missing value with average and minimum value.

Equation (1) is the formula to do the imputation value based on average value. For example, based on Equation (1), found that the average of 25 sectors was 5,073,484 m³ for water consumption and 48,280 m³ for water treatment capacity. Based on this average value, imputation value is implemented for other 13 sectors that the data are not available.

$$\text{Average of 25 Sectors} = \frac{\sum_{i=1}^{25} x_i}{25} \quad (1)$$

Equation (2) is the formula to do the imputation value based on minimum value. For example, based on Equation (2), found that the minimum value of 25 sectors was 1,020 m³ for water consumption and 30 m³ for water treatment capacity. Based on this minimum value, imputation value is implemented for other 13 sectors that the data are not available.

$$\text{Minimum Value of 25 Sectors} = \text{Min} (x_1, x_2, \dots, x_{26}, x_{25}) \quad (2)$$

Beside of missing value, neither BPS nor Indonesian Ministry of Indonesia provide data on energy consumption, potential toxic emissions, GHG, and water facilities. We conduct with some approaches to be able to get that information.

The energy consumption number is generated by this formula on Equation (3). The energy consumption is calculated by multiplying the energy generated fraction with the number of the fuel and lubricant used by each subsector.

$$\begin{aligned} \text{Energy consumption (MJ)} &= [\text{Benzene} \times 31.54] + [\text{Diesel fuel} \times 38] \\ &+ [(\text{Coal} + \text{Coal briquettes}) \times 29.3] + [\text{Gas} \times 38,18] \\ &+ [\text{LPG} \times 25] \end{aligned} \quad (3)$$

The potential toxic emission reduction number is generated by this formula on Equation (4). The potential toxic emission reduction is calculated by multiplying the toxic emission generated fraction with the number of coals, coal briquettes, and lubricant used by each subsector.

$$\begin{aligned} \text{Toxic emission (ton)} \\ &= [(\text{Coal} + \text{Coal briquettes}) \times 0.07147] \\ &+ [\text{Lubricant} \times 0.000825] \end{aligned} \quad (4)$$

The CO₂ emission will be approached by calculating the conversion from resources such as benzene, diesel fuel, coal, coal briquettes, gas, LPG, and Lubricant to CO₂ in gram. All the conversion coefficients can be seen in Appendix 1. This following equation is the formula to calculate CO₂ emission.

$$\begin{aligned} \text{CO}_2 \text{ emission gram} \\ &= (\text{Benzene} \times 2392) + (\text{Diesel fuel} \times 2640) + (\text{Coal} \times 2563) \\ &+ (\text{Coal briquettes} \times 2868) + (\text{Gas} \times 2459) + (\text{LPG} \times 1665) \\ &+ (\text{Lubricant} \times 2352) \end{aligned} \quad (5)$$

The greenhouse gas (GHG) mostly consists of CO₂, methane or CH₄, and NO₂. The potential toxic emission reduction number is generated by this formula, Equation (5), (6), and (7). The potential toxic emission reduction is calculated by multiplying the toxic emission generated fraction with the number of coals, coal briquettes, and lubricant used by each subsector.

$$\begin{aligned} \text{Methane emission gram} \\ &= \text{Benzene} \times 0.1004 + \text{Diesel fuel} \times 0.1506 + \text{Coal} \\ &+ \text{Coal briquettes} \times 0.2712 + \text{Gas} \times 0.0373 + \text{LPG} \times 0.0740 \\ &+ [\text{Lubricant} \times 0.1136] \end{aligned} \quad (6)$$

$$\begin{aligned} \text{NO}_2 \text{ emission gram} \\ &= \text{Benzene} \times 0.00003 + \text{Diesel fuel} \times 0.0571 + \text{Coal} \times 0.0397 \\ &+ \text{Coal briquettes} \times 0.0441 + \text{Gas} \times 0.0035 + \text{LPG} \times 0.0159 \\ &+ [\text{Lubricant} \times 0.0198] \end{aligned} \quad (7)$$

$$\text{Other GHG emission gram} = \text{Methane emission} + \text{NO}_2 \text{ emission} \quad (8)$$

The water facilities number will be approached by Indonesian Ministry of Indonesia data. Researcher received the number of water waste in inlet and outlet flow. Based on the received data, researcher will assume that water facilities number will equal to water waste in inlet flow. This assumption is supported because of water waste in inlet flow definition is the first phase for water to collected before got processed. The water facilities can be seen in equation (9).

$$\text{Water Facilities Number} = \text{Water Waste (Inlet Flow)} \quad (9)$$

5. Assessing and Ranking Sub-Sectors

From the previous stage we have already complete data for all indicators needed to assess each subsector potential for implementing CE and LCD. In this stage we will use VIKOR score to assess the relative benefit for each subsector. In doing so, we divide this stage into three steps:

- **Step 1:** Scenario development for scoring method and input
- **Step 2:** Scoring of each subsector based on each scenario
- **Step 3:** Ranking subsector and comparing the ranking results from each scenario

We will explain these steps in details in the following subsections.

5.1 Scenario development for scoring method and input

There are two main issues we consider when developing the scenarios. First, the differences between data from BPS and SIINAS as well as the imputation results. Second, the huge difference on some indicators between the subsectors.

For the first issue, we decided that for each indicator, we use only one source of data. The selection of the source is based on the completeness of the data, i.e. we chose the source which has more complete data. As for the imputation method, because it is not clear which method is better, we use both imputation method and set the imputation method as one factor in the scenario development, with two level: (1) minimum value imputation (2) average value imputation. In addition to this, we also use (3) ordinal score for ranking the alternative

For the second issue, based on the discussion with Ministry of Industry, we decided to make three scenarios of subsector groupings: (A) food subsectors only (B) beverage subsectors only (C) combination of food, beverage, and tobacco subsectors.

In summary, the scoring and ranking scenarios are based on two factors, each consisting of three levels as follows:

- **Factor 1: Grouping**
 - A: food subsectors only
 - B: beverage subsectors only
 - C: all subsectors
- **Factor 2: Method and data for scoring and ranking**
 - 1: VIKOR using minimum imputation
 - 2: VIKOR using average imputation
 - 3: simple ranking using ordinal data

5.2 Scoring and Ranking of Each Sub-Sector Based on Each Scenario

5.2.1 Scoring and Ranking Using VIKOR Method

VIKOR or multicriteria optimization and compromise solution (Opricovic and Tzeng, 2002) is an alternative selection that is carried out by considering the contradictions between criteria that require a compromise decision. In simply VIKOR principle is that the score assessment is relative between alternatives (sub-sectors).

There are three main reasons we used VIKOR methods:

- 1) There are many criteria/indicators in this research
- 2) Each indicator is measured with different units and magnitudes, so the assessment must be relative (numbers in tons cannot be compared with figures in rupiah)
- 3) There are only objective criteria considered so that it does not use fuzzy-VIKOR, as was planned at the beginning.

Figure 3 shows the steps to do the VIKOR methodology.

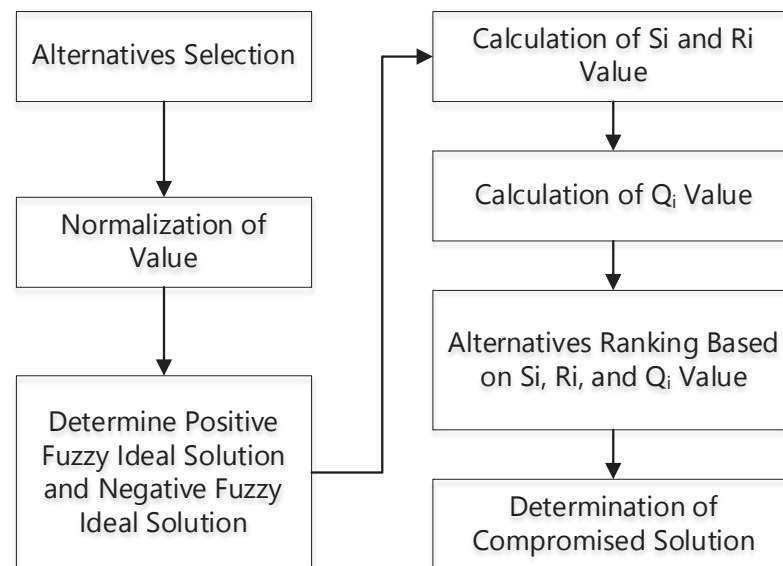


Figure 3 VIKOR methodology steps

1. Alternatives Selection

The decision alternative assessment is carried out by the decision maker on all alternatives on each criterion. The assessment of decision alternatives is summarized in an assessment matrix, called matrix A. An assessment matrix with a number of m decision alternatives (in our case this is the number of subsector in each scenario) and p decision criteria (in our case is the number of indicators) is as follows.

$$A = \begin{bmatrix} x_{11} & x_{12} & \dots & \tilde{x}_{1p} \\ x_{21} & x_{22} & \dots & \tilde{x}_{2p} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \dots & \tilde{x}_{mp} \end{bmatrix}$$

2. Normalization of Value

The second step is to normalize the assessment aggregation matrix. Normalization is done by using equation (10).

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^m a_{ij}} \quad (i = 1, 2, \dots, m; j = 1, 2, \dots, p) \quad (5)$$

3. Determine Positive Fuzzy Ideal Solution and Negative Fuzzy Ideal Solution

Determination of positive and negative ideal solutions are denoted by the notation B^+ and B^- . Equations (11) and (12) are calculations of B^+ and B^- .

$$B^+ = (b_j^+) = \{(\max_i b_{ij} | j \in J_1), (\min_i b_{ij} | j \in J_2)\} \quad (6)$$

$$B^- = (b_j^-) = \{(\min_i b_{ij} | j \in J_1), (\max_i b_{ij} | j \in J_2)\} \quad (7)$$

In our case we use positive ideal solution, since we argue that the bigger the value of the indicators the bigger its potential benefit. For example, the high current carbon dioxide emission means that the implementation of CE and LCD can potentially reduce much of the emissions. On the contrary, if one subsector is already has low emissions, it means that CE and LCD implementation can contribute little to the total reduction of CO2 emissions in Indonesia.

4. Calculation of S_i and R_i Value

Calculation of group benefit value index S_i and individual regret value R_i is done by using equations (13) and (14).

$$S_i = \sum_{j=1}^n w_j \cdot (f_j^* - f_{ij}) / (f_j^* - f_j^-) \quad (8)$$

$$R_i = \max (w_j \cdot (f_j^* - f_{ij}) / (f_j^* - f_j^-)) \quad (9)$$

Here w_j is weight for indicator j . We use the indicator importance from expert survey data for the weight of the indicator (see Appendix 3).

5. Calculation of Q_i Value

The utility value (Q_i) of each alternative is calculated using equation (15). Where $S^* = \min S_i$, $S^- = \max S_i$, $R^* = \min R_i$, $R^- = \max R_i$, dan $v = 0,5$ for retrieval decisions by consensus among decision makers (Opricovic & Tzeng, 2007; Devi, 2011). However, in this study we use $v=1$ in order to maximize the benefit from implementing CE and LCD on selected subsector(s).

$$Q_i = v \cdot \frac{(S_i - S^*)}{(S^- - S^*)} + (1 - v) \cdot (R_i - R^*) / (R^- - R^*) \quad (10)$$

6. Alternatives Ranking Based on S_i , R_i , and Q_i Value

Alternative rankings are made based on the value of the three indexes of S_i , R_i , and Q_i . The smaller the value, the higher the ranking of an alternative because it is closer to the positive ideal solution and far from the negative ideal solution (Opricovic et al, 2007; Devi, 2011).

5.2.2 Scoring and Ranking Results

During data processing, we conducted several scenarios to get the best result based on several alternative outcomes. The scenario is constructed based on the variety of method used, imputation method, and observed sector. There are three major scenarios in this study and each scenario will be divided into three sub scenarios according to the observed sector (only food, only beverage, or food and beverage).

1. Group of scenarios using minimum value imputation

The first scenario during data processing is conducted using VIKOR method, while the imputation of missing value is done with minimum value. One of steps on the VIKOR method is calculating weight importance of each indicator. During this research, the weight importance uses the value based on the importance of the indicator selection questionnaire result. The first scenario will be divided into three sub scenarios, namely Scenario A.1 (only food), B.1 (only beverage), and C.1 (food and beverage). The result of each sub scenario is explained below.

a. Scenario A.1

Scenario A.1 is scenario constructed for only food sector, using VIKOR method in data processing, and imputation by minimum value.

Table 24 List of prioritized subsectors based on Scenario A.1

Rank	KBLI Code	Sub sector	VIKOR Score
1	1043	Crude palm oil and palm cooking oil industry	<0,001
2	1071	Bread and cake industry	0,878
3	1077	Food seasoning and other cooking products industry	0,908
4	1080	Animal food industry	0,911
5	1042	Copra, coconut crude oil, coconut cooking oil, and coconut pellet industry	0,936
6	1079	Other food products industry	0,938
7	1072	Sugar industry	0,944
8	1021	Fish products processing and preservation industry	0,947
9	1074	Makaroni, noodle, and similar products industry	0,959
10	1061	Cereal and other grains milling industry (Exc. Rice and corn)	0,965

b. Scenario B.1

Scenario B.1 is scenario constructed for only beverage sector, using VIKOR method in data processing, and imputation by minimum value

Table 25 List of prioritized subsectors based on Scenario B.1

Rank	KBLI Code	Sub sector	VIKOR Score
1	1076	Coffee, tea, and herb (herb infusion) industry	<0,001
2	1105	Packaged water and refilled water industry	0,767
3	1052	Powdered milk and condensed milk processing industry	0,777
4	1073	Cacao, chocolate, and confectionery industry	0,815
5	1104	Soft drink industry	0,816

6	1051	Fresh milk and cream processing industry	0,862
7	1031	Fruit and vegetable processing & preservation with salting, drying, pulverizing, and freezing industry	0,929
8	1109	Other beverages industry	0,939
9	1053	Ice cream and similar products processing industry	0,948
10	1059	Other milk products processing industry	0,970

c. Scenario C.1

Scenario C.1 is scenario constructed for food and beverage sector, using VIKOR method in data processing, and imputation by minimum value

Table 26 List of prioritized subsectors based on Scenario C.1

Rank	KBLI Code	Sub sector	VIKOR Score
1	1043	Crude palm oil and palm cooking oil industry	<0,001
2	1071	Bread and cake industry	0,878
3	1201	Cigarette and other tobacco products industry	0,886
4	1077	Food seasoning and other cooking products industry	0,908
5	1076	Coffee, tea, and herb (herb infusion) industry	0,908
6	1080	Animal food industry	0,911
7	1042	Copra, coconut crude oil, coconut cooking oil, and coconut pellet industry	0,936
8	1079	Other food products industry	0,938
9	1072	Sugar industry	0,944
10	1021	Fish products processing and preservation industry	0,946

2. Group of scenarios using minimum value imputation

The second scenario during data processing is conducted using VIKOR method, while the imputation of missing value is done with average value. One of steps on the VIKOR method is calculating weight importance of each indicator. During this research, the weight importance uses the value based on the importance of the indicator selection questionnaire result. The second scenario will be divided into three sub scenarios, namely Scenario A.2 (only food), B.2 (only beverage), and C.2 (food and beverage). VIKOR method helps to make the order of prioritized sub sector with smaller VIKOR score will have higher rank (prioritize more). The result of each sub scenario is explained below.

a. Scenario A.2

Scenario A.2 is scenario constructed for only food sector, using VIKOR method in data processing, and imputation by average value.

Table 27 List of prioritized subsectors based on Scenario A.2

Rank	KBLI Code	Sub sector	VIKOR Score
1	1043	Crude palm oil and palm cooking oil industry	0,000
2	1071	Bread and cake industry	0,883
3	1077	Food seasoning and other cooking products industry	0,912

4	1080	Animal food industry	0,915
5	1042	Copra, coconut crude oil, coconut cooking oil, and coconut pellet industry	0,940
6	1079	Other food products industry	0,942
7	1072	Sugar industry	0,948
8	1021	Fish products processing and preservation industry	0,951
9	1074	Makaroni, noodle, and similar products industry	0,963
10	1061	Cereal and other grains milling industry (Exc. Rice and corn)	0,968

b. Scenario B.2

Scenario B.2 is scenario constructed for only food sector, using VIKOR method in data processing, and imputation by average value.

Table 28 List of prioritized subsectors based on Scenario B.2

Rank	KBLI Code	Sub sector	VIKOR Score
1	1104	Soft drink industry	0,310
2	1076	Coffee, tea, and herb (herb infusion) industry	0,437
3	1105	Packaged water and refilled water industry	0,443
4	1109	Other beverages industry	0,743
5	1031	Fruit and vegetable processing & preservation with salting, drying, pulverizing, and freezing industry	0,754
6	1052	Powdered milk and condensed milk processing industry	0,775
7	1073	Cacao, chocolate, and confectionery industry	0,830
8	1103	Alcoholic beverage from fermented malt industry and malt industry	0,845
9	1101	Alcoholic beverage from distillation industry	0,849
10	1033	Fruit and vegetable juices processing industry	0,870

c. Scenario C.2

Scenario C.2 is scenario constructed for only food sector, using VIKOR method in data processing, and imputation by average value.

Table 29 List of prioritized subsectors based on Scenario C.2

Rank	KBLI Code	Sub sector	VIKOR Score
1	1043	Crude palm oil and palm cooking oil industry	0,000
2	1071	Bread and cake industry	0,882
3	1201	Cigarette and other tobacco products industry	0,887
4	1077	Food seasoning and other cooking products industry	0,912
5	1076	Coffee, tea, and herb (herb infusion) industry	0,912
6	1080	Animal food industry	0,915
7	1042	Copra, coconut crude oil, coconut cooking oil, and coconut pellet industry	0,940
8	1079	Other food products industry	0,942
9	1105	Packaged water and refilled water industry	0,947
10	1072	Sugar industry	0,948

3. Group of Scenarios using Simple Indicator Ranking (Ordinal value)

In the third scenario, this research uses simple ranking based on value of each indicator multiple by the rank of each sector. The first step is to rank sectors in specific indicator, then after that multiple the rank number by value of related indicator in Table 2. In this method researchers using BPS data as the main reference and only using Ministry of Industry data for the calculation of "water consumption" and "water treatment facilities". If there is data that is still empty, then it is imputed with the average value of the indicator

Case example, if sector A rank is 2 from all sectors in Indicator 1 (Economic annual average growth rate of sub-sector added value) then the value for Indicator 1 for sector A is 4.354 multiple by 2 which equals to 8.708. This method is applied for all 9 indicators and then sums up at the end. The smaller the value, the subsector is more prioritized to selected.

Table 30 Value of Selected Indicators

No	Indicator	Value
1	Economic annual average growth rate of sub-sector added value	4.354
2	Potential to increase employment	3.792
3	Industrial water recycling rate	4.708
4	Potential energy consumption reduction rate per unitsub-sector output	4.813
5	Potential power consumption reduction rate per unitsub-sector output	4.438
6	Waste treatment facilities	4.563
7	Potential toxic and hazardous waste emissions reduction	4.542
8	Potential carbondioxide emission reduction	4.583
9	Potential other GHG emission reduction	4.563

The third scenario will be divided into three sub scenarios, namely Scenario A.3 (only food), B.3 (only beverage), and C.3 (food and beverage). The result of each sub scenario is explained below.

a. Scenario A.3

Scenario A.3 is scenario constructed for only food sector, using simple ranking method in data processing, and imputation by average value.

Table 31 List of prioritized subsectors based on Scenario A.3

Rank	KBLI Code	Sub sector	Score
1	1043	Crude palm oil and palm cooking oil industry	40,356
2	1071	Bread and cake industry	161,467
3	1077	Food seasoning and other cooking products industry	212,129
4	1072	Sugar industry	248,967
5	1079	Other food products industry	265,386
6	1080	Animal food industry	267,719
7	1021	Fish products processing and preservation industry	290,574
8	1042	Copra, coconut crude oil, coconut cooking oil, and coconut pellet industry	313,47
9	1074	Makaroni, noodle, and similar products industry	359,707
10	1061	Cereal and other grains milling industry (Exc. Rice and corn)	478,875

b. Scenario B.3

Scenario B.3 is scenario constructed for only beverage sector, using simple ranking method in data processing, and imputation by average value.

Table 32 List of prioritized subsectors based on Scenario B.3

Rank	KBLI Code	Sub sector	Score
1	1076	Coffee, tea, and herb (herb infusion) industry	113,916
2	1104	Soft drink industry	142,986
3	1105	Packaged water and refilled water industry	155,572
4	1052	Powdered milk and condensed milk processing industry	240,923
5	1051	Fresh milk and cream processing industry	262,924
6	1073	Cacao, chocolate, and confectionery industry	336,833
7	1053	Ice cream and similar products processing industry	343,323
8	1031	Fruit and vegetable processing & preservation with salting, drying, pulverizing, and freezing industry	364,978
9	1109	Other beverages industry	383,649
10	1101	Alcoholic beverage from distillation industry	395,312

c. Scenario C.3

Scenario C.3 is scenario constructed for both food and beverage sector, using simple ranking method in data processing, and imputation by average value.

Table 33 List of prioritized subsectors based on Scenario C.3

Rank	KBLI Code	Sub sector	Score
1	1043	Crude palm oil and palm cooking oil industry	40,356
2	1071	Bread and cake industry	210,449
3	1076	Coffee, tea, and herb (herb infusion) industry	323,565
4	1201	Cigarette and other tobacco products industry	354,898
5	1072	Sugar industry	359,759
6	1077	Food seasoning and other cooking products industry	367,985
7	1080	Animal food industry	383,574
8	1079	Other food products industry	410,658
9	1021	Fish products processing and preservation industry	464,184
10	1105	Packaged water and refilled water industry	489,131

Result Summary

Based on the nine scenarios, we make summary to compare the result of each scenario. This summary also tell about which sub sector that appears repeatedly.

Table 34 Result summary based on all scenarios

Ranking	Scenario								
	A1	A2	A3	B1	B2	B3	C1	C2	C3
1	1043	1043	1043	1076	1104	1076	1043	1043	1043
2	1071	1071	1071	1105	1076	1104	1071	1071	1071
3	1077	1077	1077	1052	1105	1105	1201	1201	1076
4	1080	1080	1072	1073	1109	1052	1077	1077	1201

5	1042	1042	1079	1104	1031	1051	1076	1076	1072
6	1079	1079	1080	1051	1052	1073	1080	1080	1077
7	1072	1072	1021	1031	1073	1053	1042	1042	1080
8	1021	1021	1042	1109	1103	1031	1079	1079	1079
9	1074	1074	1074	1053	1101	1109	1072	1105	1021
10	1061	1061	1061	1059	1033	1101	1021	1072	1105

The result summary above is converted into frequency summary table of subsector appearance on the top 10 of all scenarios.

Table 35 Frequency of subsector appears on the top 10 of scenario

KBLI Code	Frequency	Subsector
1043	6	Crude palm oil and palm cooking oil industry
1071	6	Bread and cake industry
1077	6	Food seasoning and other cooking products industry
1080	6	Animal food industry
1079	6	Other food products industry
1072	6	Sugar industry
1076	6	Coffee, tea, and herb (herb infusion) industry
1042	5	Copra, coconut crude oil, coconut cooking oil, and coconut pellet industry
1021	5	Fish products processing and preservation industry
1105	5	Packaged water and refilled water industry
1074	3	Makaroni, noodle, and similar products industry
1061	3	Cereal and other grains milling industry (Exc. rice and corn)
1052	3	Powdered milk and condensed milk industry
1073	3	Cacao, chocolate, and confectionary industry
1104	3	Other beverage industry
1031	3	Fruit and vegetable processing & preservation with salting, drying, pulverizing, and freezing industry
1109	3	Other food products industry
1201	3	Cigarette and other tobacco products industry

For the food sector only scenario (scenario group A), the three scenarios give stable results in the order of the top three:

- 1) Palm oil processing industry,
- 2) Bread and cake industry, and
- 3) Manufacture of spices and other cooking products.

For the beverage sector only scenario (scenario group B), the three scenarios generally provide the same big three sub-sectors, in slightly different order. The three sectors that appear most frequently in the top three

- 1) Coffee, tea, and herbal processing industries,
- 2) Bottled water industry, and
- 3) Soft drink industry.

For the food and beverage scenario (scenario group C), the four scenarios generally provide the same big three sub-sectors, in slightly different order. The four sectors that appear most frequently in the top three

- 1) Palm oil processing industry,
- 2) Bread and cake industry,
- 3) Cigarette and other tobacco products industry, and
- 4) Coffee, tea, and herbal processing industries,

6. Analyzing the Result and Making Recommendation for Selected Sub-Sector

The results from all the scenarios show that different scenarios resulting with different ranking of prioritized subsectors. However, the general pattern of the results is that palm oil processing industry is almost always on top of the rankings. Further analysis on the individual indicators shows that this subsector has significantly higher values on all indicators, including economic indicators (added value to GDP), social (number of workers) and environmental (energy consumption, emissions, etc.). Furthermore, food subsectors tend to be in higher ranking positions compared to beverage subsectors.

Specific within beverage subsectors, coffee, tea, and herbal processing industry tend to have higher ranking compared to bottled water industry and soft drink industry. This is resulted from the energy consumption and emissions indicators of this sector are significantly higher than other subsectors in beverage industry, although this coffee, tea, and herbal processing industry subsector is not significantly higher than bottled water industry and soft drink industry in terms of economic and social indicators.

Tobacco subsector take the third position in overall subsectors group. This is caused by tobacco subsector has a very high score in added value to GDP and number of employee, compared to other subsectors, except palm oil processing industry. However due to this subsector has issue with health concern, this study does not recommend this subsector to be selected.

Based on our QA/RA analysis result, we recommend palm oil processing industry subsector to be selected for further study using LCA and WCR. If another subsector, specifically related to beverage subsector, to be selected for further LCA and WCR study, we recommend bottled water subsector. We do not recommend coffee, tea, and herbal processing industry because this subsector is very divergent and highly heterogenous so that making the LCA and WCR can be very complicated.

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Appendix 1: Questionnaire Draft

First Iteration

Category: Economic → *the category is important but not all indicators are relevant.*

No	Indicator	1	2	3	4	5
1	Economic annual average growth rate of industrial added value					
2	Per capital industrial added value					
3	Industrial assets					
4	The proportion of research and development input value in GDP					
5	The proportion of high-tech output value in gross industrial output value					

Category: Social → *the category is important but indicator is not relevant or difficult to measure*

No	Indicator	1	2	3	4	5
1	Contribution rate of scientific and technological progress to GDP					
2	Social government revenue					

Category: Environmental → *the category is important but not all indicators are relevant and some indicators can be represented by other indicators.*

No	Indicator	1	2	3	4	5
1	Employment increase promoting degree					
2	Environmental Comprehensive energy consumption per unit of industrial added value					
3	Fresh water consumption per unit of industrial added value					
4	Industrial water recycling rate					
5	Reclaimed water reuse rate					
6	Recycling rate of industrial solid waste					
7	Repeated utilization ratio of raw material					
8	Energy recycling rate					
9	The substitution of raw material source					
10	Gross industrial output value per unit of industrial land					
11	The COD emissions of per unit of industrial added value					
12	The solid waste emissions of per unit of industrial added value					
13	The CO2 emissions of per unit of industrial added value					
14	Centralized sewage treatment rate					
15	Hazardous waste disposal rate					
16	Harmless disposal rate of garbage					
17	Waste chain perfection					
18	Waste treatment facilities					

No	Indicator	1	2	3	4	5
19	Toxic and hazardous waste emissions of per unit of industrial added value					

Category: Ecology Industry Construction → *the category is not relevant*

No	Indicator	1	2	3	4	5
1	Ecology industry construction network degree of information system					
2	Perfection of environmental management system					

Category: Management → *the category is not relevant*

No	Indicator	1	2	3	4	5
1	Network degree of water and energy systems					
2	Per capita public green space					
3	Coverage rate of green space in the park					
4	Correlation degree of enterprises					
5	The formulation of internal management system of the park					
6	The implementation of internal management system of the park					
7	The formulation of enterprises management system					
8	The implementation of enterprises management system					
9	The parks' changing monitoring capacity					
10	ISO14001 certification number of enterprises in the park					
11	Eco-industrial training					

Category: Macro System → *the category is relevant but it, including its indicators, should be renamed according to context*

No	Indicator	1	2	3	4	5
1	Total Energy Consumption of Industrial Enterprises					
2	Total carbon emissions of industrial enterprises					
3	Carbon emissions per unit of industrial value-added					

Category: Energy System → *the category is relevant but indicators should be adapted considering context*

No	Indicator	1	2	3	4	5
1	Coal consumption as a percentage of total fossil energy consumption					
2	Natural gas consumption as a proportion of fossil energy consumption					
3	Energy consumption reduction rate per unit of GDP					
4	Power consumption reduction rate per unit of GDP					
5	Water consumption reduction rate per unit of GDP					

Category: Industrial System → *the category is relevant but but indicators should be adapted considering context*

No	Indicator	1	2	3	4	5
1	The proportion of tertiary industry to GDP					
2	The proportion of industrial added value to GDP					

3	Energy consumption reduction rate per unit of industrial added-value					
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Category: Environmental System → *the category is relevant but but indicators should be adapted considering context*

No	Indicator	1	2	3	4	5
1	PM10 annual average concentration					
2	Industrial sulfur dioxide emissions per unit of industrial value-added					
3	Industrial wastewater discharged per unit of industrial added-value					
4	Sewage treatment rate					

Category: Land System → *the category is not relevant*

No	Indicator	1	2	3	4	5
1	Green area per capita					
2	The green coverage rate of urban built-up area					
3	Forest coverage					
4	Rate of decline in construction area per unit of GDP					

Category: Living System → *the category is not relevant*

No	Indicator	1	2	3	4	5
1	Annual per capita production of urban household waste					
2	Urban water consumption per capita					
3	Annual electricity consumption per capita for urban residents					
4	Urban per capita living construction area					
5	Number of buses owned by ten thousand people					

Category: Economic Prosperity Economy → *the category is relevant but but indicators should be adapted considering context*

No	Indicator	1	2	3	4	5
1	GDP					
2	Average life expectancy at birth for men					
3	Registered unemployment rate					
4	At-risk-of-poverty rate					

Category: Zero-Waste Economy → *the category is relevant but but indicators should be adapted considering context and may have been included in other categories*

No	Indicator	1	2	3	4	5
1	Municipal waste collected selectively in relation to the total amount of municipal waste collected					
2	Municipal waste collected per one inhabitant					
3	Industrial and municipal wastewater purified in wastewater requiring treatment					

No	Indicator	1	2	3	4	5
4	Outlays on fixed assets serving environmental protection and water management related to recycling and utilization of waste					

Category: Innovative Economy → *the category is currently not relevant for Indonesia*

No	Indicator	1	2	3	4	5
1	Expenditures on research and development activities					
2	Average share of innovative enterprises in the total number of enterprises					
3	Adults participating in education and training					
4	Patent applications for 1 million inhabitants					

Category: Energy-Efficient and Renewable Energy-Based Economy → *the category is relevant but but indicators should be adapted considering context and may have been included in other categories*

No	Indicator	1	2	3	4	5
1	Share of renewable energy sources in total production of electricity					
2	Outlays on fixed assets serving environmental protection and water management related to electricity saving					
3	Electricity consumption					

Category: Low Carbon Economy → *the category is relevant but but indicators should be adapted considering context and may have been included in other categories*

No	Indicator	1	2	3	4	5
1	Carbon dioxide emission from plants especially noxious to air purity					
2	Emission of particulates					
3	Passenger cars					
4	Pollutants retained or neutralized in pollutant reduction systems in total pollutants generated from plants especially noxious to air purity					
5	Outlays on fixed assets serving environmental protection and water management related to protection of air and climate					

Second Iteration

Deleting irrelevant categories.

Category: Economic → *category is important but not all indicators are relevant.*

No	Indicator	1	2	3	4	5
1	Economic annual average growth rate of industrial added value					
2	Per capital industrial added value					
3	Industrial assets					
4	The proportion of research and development input value in GDP					
5	The proportion of high-tech output value in gross industrial output value					

Category: Social → *category is important but indicator is not relevant or difficult to measure*

No	Indicator	1	2	3	4	5
1	Contribution rate of scientific and technological progress to GDP					
2	Social government revenue					

Category: Environmental → *category is important but not all indicators are relevant and some indicators can be represented by other indicators.*

No	Indicator	1	2	3	4	5
1	Employment increase promoting degree					
2	Environmental Comprehensive energy consumption per unit of industrial added value					
3	Fresh water consumption per unit of industrial added value					
4	Industrial water recycling rate					
5	Reclaimed water reuse rate					
6	Recycling rate of industrial solid waste					
7	Repeated utilization ratio of raw material					
8	Energy recycling rate					
9	The substitution of raw material source					
10	Gross industrial output value per unit of industrial land					
11	The COD emissions of per unit of industrial added value					
12	The solid waste emissions of per unit of industrial added value					
13	The CO2 emissions of per unit of industrial added value					
14	Centralized sewage treatment rate					
15	Hazardous waste disposal rate					
16	Harmless disposal rate of garbage					
17	Waste chain perfection					
18	Waste treatment facilities					
19	Toxic and hazardous waste emissions of per unit of industrial added value					

Category: Macro System → *category is relevant but it, including its indicators, should be renamed according to context*

No	Indicator	1	2	3	4	5
1	Total Energy Consumption of Industrial Enterprises					
2	Total carbon emissions of industrial enterprises					
3	Carbon emissions per unit of industrial value-added					

Category: Energy System → *category is relevant but indicators should be adapted considering context*

No	Indicator	1	2	3	4	5
1	Coal consumption as a percentage of total fossil energy consumption					
2	Natural gas consumption as a proportion of fossil energy consumption					
3	Energy consumption reduction rate per unit of GDP					
4	Power consumption reduction rate per unit of GDP					
5	Water consumption reduction rate per unit of GDP					

Category: Industrial System → *category is relevant but but indicators should be adapted considering context*

No	Indicator	1	2	3	4	5
1	The proportion of tertiary industry to GDP					
2	The proportion of industrial added value to GDP					
3	Energy consumption reduction rate per unit of industrial added-value					

Category: Environmental System → *category is relevant but but indicators should be adapted considering context*

No	Indicator	1	2	3	4	5
1	PM10 annual average concentration					
2	Industrial sulfur dioxide emissions per unit of industrial value-added					
3	Industrial wastewater discharged per unit of industrial added-value					
4	Sewage treatment rate					

Category: Economic Prosperity Economy → *the category is relevant but but indicators should be adapted considering context*

No	Indicator	1	2	3	4	5
1	GDP					
2	Average life expectancy at birth for men					
3	Registered unemployment rate					
4	At-risk-of-poverty rate					

Category: Zero-Waste Economy → *the category is relevant but but indicators should be adapted considering context and may have been included in other categories*

No	Indicator	1	2	3	4	5
1	Municipal waste collected selectively in relation to the total amount of municipal waste collected					
2	Municipal waste collected per one inhabitant					
3	Industrial and municipal wastewater purified in wastewater requiring treatment					
4	Outlays on fixed assets serving environmental protection and water management related to recycling and utilization of waste					

Category: Energy-Efficient and Renewable Energy-Based Economy → *the category is relevant but but indicators should be adapted considering context and may have been included in other categories*

No	Indicator	1	2	3	4	5
1	Share of renewable energy sources in total production of electricity					
2	Outlays on fixed assets serving environmental protection and water management related to electricity saving					
3	Electricity consumption					

Indicator untuk Kategori Low Carbon Economy → *the category is relevant but but indicators should be adapted considering context and may have been included in other categories*

No	Indicator	1	2	3	4	5
1	Carbon dioxide emission from plants especially noxious to air purity					
2	Emission of particulates					
3	Passenger cars					
4	Pollutants retained or neutralized in pollutant reduction systems in total pollutants generated from plants especially noxious to air purity					
5	Outlays on fixed assets serving environmental protection and water management related to protection of air and climate					

Third Iteration

Deleting irrelevant indicators.

Category: Economic → *category is important but not all indicators are relevant.*

No	Indicator	1	2	3	4	5
1	Economic annual average growth rate of industrial added value					
2	Per capita industrial added value					
3	Industrial assets	Data difficulties				
4	The proportion of research and development input value in GDP					
5	The proportion of high-tech output value in gross industrial output value	Currently not relevant				

Category: Social → *the category is important but indicator is not relevant or difficult to measure*

No	Indicator	1	2	3	4	5
1	Contribution rate of scientific and technological progress to GDP					
2	Social government revenue					

Category: Environmental → *the category is important but not all indicators are relevant and some indicators can be represented by other indicators.*

Category name: Circularity Potential

No	Indicator	1	2	3	4	5
1	Employment increase promoting degree					
2	Environmental Comprehensive energy consumption per unit of industrial added value	Represented in other categories				
3	Fresh water consumption per unit of industrial added value					
4	Industrial water recycling rate					
5	Reclaimed water reuse rate					
6	Recycling rate of industrial solid waste					
7	Repeated utilization ratio of raw material					
8	Energy recycling rate					
9	The substitution of raw material source					
10	Gross industrial output value per unit of industrial land					
11	The COD emissions of per unit of industrial added value					
12	The solid waste emissions of per unit of industrial added value					
13	The CO2 emissions of per unit of industrial added value	Represented in other categories				
14	Centralized sewage treatment rate					
15	Hazardous waste disposal rate					

No	Indicator	1	2	3	4	5
16	Harmless disposal rate of garbage					
17	Waste chain perfection					
18	Waste treatment facilities					
19	Toxic and hazardous waste emissions of per unit of industrial added value					

Category: Macro System → *the category is relevant but it, including its indicators, should be renamed according to context*

No	Indicator	1	2	3	4	5
1	Total Energy Consumption of Industrial Enterprises					
2	Total carbon emissions of industrial enterprises					
3	Carbon emissions per unit of industrial value-added					

Category: Energy System → *the category is relevant but indicators should be adapted considering context*

No	Indicator	1	2	3	4	5
1	Coal consumption as a percentage of total fossil energy consumption					
2	Natural gas consumption as a proportion of fossil energy consumption					
3	Energy consumption reduction rate per unit of GDP					
4	Power consumption reduction rate per unit of GDP					
5	Water consumption reduction rate per unit of GDP	Represented in other categories				

Category: Industrial System → *the category is relevant but but indicators should be adapted considering context*

No	Indicator	1	2	3	4	5
1	The proportion of tertiary industry to GDP					
2	The proportion of industrial added value to GDP					
3	Energy consumption reduction rate per unit of industrial added-value					

Category: Environmental System → *the category is relevant but but indicators should be adapted considering context*

No	Indicator	1	2	3	4	5
1	PM10 annual average concentration					
2	Industrial sulfur dioxide emissions per unit of industrial value-added					
3	Industrial wastewater discharged per unit of industrial added-value					
4	Sewage treatment rate					

Category: Economic Prosperity Economy → *the category is relevant but but indicators should be adapted considering context*

No	Indicator	1	2	3	4	5
1	GDP					
2	Average life expectancy at birth for men	Not relevant				
3	Registered unemployment rate					
4	At-risk-of-poverty rate					

Category: Zero-Waste Economy → *the category is relevant but but indicators should be adapted considering context and may have been included in other categories*

No	Indicator	1	2	3	4	5
1	Municipal waste collected selectively in relation to the total amount of municipal waste collected	Indicators can be represented in other categories				
2	Municipal waste collected per one inhabitant					
3	Industrial and municipal wastewater purified in wastewater requiring treatment					
4	Outlays on fixed assets serving environmental protection and water management related to recycling and utilization of waste					

Category: Energy-Efficient and Renewable Energy-Based Economy → *the category is relevant but but indicators should be adapted considering context and may have been included in other categories*

No	Indicator	1	2	3	4	5
1	Share of renewable energy sources in total production of electricity					
2	Outlays on fixed assets serving environmental protection and water management related to electricity saving	Indicators can be represented in other categories				
3	Electricity consumption					

Category: Low Carbon Economy → *the category is relevant but but indicators should be adapted considering context and may have been included in other categories*

No	Indicator	1	2	3	4	5
1	Carbon dioxide emission from plants especially noxious to air purity					
2	Emission of particulates					
3	Passenger cars	Not relevant				
4	Pollutants retained or neutralized in pollutant reduction systems in total pollutants generated from plants especially noxious to air purity					
5	Outlays on fixed assets serving environmental protection and water management related to protection of air and climate	Can be represented in				

No	Indicator	1	2	3	4	5
		other categories				

Fourth Iteration

Renaming and merging categories.

Category: Economic → *the category is important but not all indicators are relevant.*

No	Indicator	1	2	3	4	5
1	Economic annual average growth rate of industrial added value					
2	Per capita industrial added value					
3	Industrial assets	Data difficulties				
4	The proportion of research and development input value in GDP					
5	The proportion of high-tech output value in gross industrial output value	Currently not relevant				

Category: Social → *the category is important but indicator is not relevant or difficult to measure*

No	Indicator	1	2	3	4	5
1	Contribution rate of scientific and technological progress to GDP					
2	Social government revenue					

Category: Environmental

Category name: Circularity Potential

No	Indicator	1	2	3	4	5
1	Employment increase promoting degree	Merge with economic				
3	Fresh water consumption per unit of industrial added value					
4	Industrial water recycling rate					
5	Reclaimed water reuse rate					
6	Recycling rate of industrial solid waste					
7	Repeated utilization ratio of raw material					
8	Energy recycling rate					
9	The substitution of raw material source					
10	Gross industrial output value per unit of industrial land	Merge with economic				
11	The COD emissions of per unit of industrial added value					
12	The solid waste emissions of per unit of industrial added value	Merge with environment				
14	Centralized sewage treatment rate	Merge with environment				
15	Hazardous waste disposal rate					
16	Harmless disposal rate of garbage					
17	Waste chain perfection					
18	Waste treatment facilities					

No	Indicator	1	2	3	4	5
19	Toxic and hazardous waste emissions of per unit of industrial added value					

Category: Macro System → *the category is relevant but it, including its indicators, should be renamed according to context*

No	Indicator	1	2	3	4	5
1	Total Energy Consumption of Industrial Enterprises	Merge with other categories				
2	Total carbon emissions of industrial enterprises					
3	Carbon emissions per unit of industrial value-added					

Category: Energy System → *the category is relevant but indicators should be adapted considering context*

No	Indicator	1	2	3	4	5
1	Coal consumption as a percentage of total fossil energy consumption					
2	Natural gas consumption as a proportion of fossil energy consumption					
3	Energy consumption reduction rate per unit of GDP					
4	Power consumption reduction rate per unit of GDP					

Category: Industrial System → *the category is relevant but but indicators should be adapted considering context*

No	Indicator	1	2	3	4	5
1	The proportion of tertiary industry to GDP	Merge with economic Merge with energy system				
2	The proportion of industrial added value to GDP					
3	Energy consumption reduction rate per unit of industrial added value					

Category: Environmental System → *the category is relevant but but indicators should be adapted considering context*

No	Indicator	1	2	3	4	5
1	PM10 annual average concentration					
2	Industrial sulfur dioxide emissions per unit of industrial value-added					
3	Industrial wastewater discharged per unit of industrial added-value					
4	Sewage treatment rate					

Category: Economic Prosperity Economy → *the category is relevant but but indicators should be adapted considering context*

No	Indicator	1	2	3	4	5
1	GDP	Merge with economic				

3	Registered unemployment rate	Merge with economic or social
4	At risk of poverty rate	Merge with social

Category: Energy-Efficient and Renewable Energy-Based Economy → *the category is relevant but but indicators should be adapted considering context and may have been included in other categories*

No	Indicator	1	2	3	4	5
1	Share of renewable energy sources in total production of electricity	Can be merged with Energy System				
2	Outlays on fixed assets serving environmental protection and water management related to electricity saving	Indicators can be represented in other categories				
3	Electricity consumption	Can be merged with Energy System				

Category: Low Carbon Economy → *the category is relevant but but indicators should be adapted considering context and may have been included in other categories*

No	Indicator	1	2	3	4	5
1	Carbon dioxide emission from plants especially noxious to air purity					
2	Emission of particulates					
3	Passenger cars	Not relevant				
4	Pollutants retained or neutralized in pollutant reduction systems in total pollutants generated from plants especially noxious to air purity					
5	Outlays on fixed assets serving environmental protection and water management related to protection of air and climate	Can be represented in other categories				

Fifth Iteration

Renaming and modifying indicators.

Category: Economic → *category is important but not all indicators are relevant.*

No	Indicator	1	2	3	4	5
1	Economic annual average growth rate of industrial added value <i>Potential contribution to economic</i>					
2	Per capita industrial sub-sector added value/Potential to increase employment <i>Sub-sector potential to create job, the higher per capita added value, the more potential to create new job</i>					
4	The proportion of research and development input value in GDP <i>Proxy to sub-sector growth, the higher R&D the more productivity</i>					
4	Gross sub-sector output value per unit of land					

Category: Social

No	Indicator	1	2	3	4	5
1	Contribution rate of scientific and technological progress to GDP <i>Potential to increase education/environment issues awareness</i>					
2	Social intangible benefit potential					
3	Potential to reduce poverty					
4	Potential to increase women employment rate					

Category name: Circularity Potential

No	Indicator	1	2	3	4	5
1	Industrial water recycling rate					
2	Reclaimed water reuse rate					
3	Recycling rate of industrial solid waste					
4	Repeated utilization ratio of raw material					
5	Energy recycling rate					
6	The substitution of raw material source					

Category: Energy System

No	Indicator	1	2	3	4	5
1	Coal consumption					
2	Natural gas consumption					
3	Power consumption					
4	Potential power consumption reduction rate per unit of GDP					
5	Potential energy consumption reduction rate per unit of GDP					

No	Indicator	1	2	3	4	5
6	Potential energy consumption reduction rate per unit of industrial added-value					
7	Potential use of renewable energy sources					

Category: Environmental System

No	Indicator	1	2	3	4	5
1	PM10 annual average concentration					
2	Potential industrial sulfur dioxide emissions reduction					
3	Potential industrial wastewater discharged reduction					
4	Sewage treatment rate					
5	The COD emissions of per unit of industrial added value					
6	The solid waste emissions of per unit of industrial added value					
7	Potentially hazardous waste disposal reduction					
8	Potential harmless disposal rate of garbage reduction					
9	Waste treatment facilities					
10	Potential toxic and hazardous waste emissions reduction					
11	Fresh water consumption per unit of industrial added value					

Category: Low Carbon Initiatives

No	Indicator	1	2	3	4	5
1	Potential Carbon dioxide emission reduction					
2	Potential other GHG emission reduction					
4	Potential to capture carbon emission/to absorb carbon					

New Category: Investment or outlays needed to promote CE & LCDI

No	Indicator	1	2	3	4	5
1	Investment or outlays needed on fixed assets related to environmental protection					
2	Investment or outlays needed on fixed assets related to energy saving					
4	Investment or outlays needed in pollutant reduction systems					
4	Investment or outlays needed related to carbon reducing system					

Sixth / Final Iteration

Including new indicators from previous Bappenas CE and LCDI studies.

1. Category: Economic

No	Indicator	1	2	3	4	5
1	Economic annual average growth rate of industrial added value <i>Potential contribution to economic</i>					
2	Per capita sub-sector added value/Potential to increase employment <i>Sub-sector potential to create job, the higher per capita added value, the more potential to create new job</i>					
3	The proportion of research and development input value in GDP <i>Proxy to sub-sector growth, the higher R&D the more productivity</i>					
4	Gross sub-sector output value per unit of land					

2. Category: Social

No	Indicator	1	2	3	4	5
1	Contribution rate of scientific and technological progress to GDP <i>Potential to increase education/environment issues awareness</i>					
2	Social intangible benefit potential					
3	Potential to reduce poverty					
4	Potential to increase women employment rate					
5	<i>Potential to increase household saving</i>					

3. Category: Circularity Potential

No	Indicator	1	2	3	4	5
1	<i>Industrial water recycling rate</i>					
2	<i>Reclaimed water reuse rate</i>					
3	<i>Recycling rate of industrial solid waste</i>					
4	<i>Repeated utilization ratio of raw material</i>					
5	<i>Energy recycling rate</i>					
6	<i>The substitution of raw material source</i>					

4. Category: Energy System

No	Indicator	1	2	3	4	5
1	Coal consumption					
2	Natural gas consumption					
3	Power consumption					
4	Potential energy consumption reduction rate per unit of GDP					
5	Potential energy consumption reduction rate per unit of industrial added-value					

No	Indicator	1	2	3	4	5
6	Potential use of renewable energy sources					

5. Category: Environmental System

No	Indicator	1	2	3	4	5
1	PM10 annual average concentration					
2	Potential industrial sulfur dioxide emissions reduction					
3	Potential industrial wastewater discharged reduction					
4	Sewage treatment rate					
5	The COD emissions of per unit of industrial added value					
6	The solid waste emissions of per unit of industrial added value					
7	Potentially hazardous waste disposal reduction					
8	Potential harmless disposal rate of garbage reduction					
9	Waste treatment facilities					
10	Potential toxic and hazardous waste emissions reduction					
11	Fresh water consumption per unit of industrial added value					

6. Category: Low Carbon Initiatives

No	Indicator	1	2	3	4	5
1	Potential Carbon dioxide emission reduction					
2	Potential other GHG emission reduction					
3	Potential to capture carbon emission/to absorb carbon					

7. Category: Investment or outlays needed to promote CE & LCDI

No	Indicator	1	2	3	4	5
1	Investment or outlays needed on fixed assets related to environmental protection					
2	Investment or outlays needed on fixed assets related to energy saving					
3	Investment or outlays needed in pollutant reduction systems					
4	Investment or outlays needed related to carbon reducing system					

8. Category: Stakeholder Involvement (added category from previous Bappenas Study)

No	Indicator	1	2	3	4	5
1	Government priority					
2	Potential of private sector involvement					
3	Potential of international support					

Appendix 2: List of Experts Invited in the Survey

No	Nama	Jabatan	Institusi	Kategori
1	Mohamad Bijaksana Junerosano	CEO and Founder Waste4Change	Waste4Change	Think Tank/CSO
2	Dr Ichsan	Business Advisor A-Wing Group	A-Wing Group	Industry
3	Dyah Roro Esti	Chair & Co-Founder of Indonesian Energy and Environmental Institute (IE2I)	Indonesian Energy and Environmental Institute (IE2I)	Think Tank/CSO
4	Muhammad Agung Saputra	Founder and CEO Surplus	Surplus	Think Tank/CSO
5	Nirarta Samadhi	Direktur WRI (Worlds Resources Institute) Indonesia	World Resources Institute) Indonesia	Think Tank/CSO
6	Nurdiana Darius	Head of Corporate Affairs and Sustainability-Unilever		Industry
7	Rosa Vivien Ratnawati, SH., M.Sc.	Direktur Jenderal Pengelolaan Limbah, Sampah, dan Bahan Beracun Berbahaya (PSLB3) - Kementerian Lingkungan Hidup dan Kehutanan	Kementerian Lingkungan Hidup dan Kehutanan	Government
8	Shinta Widjaja Kamdani	Chief Executive Officer at Sintesa Group; President of Indonesia Business Council for Sustainable Development (IBCSD); Vice Chairwoman for Int'l Relations KADIN	Sintesa Group	Industry
9	Intan Anggita Pratiwie	Recycling Artist, Sustainability Practitioner, Co-Founder di Setali Indonesia	Setalil Indonesia	Industry
10	Maria Dian Nurani	CSR & Sustainability Management Expert	Management Expert	Academia
11	Jane Marlen von Rabenau	CEO & Co-Founder of Siklus	Siklus	Industry
12	Professor M Akbar Rhamdhani	Director of Fluid and Process Dynamics (FPD) Group at Swinburne	Swinburne University	Academia
13	Professor Tjandra Setiadi	Guru Besar Teknik Kimia ITB	Institut Teknologi Bandung	Academia
14	Ir. Achmad gunawan Widjacksono, MAS	Direktur Verifikasi pengelolaan Limbah Bahan Berbahaya beracun, Limbah Non-Bahan Berbahaya beracun KLHK	Kementerian Lingkungan Hidup dan Kehutanan	Government
15	Dr. Ir. Mohamad Satori, MT., IPU.	Ketua Forum Bank Sampah Jawa Barat/ Dekan Fakultas Teknik Unisba	Universitas Islam Bandung	Academia

No	Nama	Jabatan	Institusi	Kategori
16	Prof. Dr. Ir. Udisubakti Ciptomulyono M.Eng.Sc.	Dosen Institut Teknologi Sepuluh Nopember Surabaya	Institut Teknologi Sepuluh Nopember Surabaya	Academia
17	Ir. Noer Adi Wardoyo, M. Sc	Kepala Pusat Standardisasi Lingkungan dan Kehutanan	Kementerian Lingkungan Hidup dan Kehutanan	Government
18	Ir. Muhammad Khayam. M.T.	Direktur Jenderal Industri Kimia, Farmasi, dan Tekstil (KEMENPERIN)	Kementerian Perindustrian	Government
19	Sri Gadis Paribekti	Analisis Kebijakan Pusat Industri Hijau Kementerian Perindustrian	Kementerian Perindustrian	Government
20	Karyanto Wibowo	Sustainability Director-Danone Chairman of PRAISE	Danone	Industry
21	Egi Suarga	Low Carbon Development Initiative (LCDI) Program Lead at World Resources Institute	World Resource Institute	Think Tank/CSO
22	Dadan Kusdiana	Director General NREEC Ministry of Energy and Mineral Resources	Kementerian ESDM	Government
23	Chrisnawan Andistya	Direktur Aneka Energi Baru dan Energi Terbarukan Kementerian ESDM	Kementerian ESDM	Government
24	Irfan Darliazi Yunanto	Perencana Direktorat Lingkungan Hidup Bappenas	Bappenas	Government
25	Dr. Eng. Pandji Prawisudha ST, MT	Dosen FTMD ITB	Institut Teknologi Bandung	Academia
26	Hendricus Andy Simarmata, ST, M.Si.	Dosen Pengembangan Perkotaan UI; Ketua Umum IAPI (Ikatan Ahli Perencanaan Indonesia)	Universitas Indonesia	Academia
27	Dr. Mahawan Karuniasa	Dosen Teknik Lingkungan UI; CEO Environment Institute	Universitas Indonesia	Academia
28	Dr. Ir. Agung Hendriardi	Kepala Badan Ketahanan Pangan Kementerian Pertanian RI	Kementerian Pertanian	Government
29	Welly Soegiono	Corporate Affairs Director Great Giant Pineapple (GGP)	Great Giant Pineapple (GGP)	Industry
30	Dr. Tri Edhi Budhi Soesilo	Direktur Sekolah Ilmu Lingkungan, Universitas Indonesia	Universitas Indonesia	Academia
31	Prof. Purnomo Yusgiantoro	Guru Besar Institut Teknologi Bandung, Pendiri Purnomo Yusgiantoro Center (PYC)	Institut Teknologi Bandung	Academia
32	Dr. Agus Prabowo	Head of Environment Unit, UNDP Indonesia	UNDP Indonesia	OI

No	Nama	Jabatan	Institusi	Kategori
33	Dr. Verania Andria	Senior Advisor on Sustainable Energy	UNDP Indonesia	OI
34	Mariski Nirwan	Knowledge and Capacity Development Lead @Global Green Growth Institute	Global Green Growth Institute	Think Tank/CSO
35	Ari W. Adipratomo	Project Coordinator for LCDI @World Resource Institute (WRI)	World Resource Institute	Think Tank/CSO
36	Andriati Cahyaningsih	Koordinator fungsi kerjasama, harmonisasi kebijakan, pengendalian dan pengawasan industri hijau, Direktorat Industri Kimia Hilir	Kementrian Perindustrian	Government
37	Prof.Dr.Ir. Enri Damanhuri	Guru Besar Teknik Lingkungan ITB	Institut Teknologi Bandung	Academia
38	Angga Dwiartama, S.Si., M.Si., Ph.D.	Associate Professor SITH ITB	Institut Teknologi Bandung	Academia
39	Paul Butarbutar	Direktur Eksekutif	Masyarakat Energi Terbarukan Indonesia (METI)	Think Tank/CSO
40	Moekti (Kuki) Soejachmoen	Direktur Eksekutif	Indonesia Research Institute for Decarbonization (IRID)	Think Tank/CSO
41	Faisal	Direktur Eksekutif	CORE Indonesia	Think Tank/CSO
42	Misbah Hasan	Direktur Eksekutif	SEKNAS FITRA/ GENERASI HIJAU	Think Tank/CSO
43	Tiza Mafira	Direktur Eksekutif	CPI International	Think Tank/CSO
44	Dr. Ir. Janti Gunawan, M.Eng.Sc., M. Com.IB	Dosen ITS, Green Economy Expert	ITS Surabaya	Academia

Appendix 3: Indicators Importance Score

Indicator	Importance
Economy 1	4.354
Economy 2	4.500
Economy 3	3.792
Economy 4	4.125
Social 1	4.583
Social 2	4.146
Social 3	4.479
Social 4	3.792
Social 5	3.833
Circularity 1	4.708
Circularity 2	4.417
Environment System 1	4.104
Environment System 2	4.292
Environment System 3	4.417
Environment System 4	4.229
Environment System 5	4.146
Environment System 6	4.354
Environment System 7	4.542
Environment System 8	4.333
Environment System 9	4.563
Environment System 10	4.604
Environment System 11	4.438

Indicator	Importance
Circularity 3	4.583
Circularity 4	4.563
Circularity 5	4.813
Circularity 6	4.708
Energy System 1	4.271
Energy System 2	4.188
Energy System 3	4.438
Energy System 4	4.521
Energy System 5	4.542
Energy System 6	4.500
Low Carbon Development 1	4.583
Low Carbon Development 2	4.563
Low Carbon Development 3	4.479
Investment & Outlay 1	4.396
Investment & Outlay 2	4.604
Investment & Outlay 3	4.333
Investment & Outlay 4	4.521
Stakeholder 1	4.521
Stakeholder 2	4.813
Stakeholder 3	4.292



PART 2

System Dynamics Modeling

Table of Contents

1. Background and Objective of System Dynamics Modelling	2
2. Methodology for System Dynamics Modelling	3
3. Indonesia and World CPO Profile	4
4. Data Collection	5
5. System Dynamics Model	7
5.1 Causal Loop Diagram	7
5.2 Stock Flow Diagram - Macro Structure	8
5.2.1 CPO Resources.....	8
5.2.2 CPO Milling Process	9
5.2.3 CPO Refinery Production	10
5.2.4 CPO Supply-Demand	10
5.2.5 Waste and CPO Emission.....	11
5.2.6 CPO Added Value & Total Labor	12
5.3 Stock Flow Diagram - Policy Structure	12
5.3.1 Policy 1: Use of organic fertilizers and decentralization of CPO factories	12
5.3.2 Policy 2: Increased planting productivity	13
5.3.3 Policy 3 & 4: POME Biogas & Empty Fruit Bunches and Palm Shell Biomass.....	14
5.3.4 Policy 5: Waterless Milling.....	15
5.3.5 Policy 6: CPO Processing Technology Efficiency.....	15
5.3.6 Policy 7: Shifting Diesel Fuel Trucks to BioCNG.....	16
6. Simulation of Indicator and Policy Intervention	17
7. Conclusion and Recommendation	20
References	24

1. Background and Objective of System Dynamics Modelling

This report will present a generic methodology of systems dynamics modelling for general products. The method will later be tailored to the palm oil industry. We are focusing on the inter-relations between production, consumption (demand), export, and import. Later we will add some interventions to this generic model base on the results of the Waste & CO2 Reduction Life Cycle Assessment Study.

According to Sterman (2004), system dynamics is a method for studying complex systems, based on the theory of nonlinearity, dynamics and feedback control. Martin (1997) defines System dynamics as a methodology used to understand a system that changes over time. System dynamics is a methodology for studying and managing complex feedback systems, such as business and other social systems. System dynamics takes the additional step of constructing computer simulation models to confirm that the structure hypothesized can lead to the observed behaviour and to test the effects of alternative policies on critical variables over time. Feedback control is a basic concept of system dynamics.

Complexity, dynamics, non-linearity, and feedback further characterize system dynamics. Detail complexity is the complexity of the system because of the many elements or components of the system, so the more elements or components, the more complex the system is. Dynamic complexity is the complexity of the system due to the many interrelated components in the system, which means that the more interrelationships between the elements or components, the more complex the system (Soesilo, 2007). System dynamics illustrate that system performance is always changing with changing times. There is no widely accepted definition of non-linearity in the scientific world. In simple terms, the non-linearity of the system is defined as all non-linear systems (Gibson, 1963).

According to Forrester (1971), feedback is system output that returns to system input to affect system work. In the view of O'Conner (1997), feedback is a fundamental system, without feedback, there is no system. Feedback is defined as system output that is returned or becomes system input to affect system performance.

According to Gilpin (2011), the state is the dominant actor both in the domestic economy and in the international economy because the course of economic development is determined by the market and state policies. Competition, interests, and political goals in cooperation between countries have been stated in several agreements, including regional agreements and bilateral trade agreements between two countries. The state is the dominant factor in determining policy, in the process of determining policy the state must protect the interests of the domestic industry and must also protect the national interest. Comprehensive information on the conditions and developments of the related industry must be mastered so that the formulated policies prioritize the national interest.

In international political economy, the interests and policies of the state are determined by the political elite, pressure from interest groups and the national system of political economy. The

foreign economic policy reflects the national interest defined by its elites. Therefore, the direction of the market can still be determined by the interests of the state which is the goal of the economic activity itself.

Each political-economic system has different characteristics, they have priority given to four aspects namely prosperity, order, justice, and freedom. The government must be able to manage all these aspects to become a policy that prioritizes the interests of the domestic industry. Studies in several developing countries show a strong relationship between the political system in developing countries and the expansion of a market-oriented capitalistic economy.

It should be noted that a large industry in Indonesia absorbs a lot of labor (labor intensive), so the impact of global trade that is not controlled effectively will have wide implications for labor problems in Indonesia, which is one of the performance criteria in this model. The central role of the government here is very dominant in maintaining national interests related to employment, economic stability, and domestic security.

Information on industrial conditions studied at the domestic level is very important in formulating global trade policies, especially information on the cost structure for related industries in the country and the cost structure for related industries in other countries.

2. Methodology for System Dynamics Modelling

In general, a sequential exploratory study was used in this study. It begins with either a stage of quantitative or qualitative data collection and analysis. The output will be used in the next stage of inquiry, and later, these results will feed into an interpretation stage. The study procedure builds on the framework of the systems thinking and modelling (STM) intervention process. The five phases in the STM process are illustrated in Figure 1. Given the time constraint of the working period, the depth of analysis in this study covers the first three STM phases, which are Problem Structuring, Causal Loop Modelling, and Dynamic Modelling.

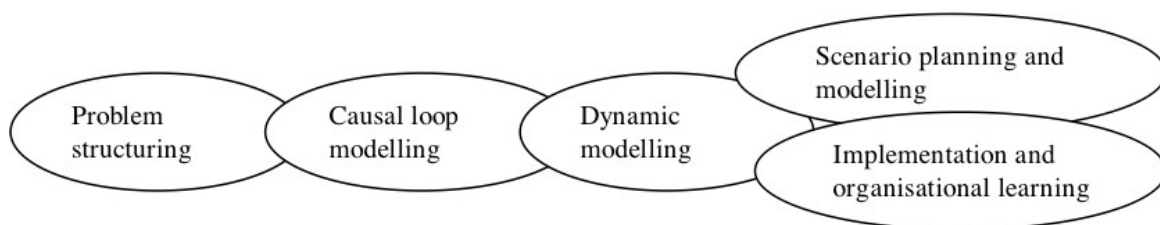


Figure 1. The five phases of systems thinking and modelling (STM)

1. Problem structuring

The analytical purpose of the problem structuring phase was to define the system's boundary. The main activities were literature reviews (i.e., scientific journal articles) and consultations with a multi-disciplinary group of experts based in the LCDI Secretariate in Bappenas and other institutions.

2. Causal loop modelling

The analytical purpose of the causal loop modelling was to visually assess the interactions of the components in a system (i.e., variables influencing the state variables) and their feedback relationships within the boundary of the system of interest. The main activities were to develop a causal loop diagram (CLD) by triangulating information from the literature and participatory model building with experts from the LCDI Secretariate in Bappenas and other institutions. The depth of analysis was subject to the complexity of the system boundary (i.e., the number of variables and interactions captured in the CLD) and the study time constraints.

3. Dynamic modelling

The analytical purpose of dynamic modelling was to allow computer-aided simulation of the dynamics conceptualized under the causal model. The main activity in this phase was stock-and-flow modelling to simulate the accumulation and the rate of change of materials or information. This study was limited to developing a prototype stock-flow model structure using the CLDs as a 'seed structure' to simulate problematic system behaviours (i.e., trends) contributed by the feedback loops identified in the previous phase.

3. Indonesia and World CPO Profile

Before the researcher continues to find data and so on, we need to check the profile of the Indonesian Crude Palm Oil (CPO) industry. Table 1 is the palm oil production data for 2021/2022 for several countries. Based on Table 1, we can conclude that Indonesia is one of the main stakeholders in the CPO Industry in the world. Indonesia can provide CPO in 2022 in the amount of 44,500 tons/year. Indonesia's competitor in SEA is Malaysia with 18,700 tons/year of production.

Table 1. CPO Production for Several Countries

No	Country	Production (ton/year)	Domestic demand (ton/year)	Export (ton/year)	Import (ton/year)
1	Indonesia	44,500	15,675	26,874	-
2	Malaysia	18,700	3,440	15,878	1,300
3	Thailand	3,120	2,510	608	-
4	Colombia	1,615	1,139	454	156
5	Nigeria	1,400	1,665	18	424
Source		(Statista.com, 2022)	(Indexmundi.com, 2022)	(Indexmundi.com, 2022)	(Indexmundi.com, 2022)

Table 2. Indonesia CPO Productions from 2010 - 2020

Year	Production	Domestic Demand	Export	Import
2010	22.496.857	6.234.000	16.291.856	46.720
2011	23.995.973	6.940.000	16.436.202	23.344
2012	26.015.519	7.835.000	18.845.020	616
2013	27.782.004	9.020.000	20.577.976	65.561
2014	29.278.189	7.065.000	22.892.224	299
2015	31.070.015	8.310.000	26.467.564	7.572
2016	31.487.986	12.750.000	22.761.814	2.658
2017	34.940.289	11.056.000	27.353.337	2.518
2018	42.883.631	13.491.000	27.898.875	806
2019	47.120.247	16.747.000	28.279.350	93.285
2020	44.759.147	17.349.000	25.935.257	957
Source	(BPS - Statistics Indonesia, 2021)			

From Table 2 can be seen that Indonesia had big number in Export than Import. The CPO industry turns out to be an export-oriented industry. So the amount of Indonesian CPO production will depend on foreign demand. This domestic production will directly affect the number of workers.

4. Data Collection

During this study, we collected several data (Table 3) as input for this model and illustration the existing situation. Several data that we collect namely:

Table 3 Data Collection for Modelling Input

Data	Description	Unit
The need for production workers per ton of CPO	Number of workers to produce CPO per tonne	person/ton
Domestic CPO Price	National CPO Price	USD/ton
Export CPO Prices	Export CPO Prices	USD/ton
PLTBm efficiency	Biomass Power Plant efficiency	%
Share of Electricity Production from Business-as-Usual (BAU) Biomass	The amount of biomass energy per total energy used as a source of electricity generation for CPO production	%
Share of Electricity Production from Biogas BAU	The amount of biogas energy per total energy used as a source of electricity generation for CPO production	%
Electricity Share Production from BAU Gas	The amount of gas energy per total energy used as a source of electricity generation for CPO production	%
Share of Electricity Production from BAU Diesel	The amount of diesel energy per total energy used as a source of electricity generation for CPO production	%

Share of Electricity Production from BAU Coal	The amount of coal energy per total energy used as a source of electricity generation for CPO production	%
Data	Description	Unit
	production	
PLTBg efficiency	Biogas Power Plant efficiency	%
Palm Oil Mill Effluent (POME) Biogas Calorific Value	Energy value per unit volume of POME biogas	BOE/m3
Palm Shell Calorific Value	Energy value per unit ton of palm shell	BOE/ton
Calorific Value of Empty Bunches	Energy value per unit tonne of empty fruit bunches	BOE/ton
Yield Biogas from POME	The volume of biogas that can be produced per tonne of POME	m3/ton
Palm Shell Yield	Percentage of palm shells produced per tonne of CPO	%
Empty Bunch Yield	Percentage of empty fruit bunches produced per tonne of CPO	%
POME Yield from CPO	Percentage of POME waste generated per tonne of CPO	%
Biomass Emission Factor	CO2 emissions generated per unit of energy from biomass	ton of CO2/BOE
Biogas Emission Factor	CO2 emissions produced per unit of energy from biogas	ton of CO2/BOE
Share Gas for CPO production	Proportion of gas to total energy consumed for CPO production	%
Share for CPO production	Proportion of electricity to total energy consumed for CPO production	%
Share for CPO production	The proportion of coal to total energy consumed for CPO production	%
Emission Factors for Oil Palm Plantation Activities	Emissions generated from plantation activities per hectare of oil palm plantations	ton of CO2/ha
Coal Emission Factor	CO2 emissions produced per unit of energy from coal	ton of CO2/BOE
Share Diesel for CPO production	Proportion of diesel to total energy consumed for CPO production	%
FFB (fresh fruit bunches) Productivity Level	Production of fresh fruit bunches per hectare of garden per year	ton/ha/ year
CPO Wastewater Emission Factor	CO2 emissions produced per tonne of CPO liquid waste	ton of CO2/ton of CPO
Gas Emission Factor	CO2 emissions produced per unit of energy from coal	ton of CO2/BOE
Diesel Emission Factor	CO2 emissions produced per unit of energy from coal	ton of CO2/BOE
Land Transfer Emission Factors	Emission factors from land conversion to oil palm	ton of CO2/ha
Production capacity depreciation rate	CPO refinery production machine depreciation per year	%/ year
CPO Solid Waste Emission Factor	CO2 emissions produced per tonne of CPO solid waste	ton of CO2/ton of CPO

Emission Factor of Empty Bunches	CO2 emissions produced per unit energy from empty fruit bunches	CO2
Data	Description	Unit
Palm Shell Emission Factors	CO2 emissions produced per unit of energy from palm shells	CO2
Yield from FFB	Percentage of CPO produced per tonne of fresh fruit bunches	%
CPO Production Energy Consumption	The energy required per tonne of CPO produced	BOE/ton
CPO Production Capacity	CPO refinery capacity	ton
Oil Palm Plantation Area	Oil palm plantation area	Ha

5. System Dynamics Model

5.1 Causal Loop Diagram

To conduct analysis with a system dynamic, we need to formulate the model. The model is constructed based on the relation between variables. To make easier the model formulation step, we build the conceptual model first. The conceptual model for system dynamics formulation is using Causal Loop Diagram (CLD). After the CLD is constructed, we determine the mathematical equation and value of each variable. Then, we simulate the model to gain insights into the policy that we want to implement in the real case.

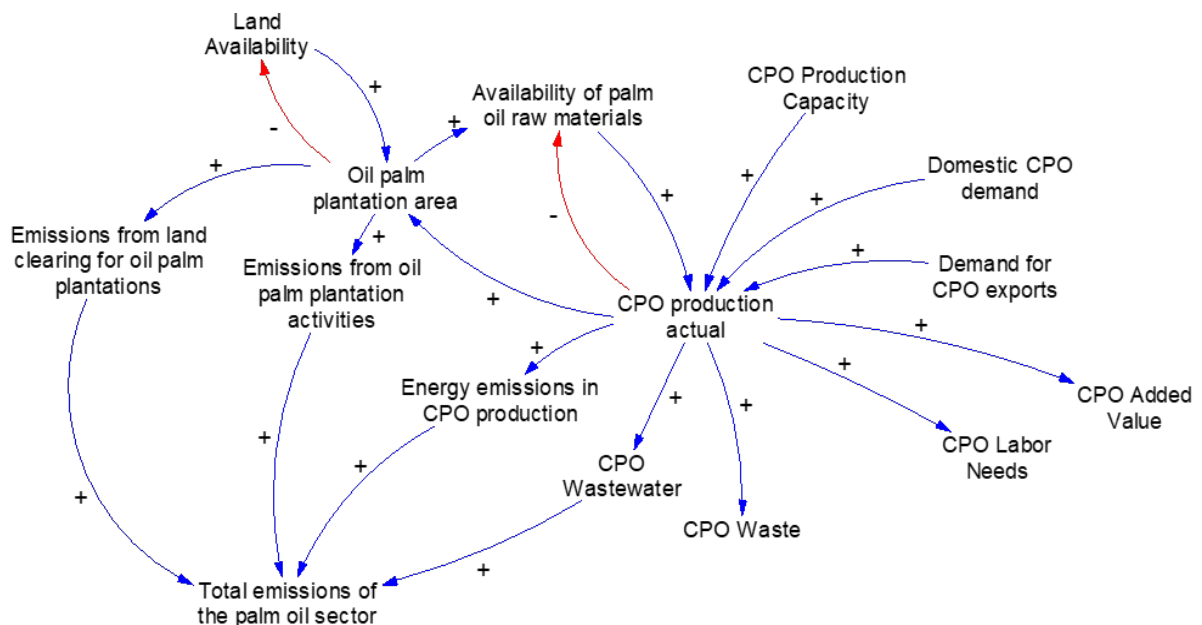


Figure 2. Causal Loop Diagram

In the following CLD, it can be seen that the area of oil palm plantations will affect land conversion and land availability. The area of oil palm plantations will affect emissions from land clearing for oil palm plantations and emissions from oil palm plantation activities. On the other hand, the area of oil palm plantations will affect the availability of palm oil raw materials which will affect the actual production of CPO and at the same time the actual production of CPO will affect the area of oil palm plantations so that it will form a positive feedback. Actual production of CPO will also be affected by CPO production capacity, domestic CPO demand, demand for CPO exports, and CPO added value. On the other hand, the actual production of CPO will affect energy emissions in CPO production, CPO wastewater, CPO waste and CPO labor requirements. Meanwhile, the total emissions of the palm oil sector are influenced by emissions of waste and wastewater, CPO production energy, emissions from oil palm land activities and emissions from opening oil palm plantations. The structure of the flow diagram for each variable will be explained in more detail in the next sub-chapter.

5.2 Stock Flow Diagram - Macro Structure

The development of the CPO model follows the business flow of the Results of the Waste & CO₂ Reduction Life Cycle Assessment Study, which consists of Palm Oil Resources, CPO Milling Process, and CPO Refinery Production.

5.2.1 CPO Resources

The structure of this model (Figure 3) is taken into account as an analysis to project the availability of land that can be used as oil palm plantation land, as well as to project actual FFB production. The addition of oil palm plantation area is influenced by the need for additional oil palm land. The need for oil palm land is influenced by the desired fresh fruit bunch (FFB) production, the productivity level of FFB, the potential for fresh fruit bunch (FFB) production, CPO demand forecasts, and the yield of CPO production from FFB. Meanwhile, actual FFB production is influenced by actual oil palm plantation area, maximum FFB production potential, and desired FFB production.

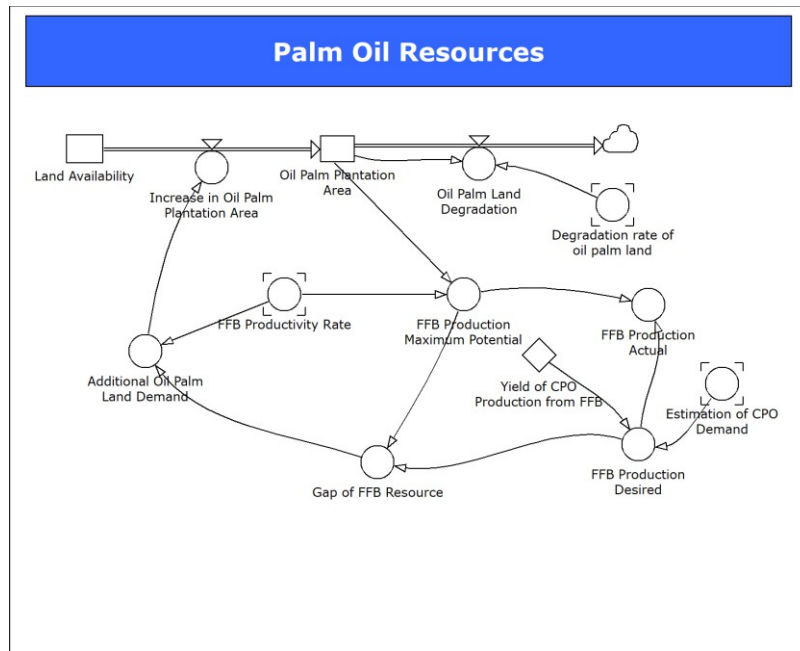


Figure 3. Palm Oli Resources Structure Model

5.2.2 CPO Milling Process

In this model structure (Figure 4) is used to project CPO milling capacity and total fresh water requirement for CPO milling process, as well as total wastewater production. CPO milling capacity is influenced by the need for additional milling capacity, actual FFB production, maximum process potential. The total freshwater milling demand is obtained from the actual FFB milling and the average freshwater milling demand. Whereas in determining the total production using the yield wastewater fraction of feedstock milling.

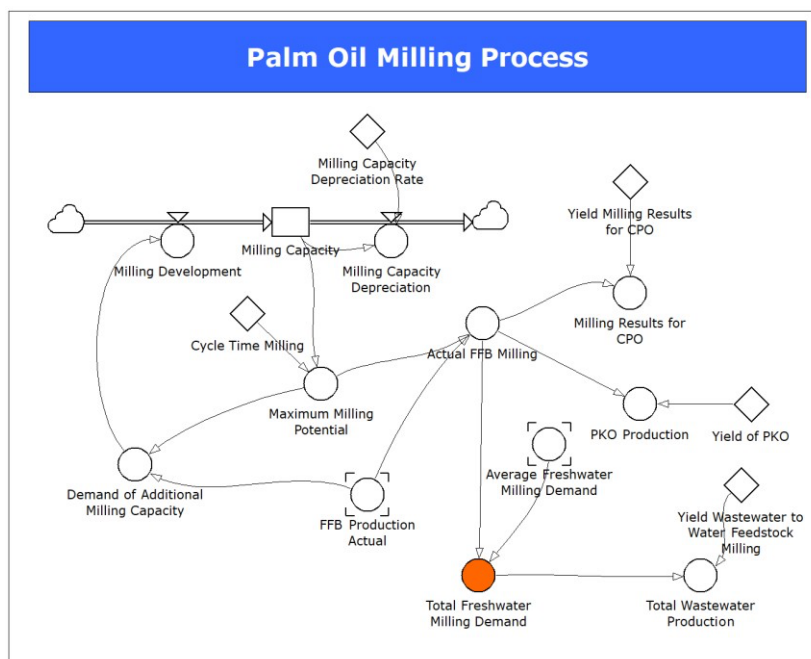


Figure 4. Palm Oil Milling Structure Model

5.2.3 CPO Refinery Production

The CPO Refinery Production model structure (Figure 5) is used to determine capacity in the CPO Refinery process. The need for additional CPO production capacity in the refinery process is influenced by milling results for CPO and the maximum refinery production potential of CPO. CPO refinery capacity will affect the level of production capacity utilization and actual CPO production capacity.

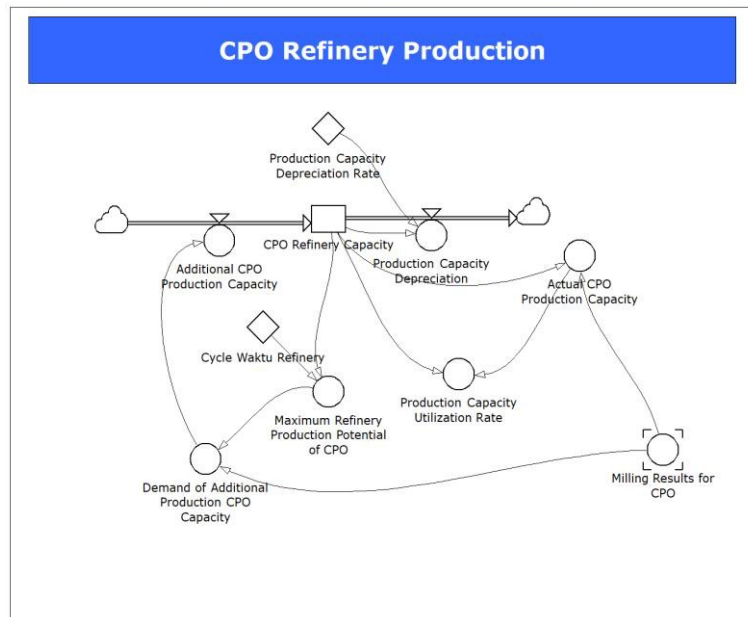


Figure 5. CPO Refinery Production Structure Model

5.2.4 CPO Supply-Demand

The CPO Supply-Demand model (Figure 6) is used to determine the total CPO demand and total CPO consumption. To be able to know the total amount of CPO produced, it can be adjusted to the CPO Demand which is analysed through the model structure related to CPO Supply-Demand. The total CPO demand is influenced by the desired domestic CPO demand and the desired CPO export. Meanwhile, total CPO demand is influenced by actual CPO production capacity and total CPO demand. Note that the input data for CPO requests are data on all CPO production.

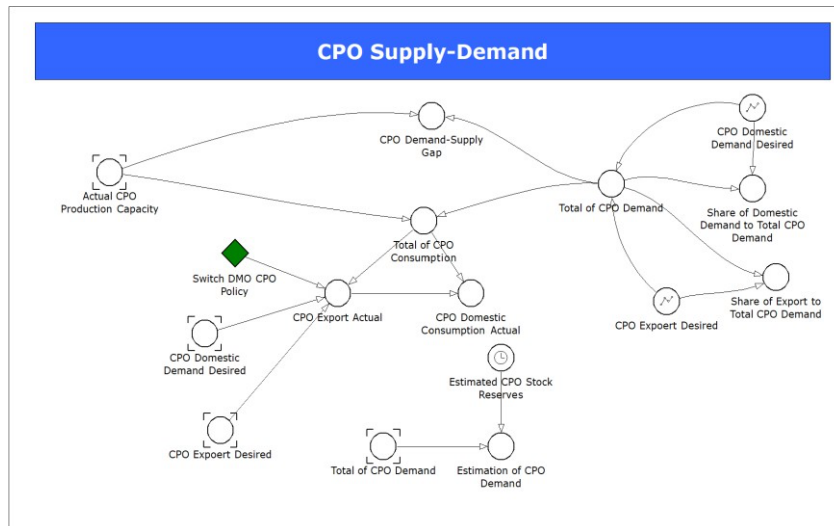


Figure 6. CPO Supply-Demand Structure Model

5.2.5 Waste and CPO Emission

In the structure of the waste and CPO emission model (Figure 7), total potential CPO emissions have been analysed from land conversion activities, oil palm plantation activities, total energy consumption for CPO production, CPO wastewater and CPO waste.

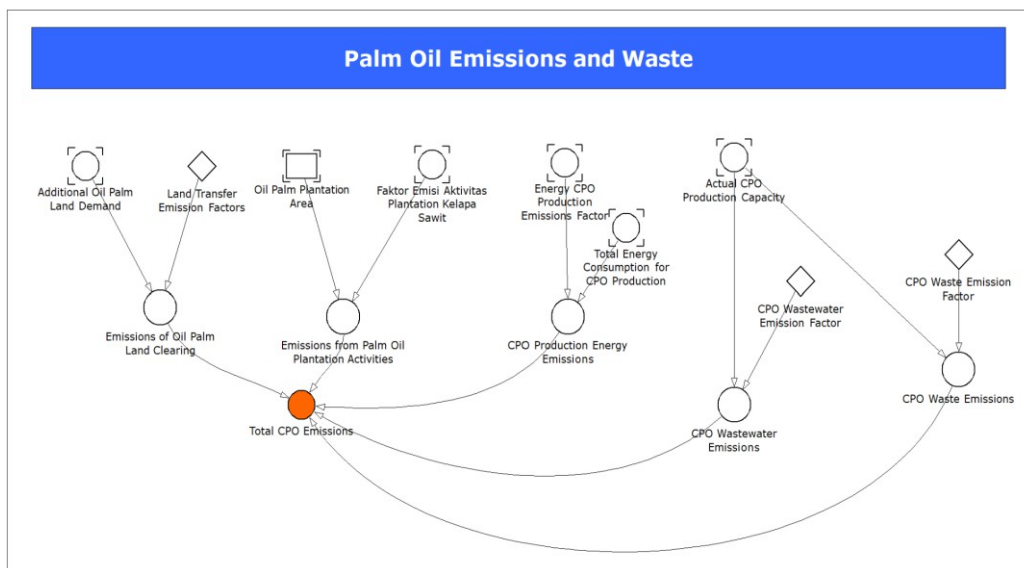


Figure 7. Waste and CPO Emissions Structure Model

5.2.6 CPO Added Value & Total Labor

The added value model structure (Figure 8) is used to analyse the emission intensity of the CPO sector resulting from the total CPO emissions compared to the total added value of CPO. While the total added value of CPO is generated from added value from CPO exports and added value from domestic CPO sales. Meanwhile, the structure of the number of workers takes into account the number of production workers per ton of CPO which is influenced by the total consumption of CPO and the need for labor per ton of CPO. In the CPO sector value-added model, the scenario does not add CPO value because it does not increase CPO demand as a waste & CO2 reduction effort.

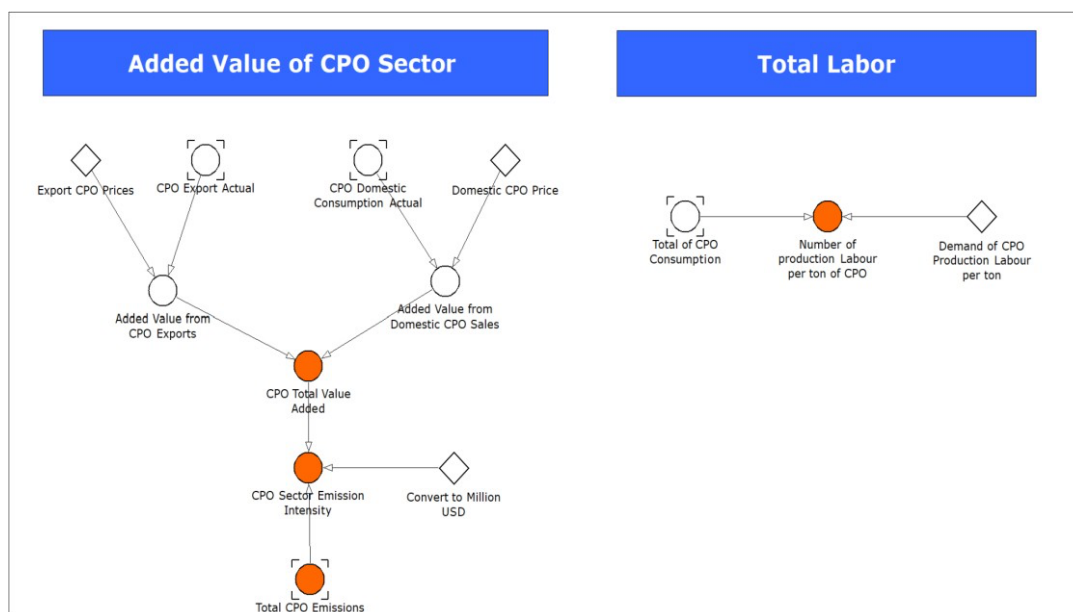


Figure 8. CPO Added Value & Total Labor Structure Model

5.3 Stock Flow Diagram - Policy Structure

5.3.1 Policy 1: Use of organic fertilizers and decentralization of CPO factories

This structure (Figure 9) is used as a model for analysis of policy interventions related to the use of organic fertilizers and the decentralization of CPO factories towards the implementation of a circular economy in the CPO plantation process. The intervention using organic fertilizers in the planting process will increase emission reductions compared to emissions using chemical fertilizers. Meanwhile, the CPO mill decentralization intervention in the planting process will be influenced by the distance between the plantation and the processing area, which will have implications for transportation emissions.

Switching from the use of chemical fertilizers to organic fertilizers can affect land degradation. So that if the use of organic fertilizers increases, the land degradation will be lower. Organic fertilizers can be in the form of solid fertilizers and liquid fertilizers by utilizing and managing solid waste from the CPO process because it can reduce the potential for methane gas. As an additional note that it does not highlight organic fertilizer from POME, because it still requires enrichment and more detailed data so that a more in-depth study can be carried out.

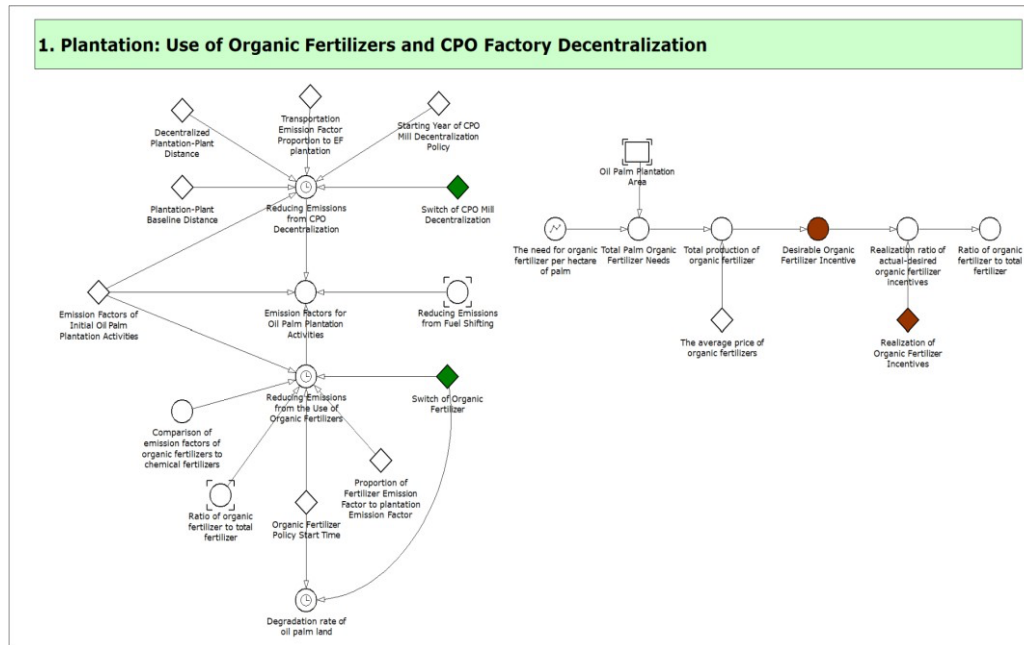


Figure 9. Plantation Policy 1 Structure Model

5.3.2 Policy 2: Increased planting productivity

The CPO planting increase policy (Figure 10) was analyzed based on the intervention target to increase productivity from the baseline as usual productivity and the year the plantation productivity increase policy was started.

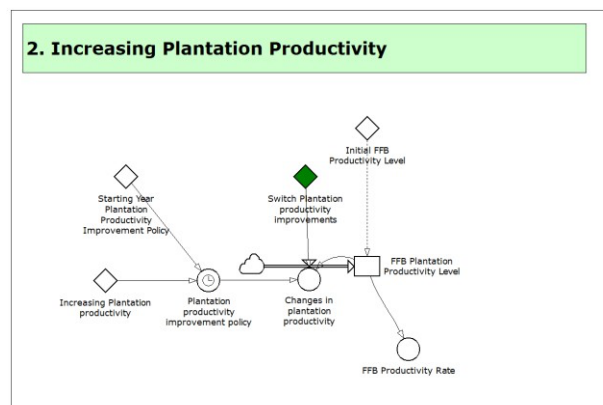


Figure 10. Plantation Policy 2 Structure Model

5.3.3 Policy 3 & 4: POME Biogas & Empty Fruit Bunches and Palm Shell Biomass

The structure of this model (Figure 11) is used to analyze policy interventions for the management of liquid waste and solid waste in the CPO process through biogas and biomass processing. The processing of biogas from palm oil mill effluent is influenced by actual CPO production capacity, PME production and biogas yield from POME. Biomass potential is generated from solid waste production in the form of empty fruit bunches, palm shells and fibres which are affected by the actual FFB milling process.

Biogas and biomass products from solid waste of empty fruit bunches, palm shells and fibres as potential sources of electrical energy that affect the share of potential energy from biomass and biogas to total electricity demand. In addition, the potential share of electricity from biomass and biogas is affected by electricity consumption for CPO production, electricity production from PLTBm (Biomass Power Plants) - PLTBg (Biogas Power Plants), the efficiency of PLTBm and PLTBg, share utilization of biomass and biogas for electricity which is desired.

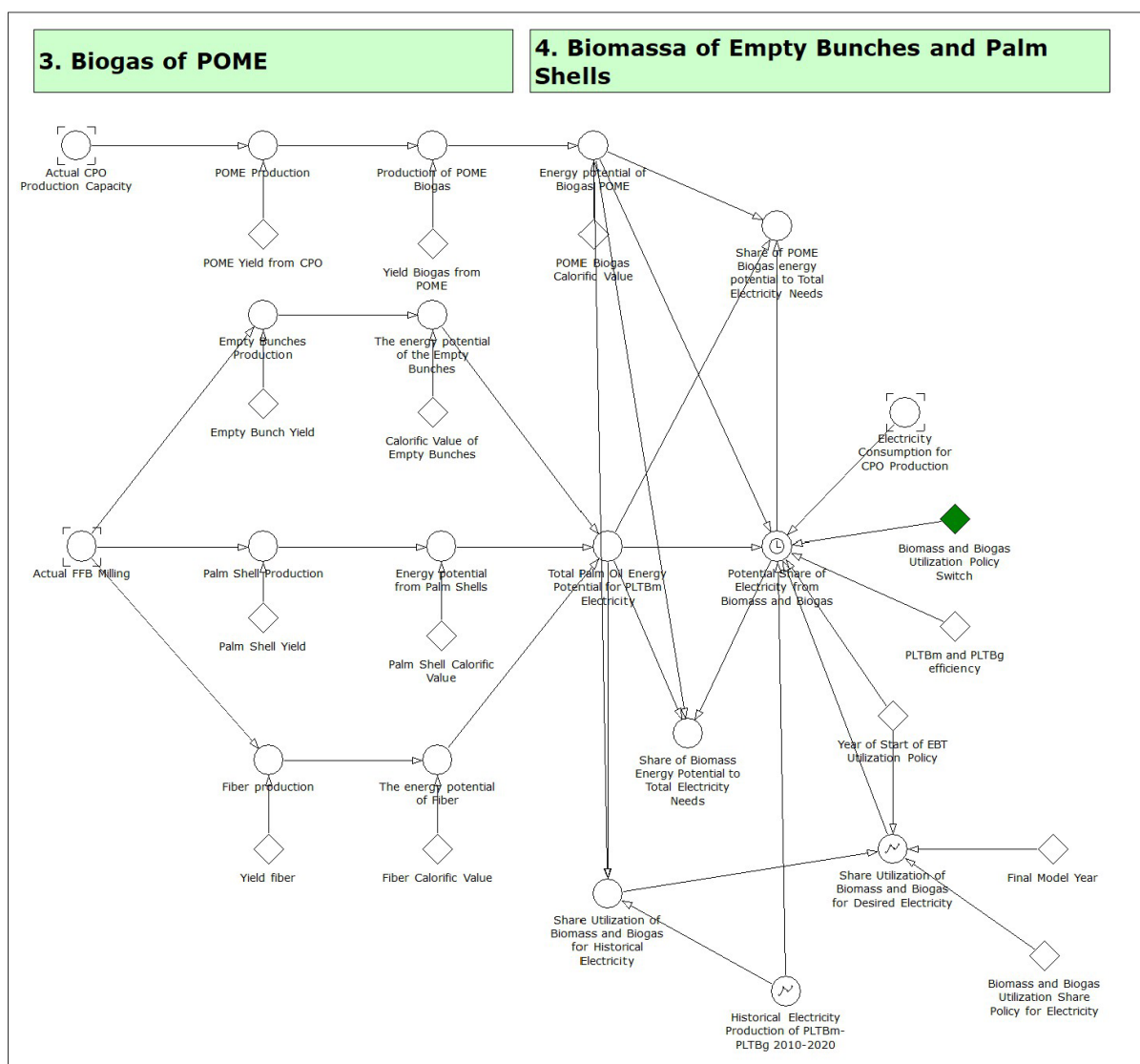


Figure 11. Policy 3&4 Structure Model

5.3.4 Policy 5: Waterless Milling

Waterless policy interventions in the milling process (Figure 12) can be analyzed through the structure of this policy model which considers the ratio of actual and desired waterless milling investment realization. Waterless milling policy investment needs are influenced by milling capacity, waterless milling investment needs per ton, milling time cycle, and the year the waterless milling policy starts. For milling capacity, it is assumed that 1 year is 200,000 USD calculated from a capacity of 10 tons/hour. However, investment data is still limited, CAPEX data does not include OPEX which can be used as further analysis.

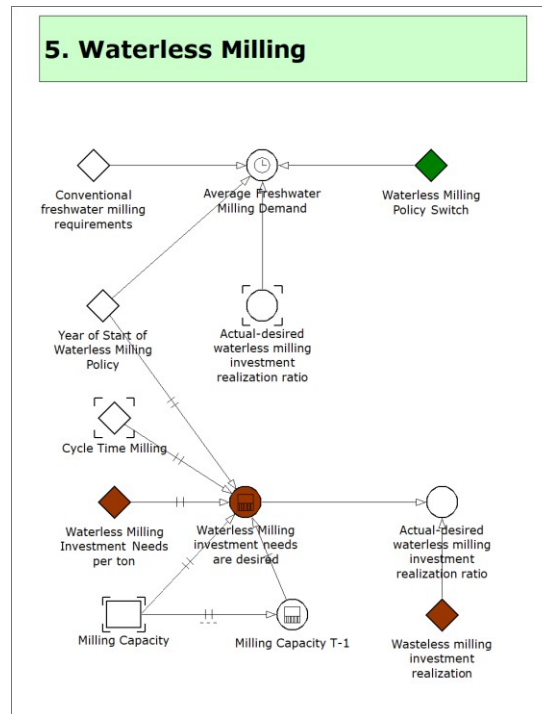


Figure 12. Policy 5 Structure Model

5.3.5 Policy 6: CPO Processing Technology Efficiency

The CPO processing technology efficiency policy (Figure 13) is analyzed through this policy structure by considering the start time of the CPO energy efficiency policy and industrial energy efficiency targets. Technology efficiency policies in CPO processing have an impact on the energy consumption of CPO production. Technological efficiency in CPO processing can be calculated from the assumption of the average manufacturing industry.

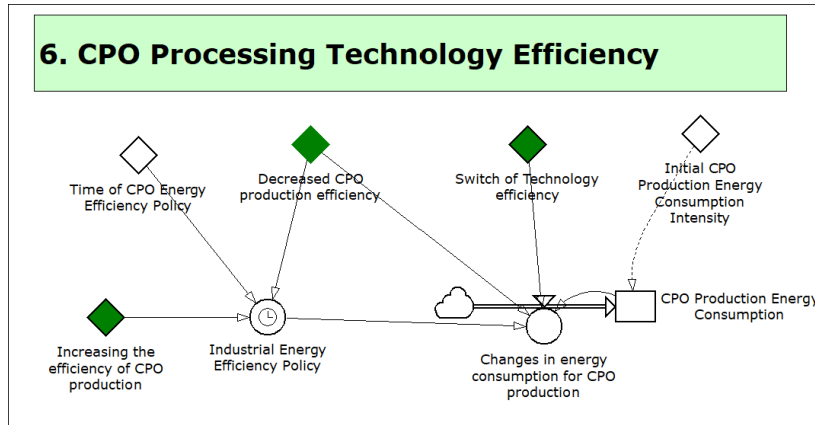


Figure 13. Policy 6 Structure Model

5.3.6 Policy 7: Shifting Diesel Fuel Trucks to BioCNG

Structure of Diesel-BioCHG Truck fuel shifting policy (Figure 14) to analyze the effect of Diesel-BioCNG Truck fuel shifting intervention on emission reduction. Reducing emissions from fuel shifting is influenced by the initial oil palm plantation activity emission factors, gas emission factors, diesel emission factors, the proportion of transportation emission factors to plantation emission factors and the year the BioCNG fuel shifting policy starts.

The gas emission factor is smaller than the diesel emission factor, so it will affect transportation emissions from the plantation to the factory where the new scope model is calculated for the transportation model to the factory. Meanwhile, policies are installed to accommodate transportation needs which are controlled by the industry itself.

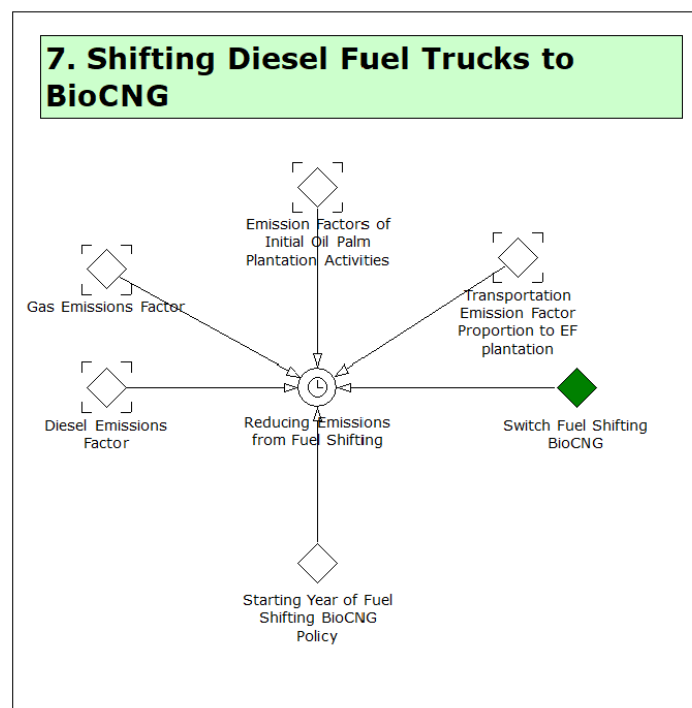
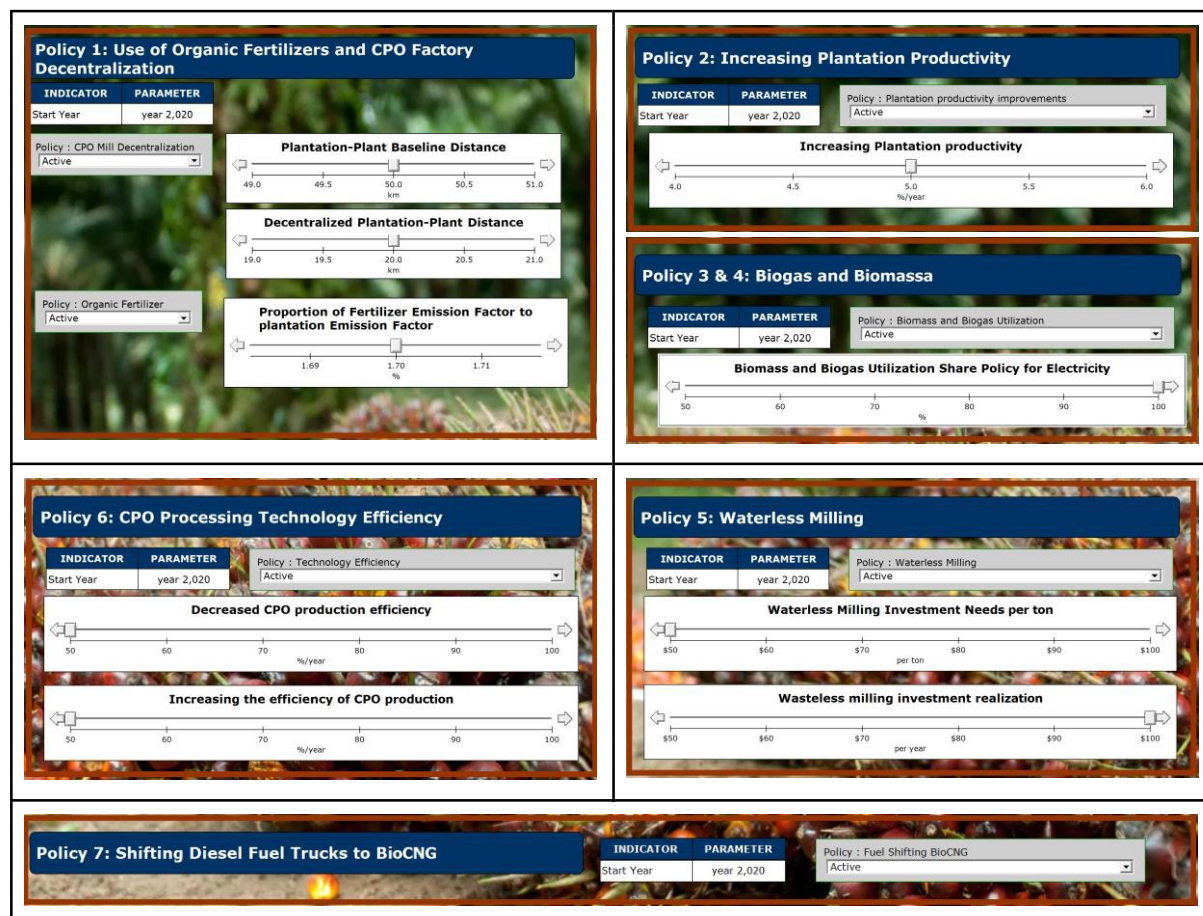


Figure 14. Policy 7 Structure Model

6. Simulation of Indicator and Policy Intervention

To know the illustration if one or some policies will be implemented in the real world, there will be a need to conduct simulation. This simulation is conducted by changing value on the decision variables. Policy analysis is exercised based on socio technical options of waste and CO2 Reduction Strategy from the Waste & CO2 Reduction Life Cycle Assessment study with the following conditions:



After the all the scenario was simulated, we get several information regarding to simulation result. To ease the understanding, we focus on the performance measurement indicators. There are 5 (five) performance measurement indicators.

- **Total of CPO Emissions**

Total CPO emissions (Figure 15) fluctuate due to changes in land use change (sequestration). The area of oil palm plantations will affect land efficiency. Total CPO emission consists of land conversion activities, oil palm plantation activities, total energy consumption for CPO production, CPO wastewater and CPO waste. If viewed from the results of a business as usual (BAU) simulation, the total emission of the CPO sector will relatively continue to increase in line with the increase in CPO activity of 269,532,359 tons of CO₂-Eq in 2060. However, if policy interventions begin to be implemented from 2020, the total emission in the CPO sector is projected to be reduced to 72,995,407 tons of CO₂-Eq or 72.3% compared to BAU conditions.

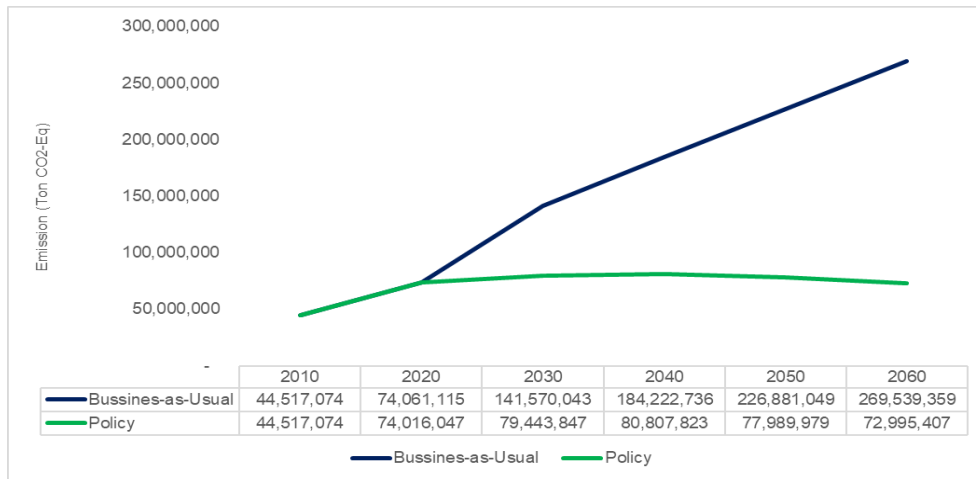


Figure 15. Total CPO Emissions

- **Total of CPO Demand**

Total of CPO Demand (Figure 16) will increase from year to year in line with population growth and export growth which will affect the total consumption of CPO. The model simulation has projected that the total CPO demand in 2060 will be 126,317,861 tons per year. Meanwhile, the actual production of CPO in 2060 is 143,756,184 tons per year.

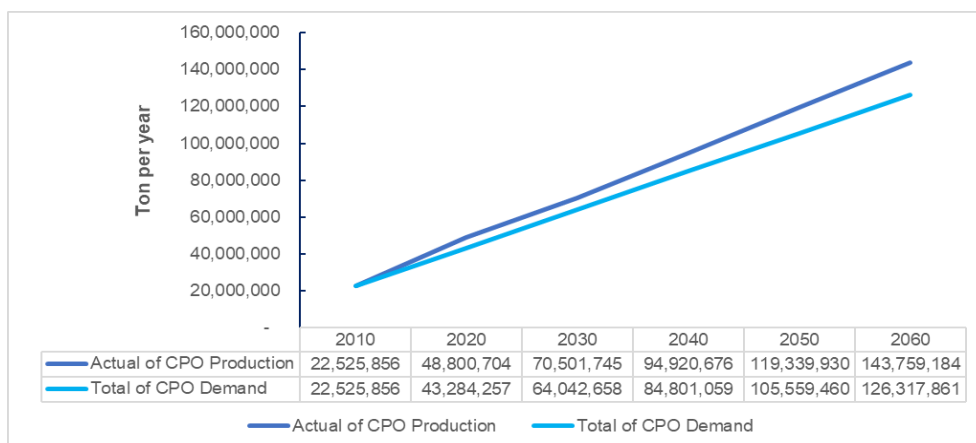


Figure 16. Actual of CPO Demand and Total of CPO Production

- **CPO Emission Intensity**

CPO Emission intensity (Figure 17) is calculated from the ratio of CPO Total Value Added to the total emissions of the CPO sector. In a business as usual simulation, CPO emission intensity is projected to stagnate, whereas if policy interventions begin in 2020 CPO emission intensity will decrease by 73% compared to BAU conditions in 2060. Emission intensity will decrease, which means the intensity will support green economy.

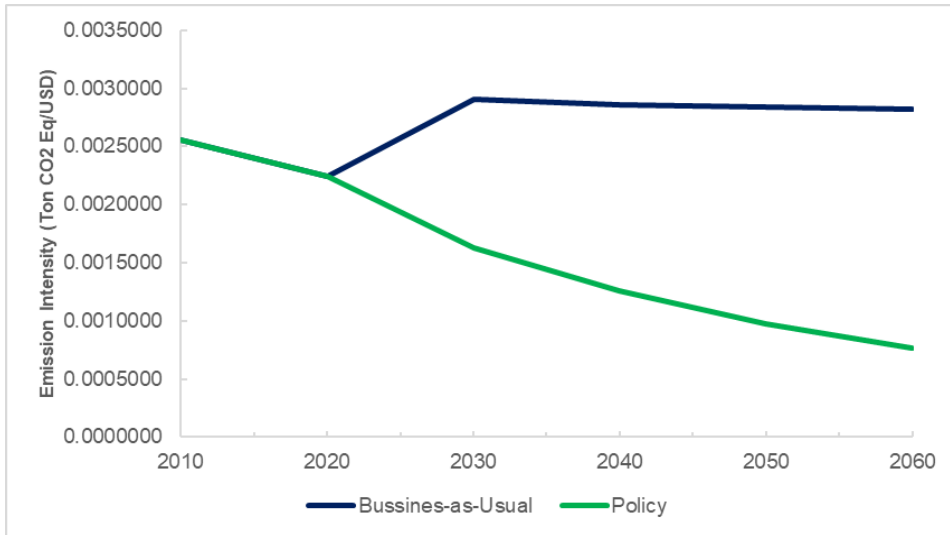


Figure 17. CPO Emission Intensity

- **Labor**

Labor for the CPO production (Figure 18) process are projected to continue to increase in accordance with the increase in CPO production. From the model results it can be seen that the total labor in 2060 is 348.637 labor per ton of CPO

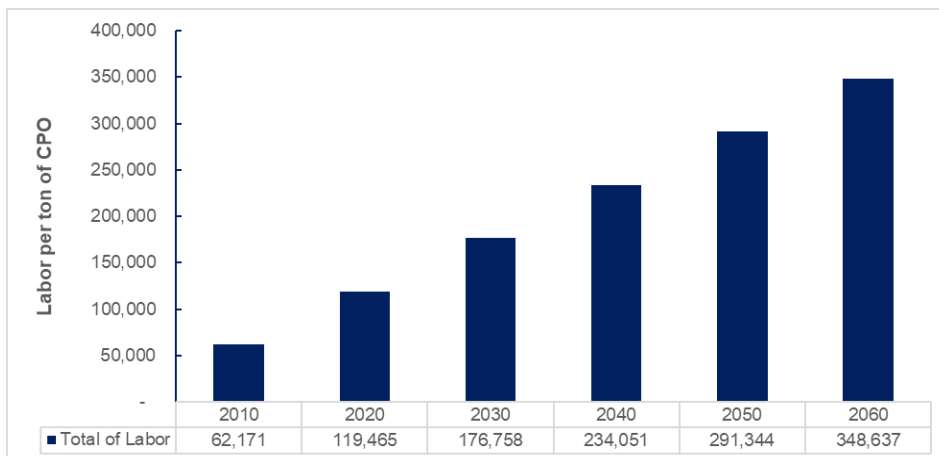


Figure 18. Labor

- **Freshwater Milling Needed**

The simulation results of freshwater milling policy interventions to increase the productivity of the CPO milling process have an impact on the need for investment in freshwater milling technology (Figure 19) which will increase from the business-as-usual simulation. The increase in investment requirements for freshwater milling technology in 2060 will reach USD 14,126,690 per year.

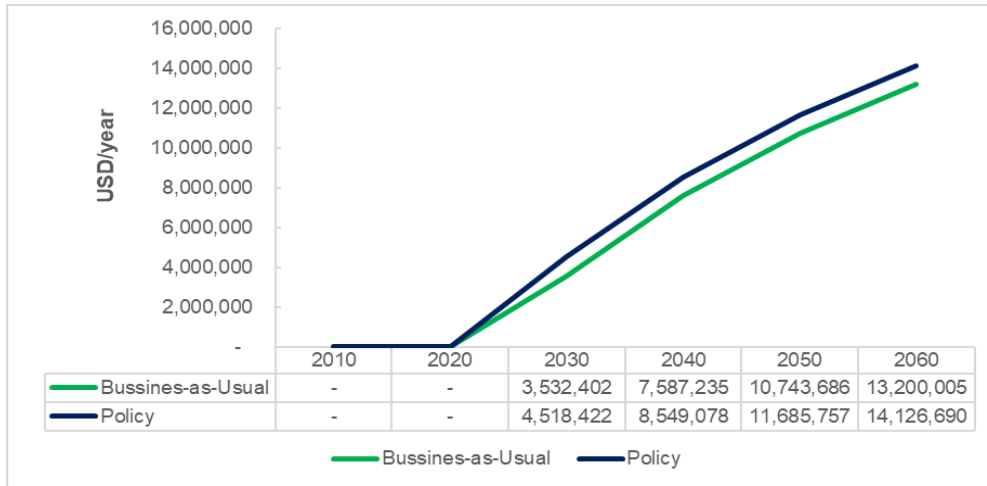


Figure 19. Waterless Milling Investment Desired

7. Conclusion and Recommendation

The results of the Waste and CO2 Reduction Life Cycle Assessment have identified potential policies that support circular economic activities in the CPO sector. Meanwhile, the study has also been analyzed and simulated through a system dynamics model that has considered the available quantitative and qualitative data, expert judgment and other discussions. After constructing a system dynamic model and conducting simulation for scenario analysis, we get several recommendations based our findings in this study. Then, these recommendations can be developed further and exercise the feasibility to implement it. We need to study further about the alternative of investment that can lower the carbon emission. The selected policy should be made in a timeline when the policy will be implemented. As an input in the implementation of policy potential in terms of the results of the analysis of models and enabling conditions, the strategy design also considers the strategy implementation period which is determined by expert judgment based on the time feasibility to achieve the strategy. Three categories of the strategy implementation period are the short term period (1 year), medium term period (5 years) and the long term period (25 years).

Table 3. Strategy for Improving

No	Policy	Period	Enabling Condition
1	Use of organic fertilizers	Short term	<ul style="list-style-type: none"> a. It is easy to find in oil palm plantations because it can be obtained from empty fruit bunches and palm oil mill effluent b. Efforts to avoid garden dependence on chemical fertilizers as well as anticipate reduced nutrient and organic matter levels in the soil, as well as help disease
		20	
No	Policy	Period	Enabling Condition
			<ul style="list-style-type: none"> c. Easy to apply to cropland
2	Decentralization of CPO factories	Medium term	<ul style="list-style-type: none"> a. Need support, collaboration and empowerment of smallholders b. Empowering smallholders to the owner as well as the worker of the facilities could be a way out to lower the emission and cost, as well as alleviation of poverty
3	Increased planting productivity	Short term	<ul style="list-style-type: none"> a. Soil health includes optimum and mutually supportive physical, chemical, and biological properties of the soil b. It is quite easy to apply to planting land c. Increase the availability of ground water
4	Wastewater management: POME Biogas	Medium term	<ul style="list-style-type: none"> a. Availability of funding and rate of return on investment, and lack of interest in investing or providing

5	Waste management: Empty Fruit Bunches and Palm Shell Biomass		<p>loans</p> <p>b. Application of technology that fits the market and makes it a profitable commercial project</p> <p>c. Perceptions of companies regarding the difficulty of working with PLN</p> <p>d. Limited information regarding technology, incentives, and human resources for operationalization</p>
6	CPO Processing Technology Efficiency	Long term	<p>a. Investment in CPO process efficiency technology is needed</p> <p>b. Availability of funding and rate of return on investment, and lack of interest in investing or providing loans</p> <p>c. Limited information regarding technology, incentives, and human resources for operationalization</p>
7	Waterless Milling	Long term	<p>a. Investment in waterless milling technology is required</p> <p>b. Availability of funding and rate of return on investment, and lack of interest in investing or providing loans</p> <p>c. Limited information regarding technology, incentives, and human resources for operationalization</p>
No	Policy	Period	Enabling Condition
8	Shifting Diesel Fuel Trucks to BioCNG	Medium term	a. Limited information regarding technology, incentives, and human resources for operationalization

In conclusion, based on the result and analysis from it, we can construct six recommendations for government:

1. Capacity building of stakeholders such as companies, government, NGOs (non-governmental organizations, and financial institutions. Knowledge sharing by companies that have successfully intervened in policies related to the economic circular, construction of training centres, application of international standards, development of guidelines and national standards by the government and safety standards for PLTBg and PLTBm.
2. The government encourage for the obligation to develop methane capture through ISPO (Indonesian Sustainable Palm Oil) establishing GHG emission standards that require methane capture installations; additional points in the PROPER (Company Performance Rating Program in Environmental Management) assessment for mills with methane capture facilities and GHG emission reports.
3. The government needs to build a pilot project that can serve as a training centre and make referrals to projects in neighbouring countries such as Thailand and Malaysia.
4. Looking for the more efficient options to conduct investment that lower the carbon emission. The more efficient options mean the alternative outside reforestation or combination of reforestation and another alternative. Another alternative that should be consider is investment in more advanced machinery which produce less carbon emission.
5. Prioritize the application of the intervention policies that implement the obligation to conduct investment that lower the carbon emission and carbon tax. It should be noted that both of policies should be implemented together at the same time to fulfill the better performance on labor, taxes collected by the government, and carbon emission reduction.
6. Consider changing the tax incentives to a subsidy or incentives that can reduce the average cost of investment to lower the carbon emission. The subsidy can be given during the investment process that reduce carbon emission or subsidy that can lower the product price of palm oil company in the domestic/foreign market. The subsidy sources can be taken from the carbon tax revenue, so the government can implement cross subsidy mechanism.

Then, for palm oil industry, we generate three recommendations:

1. Support and participate the implementation of the policy. The policy will not deliver the outcome if the palm oil industry company as the one who implement in the real condition.
2. Give opinion and feedback before (policy construction process) and during the implementation of the policy. The industry party should assess the impact and outcome, especially in terms of cost and revenue, if the policy will be implemented. The process before and during the implementation should be in two directions from and to government and palm oil industry, so it can generate win-win solution for both parties.
3. Focus on balance sheet financing, bearing in mind that biogas projects are considered small for an investment project scale, making it less attractive for financial institutions to support project financing schemes. Ensure financial feasibility through a complete feasibility study, and pursue concessional loan options.

Furthermore, there is a recommendation for both government and palm oil industry. Government and palm oil industry parties should det up discussions to promote the policy that will be implemented and the capability of the industry to support that. The discussion should generate additional benefit to company who will implement the policy. For example, there will be eco-friendly logo or awarding that can be placed on the product of company or more support of government in terms of export palm oil product to specific countries that have high awareness in eco-friendly (i.e., Europe).

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PART 3

Waste & CO₂ Reduction Life Cycle Assessment

Table of Contents

Part 3 | Waste & CO₂ Reduction Life Cycle Assessment

1. Introduction	1
2. Metodology	4
3. Life Cycle Assessment	11
3.1 Plantation/Cultivation Value Chain	11
3.2 Mill Value Chain.....	14
3.3 Refinery Value Chain.....	20
3.4 Packaging and Distribution Value Chain	20
3.5 Consumption and Disposal Value Chain	24
4. Sociotechnical Options of Waste and CO ₂ Reduction Strategies	26
References	31
Appendix 1: System Boundaries for LCA Analysis	33
Appendix 2: Inventory Background Data for LCA Analysis	42
Appendix 3: Detailed Foreground Data for LCA Analysis	46

1. Introduction

The new global food emissions database (EDGAR-FOOD), which was built on the Emissions Database of Global Atmospheric Research (EDGAR) and land use/land-use change emissions from the FAOSTAT emissions database, shows that the most significant contributor to Greenhouse Gas (GHG) emissions is from the Food sector. For Developing Countries, the largest GHG emissions come from land use and land-use change (LULUC) followed by production, distribution, and end of life processes. Through the Quick Assessment/Rapid Assessment (QA/RA) study, it has been discovered that the Palm Oil Processing industry (mill and refinery) is the most potential subsector for implementing circular economy and low carbon development policies in the Food Industry. Palm oil is a strategic export commodity that contributes to USD 18.3 billion of the national GDP, 16.2 million employment, and regional developments.¹ It has a growing market in the food sectors and the energy, cosmetics, and other industrial sectors. The growth of the palm oil industry has increased rapidly, with the plantation expansion almost doubling from 2010 -to 2020. As of 2019, the total land area of oil palm plantations in Indonesia achieved 16.38 million ha.²

In 2019, Indonesia produced 47.12 million metric tons of palm oil (more than half of global production).³ On the other hand, palm oil plantation responsible to approximately 20-25 tons of CO₂-eq emissions per hectare per year or equals to 13.8% of national emissions.^{4,5} Therefore, the palm oil industry can support the Indonesian government's commitment to achieving net zero-emission in 2060 by setting up mitigation activities, especially in the energy, agriculture, and waste sectors. Figure 1 shows the distribution of oil palm plantations in Indonesia. Most of the oil palm plantations (more than 60%) were located in Sumatera, Kalimantan, and Sulawesi. The government owns only 7% of the oil palm plantation areas, while the rest are owned by private companies (52%) and smallholders (41%).⁵ The major privately-owned palm oil producers in Indonesia are PT. Astra Agro Lestari TBK, PT. Perusahaan Perkebunan London Sumatra Indonesia TBK, PT. Sinar Mas Agro Resources and Technology Tbk., and PT. Bakrie Sumatera Plantation Tbk.

¹ Tropenbos Indonesia, Info brief – Oktober 2020

² Surat Keputusan Menteri Pertanian No. 833/KPTS/SR.020/M/12/2019 tentang Penetapan Luas Tutupan Kelapa Sawit Indonesia Tahun 2019

³ <https://www.statista.com/statistics/>

⁴ <https://www.bpdp.or.id/en/research-shows-palm-oil-produces-lower-emission>, 12 March 2020

⁵ Vita Dhian Lelyana, Mugiyanto, Agus Haryanto, The Potential Reducing of GHG Emission from Palm Oil Plantation and Mill in The Contribution of National Target.

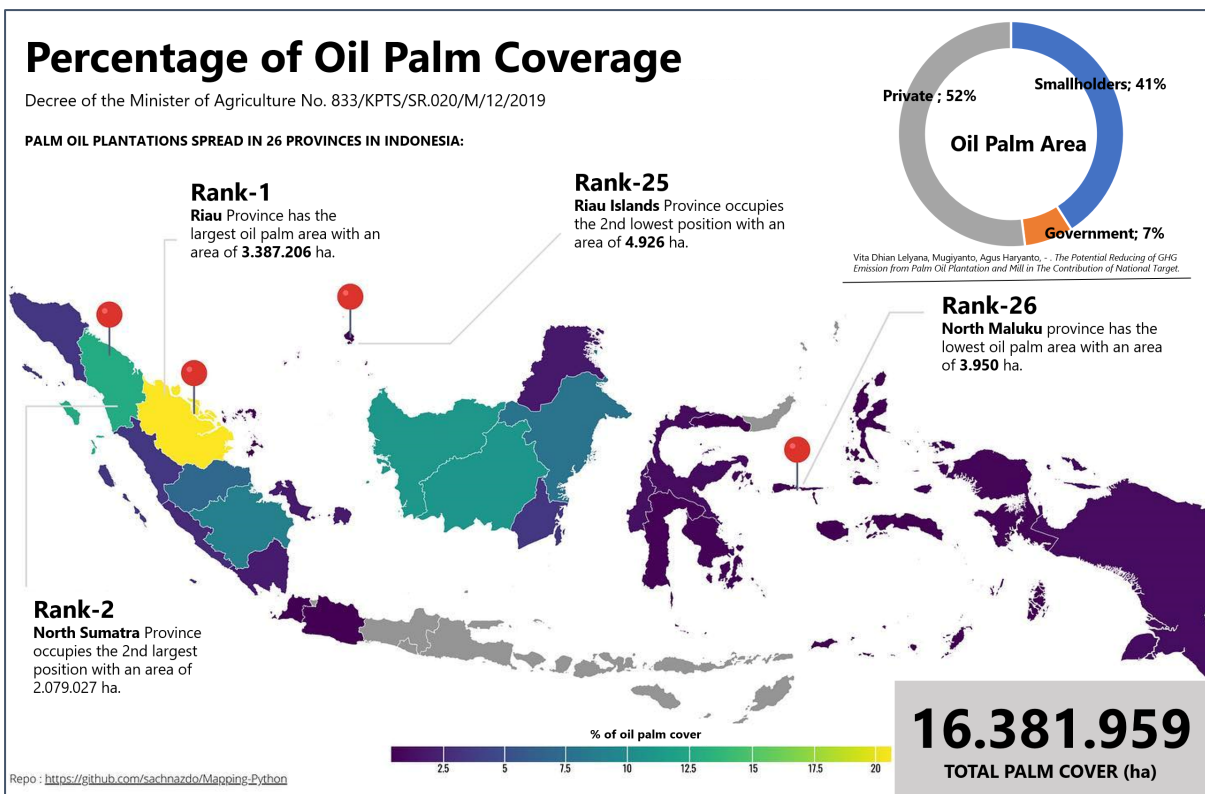


Figure 1 Distribution of Palm Oil Plantation and Production in Indonesia ^{2, 5}

Palm oil plantation development has been closely related to the issues of deforestation and the destruction of carbon-rich peatlands. However, as more and more international companies demand sustainable palm oil that meets the criteria of the Malaysia-based Roundtable on Sustainable Palm Oil (RSPO), in 2011, Indonesia established its own Indonesian Sustainable Palm Oil (ISPO), which aims to enhance the global competitiveness of Indonesian palm oil and brings it under stricter environmental legislation. As a result, all Indonesian palm oil producers are now compelled to receive ISPO certification. Until the end of June 2020, there were 621 ISPO certificates issued, covering an area of 5,450,329 ha of oil palm plantations or 38.03% of the total area of oil palm plantations in Indonesia.⁶ After Perpres No. 44/2020, all stakeholders (including smallholders) are obligated to have ISPO certificate within 5 years. In addition, the establishment of sustainable Palm Oil Initiatives (SPOI) and the Indonesian Oil Palm Research Institute benefit from providing data for this study.

Production of cooking oil (refined palm oil olein) from Indonesian palm oil refinery industry reaches 15.5 MMt in 2009 (see Table 1) the production has grown rapidly surpassing the growth of consumption. Palm cooking oil local food consumption in Indonesia in 2020 was about 11.58-liter cooking oil per capita per year (approximately 6 MMt/year).⁷ In a Publication in Food Consumption Bulletin of the Ministry of Agriculture (2019), the production of palm cooking oil in Indonesia is able to meet the overall national consumption and even exported abroad with estimated volume of 20.36 MMt. Data from the Large-Medium Industry (Industri Besar Sedang) survey shows that there are 74 palm cooking oil factories in Indonesia, of which 45 factories are concentrated on the Java Island (see Figure 2).⁸

⁶ Daily Investor Indonesia, 2020. Pemerintah Takkan Intervensi Penerbitan Sertifikat ISPO. Diunduh dari <https://investor.id/business/pemerintah-takkan-intervensipenerbitan-sertifikat-ispo>.

⁷ Susenas, BPS (Maret 2015-2020) – menggunakan rasio minyak goreng sawit dengan minyak kelapa

⁸ BPS 2021 Distribusi Perdagangan Komoditas Minyak Goreng Indonesia

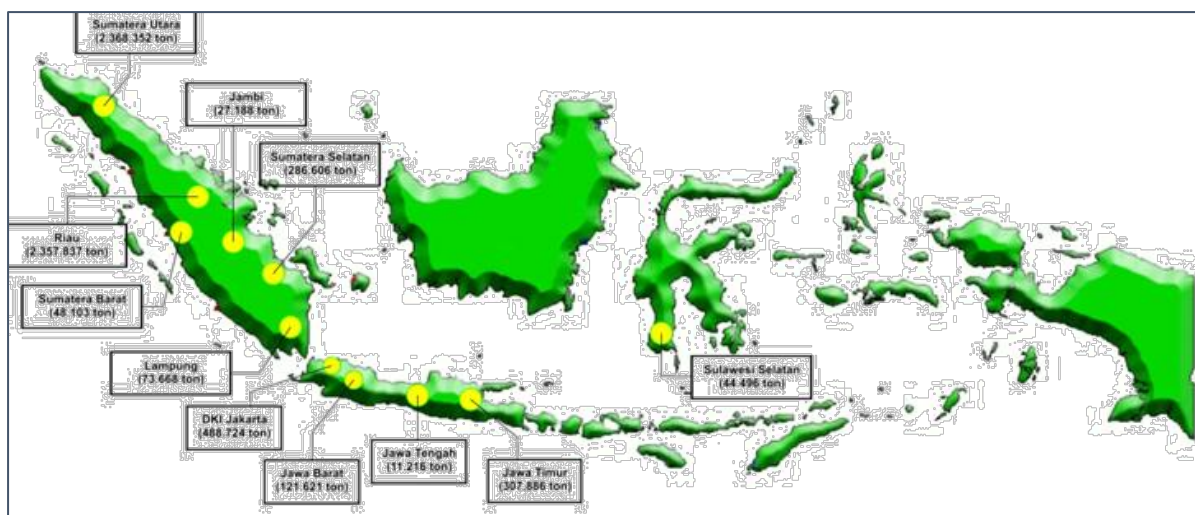


Figure 2 Indonesian Palm Oil Refinery Industry Profile⁹

Table 1 Production Capacity & Market Share of Cooking Oil Industries in 2009¹⁰

No	Shareholders	Production Capacity (Ton/year)	Market Share (%)
1	Wilmar Group (5 companies)	2,819,400	18.24
2	Musim Mas (6 companies)	2,109,000	13.64
3	Permata Hijau (3 companies)	932,000	6.03
4	PT Smart	713,027	4.61
5	Salim Group	654,900	4.24
6	PT Bina Karya Prima	370,000	2.39
7	PT Tunas Baru Lampung (Sungai Budi Group)	355,940	2.30
8	BEST Group	341,500	2.21
9	PT Pacific Palmindo Industri	310,800	2.01
10	PT Asian Agro Agung Jaya (RGM Group)	307,396	1.99
11	Others	6,542,637	42.33
Total		15,456,600	100.00

⁹ Profil Komoditas Minyak Goreng, Kemenperin (2009).

¹⁰ Profil Komoditas Minyak Goreng, Kemenperin (2009).

2. Metodology

The study will identify the downstream value chain to obtain the potential for waste and CO₂ reduction by finding the current state of its Life Cycle (VSM). Then, the finding will lead to the technology available to reduce waste and CO₂ production to promote a circular economy, such as the waste to energy technology to transform current waste into energy. The study will perform a data collection in the technology portfolio to obtain the comprehensive finding to reduce or transfer waste with every trade-off. Then, the assessment will be calculated based on the current state of food and beverage waste with the available technology considering CO₂ reduction, cost, and circular implementation. The output of this phase is the feasible technology and its implementation to reduce waste and CO₂, as shown in Figure 3 below.

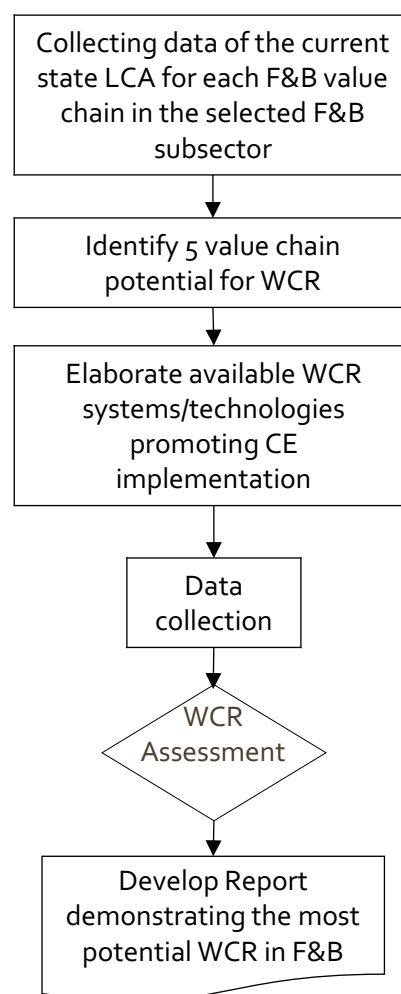


Figure 3 Methodology of WCR Potential Assessment

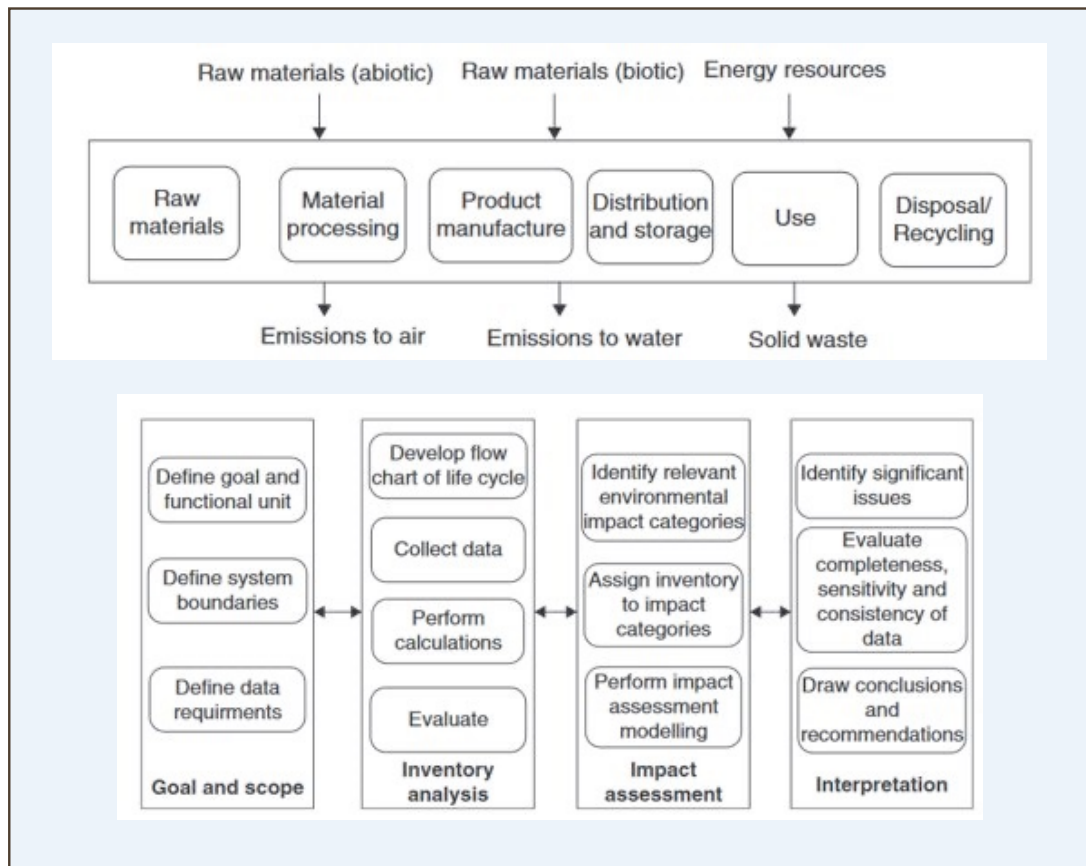


Figure 4 Life Cycle Assessment Stages ¹¹

The Life Cycle Assessment is conducted by using a methodological framework based on ISO (International Standardization Organization) 14040 standards carried out using the SimaPro software with secondary data obtained from the related industrial inventory adjusted to the domestic production and distribution capacity. A detailed step-by-step procedure for processing life cycle analysis (LCA) using SimaPro software is displayed in Figure 5. Inventory databases used in this study comprise background data from Agri-footprint 5 – mass allocation and Ecoinvent 3 – allocation at point of substitution (APOS). Impact assessment was conducted under ReCiPe 2016 Method, Midpoint-Hierarchy Perspective. Foreground inventory database have also been collected through survey. The assessments of foreground data are conducted with software as well as with manual calculations to show the variation of scenarios.

¹¹ Adapted from: Verghese K, Lockrey S, Clune S, Sivaraman D (2012) Life cycle assessment (LCA) of food and beverage packaging. Emerging Food Packaging Technologies Ch. 19, 380-408.

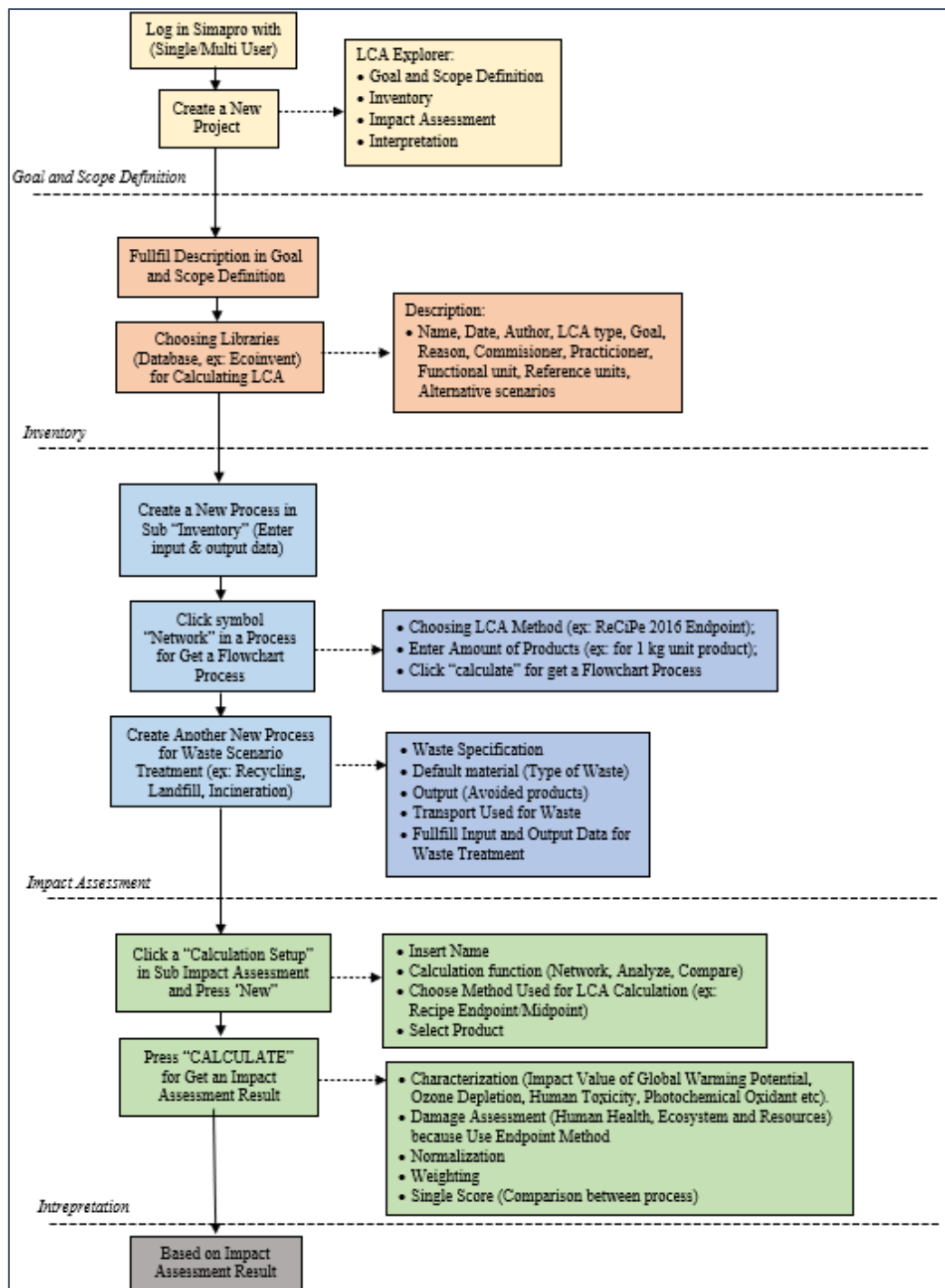


Figure 5 Detail Flowchart of Life Cycle Analysis (LCA) using SimaPro Software

LCA is carried out in 4 stages:

- 1) **Goal and scope** – Goal: determine the supply chain with the most significant potential in reducing waste and CO₂ output in the selected sub-sector. Prospective stakeholders include PTPN, BDPDKS, and Wilmar. Scope: gate to gate or gate to the grave scenario, namely by analyzing raw materials that have been processed to disposal (without involving analysis of recycling, reuse, and ecological loop processes). The needed data are raw material consumption, processing, manufacturing, packaging and distribution, consumption, and end of life/disposal. The functional unit used in this assessment is 100 kg CPO – 25 kg cooking oil (25% OER) with system boundaries as follows:

- Raw materials: Palm oil, fresh fruit bunches
- Products: Crude palm oil (CPO) & cooking oil
- Material processing – is displayed in Figure 6
- Product manufacture: production of CPO & cooking oil
- Distribution & storage: transportation + plastic packaging
- Use: food processing
- Disposal/recycling: Palm oil mill effluent (POME) + Empty fruit bunch (EFB) & cooking oil recycle

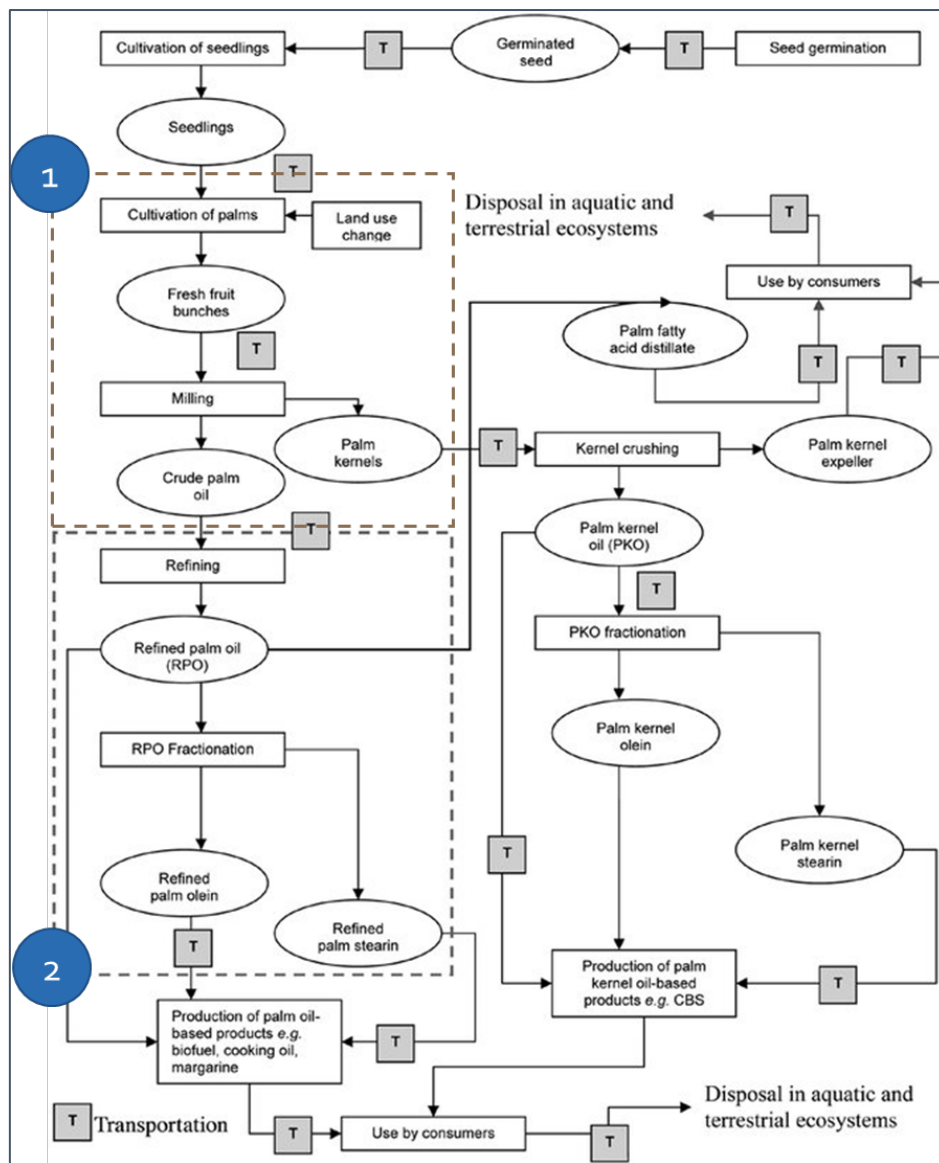


Figure 6 Scope of Study (1) CPO Production and (2) Cooking Oil Production ¹²

¹² Adapted from: Tan YA, Halimah M, Zulkifli H, Subramaniam V, Puah CW, Chong CL, Ma AN, Choo YM (2010) Life cycle assessment of refined palm oil production and fractionation (Part 4). Journal of Oil Palm Research, 22, 913-926.

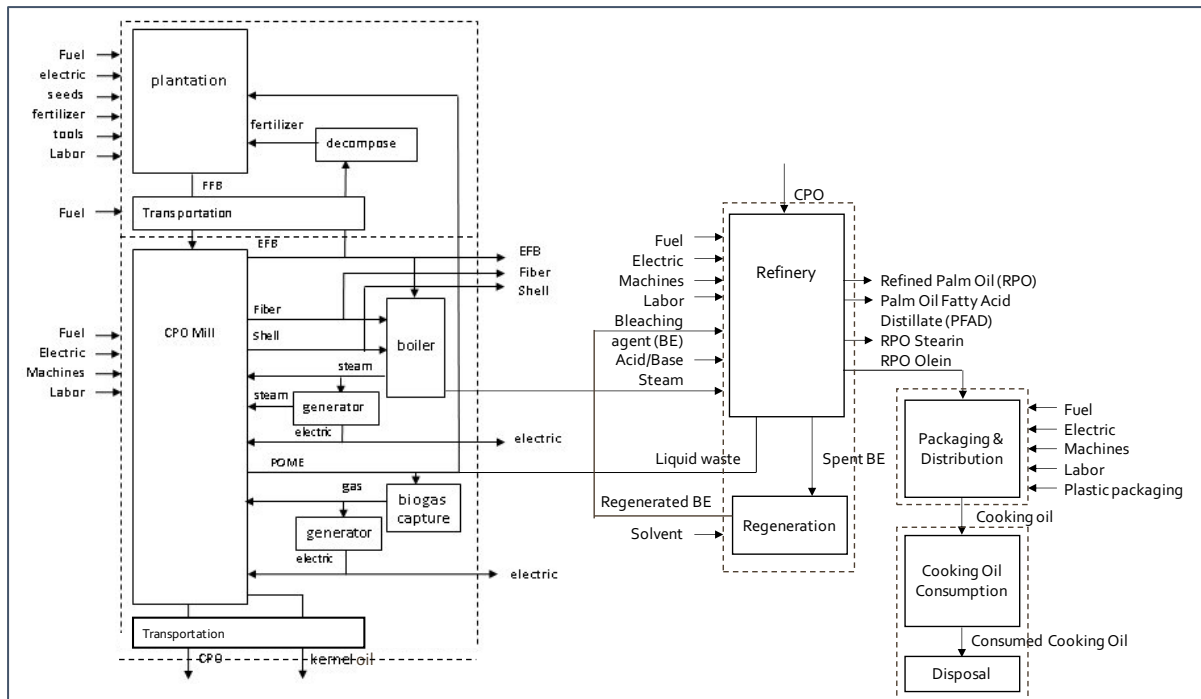


Figure 7 System Boundaries for Plantation, Mill, Refinery, Packaging and Distribution, as well as Consumption and Disposal ¹³

- 2) **Life cycle inventory** – the use of a database of related industrial inventories provided by SimaPro software will be used as a reference to adjust to the production capacity and distribution of associated industries in the country. Some alternative LCI databases available at SimaPro include the renowned Ecoinvent V3 database (EIN_UNIT06567700392 & EIN_UNIT06567700391), the industry-specific Agri-footprint database, the EU and Danish Input-Output database, and Industry data 2.0. Data collections are necessary to perform LCA and WCR analysis. It is classified into four main steps: plantation, mill, refinery, packaging and transport, and use and disposal (Figure 8).
- 3) **Life cycle impact assessment** – an assessment will be carried out on each supply chain that has the potential to reduce waste and CO₂. Considering the Rapid/Quick Assessment study results, which are based on KBLI level 4, the impact of LULUC will be excluded from the discussion.
- 4) **Interpretation** – Select one of the supply chains with the greatest potential to reduce waste and CO₂ and then develop strategic policy recommendations for the selected sub-sector.

¹³ Adapted from: Jaizuluddin Mahmud, Marimin, Erliza Hambali, Yandra Arkeman & Agus R. Hoetman. The Design of Net Energy Balance Optimization Model for Crude Palm Oil Production. Communications in Computer and Information Science (2015) 516:76-88

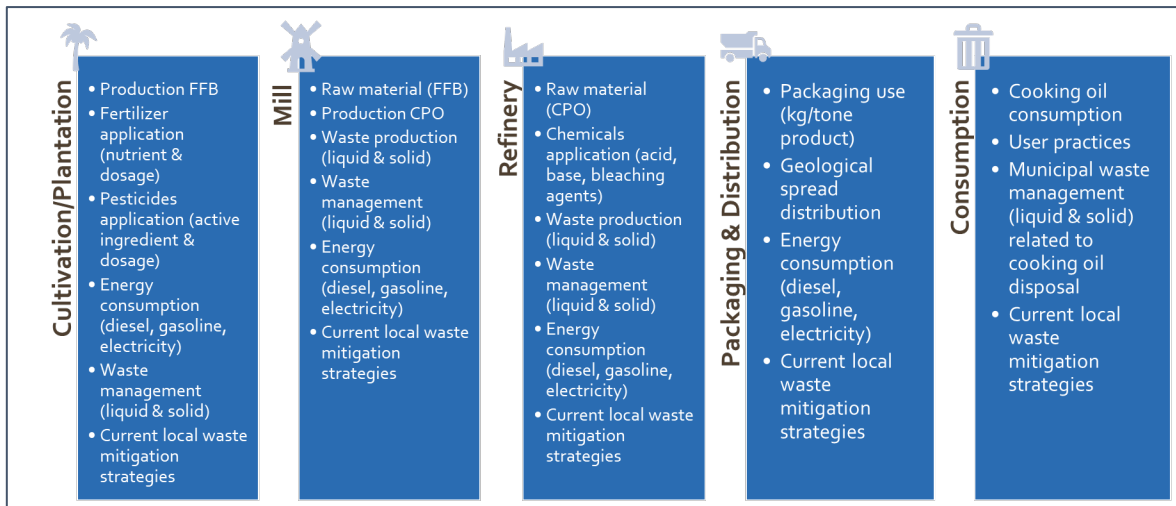


Figure 8 List of Data Collections at Each Observed Chain

In this study, performance and process indicators will be used to report an in-depth assessment of Waste & CO₂ Reduction Potential in the Palm Oil Processing Industry Subsector. Performance indicators address what should be changed in our value chain, focusing on production steps and materials flows, showing where interventions are required. For example, performance indicators may include the waste generated within each step of the value chain, the share of secondary resources used within the production processes, or the recycling rate of the products. Process indicators address how the necessary change can be brought about, which links to culture, market failure, human behavior, operational activities, and institutional reform.

A recent study, *Decarbonizing the food and beverages industry: A critical and systematic review of developments, sociotechnical systems, and policy options*, has presented a comprehensive, critical and systematic review of more than 350,000 sources of evidence and a shortlist of 701 studies, on the topic of greenhouse gas emissions from the food and beverage industry. It utilizes a sociotechnical lens that examines food supply and agriculture, manufacturing, retail and distribution, and consumption and use. The review identifies the most carbon-intensive processes in the industry and the corresponding energy and carbon "footprints." Potentially transformative technologies are to be brought about as emerging options and practices for decarbonization providing benefits to decarbonization—including energy and carbon savings, cost savings, and other co-benefits related to sustainability or health—as well as barriers across financial and economic, institutional, and managerial, and behavioral and consumer dimensions. It also gives gleams on how financing, business models, and policy can be harnessed to overcome these barriers. The sociotechnical system approach used in explaining social and technological options for reducing waste production and CO₂ emissions is depicted in Figure 9.

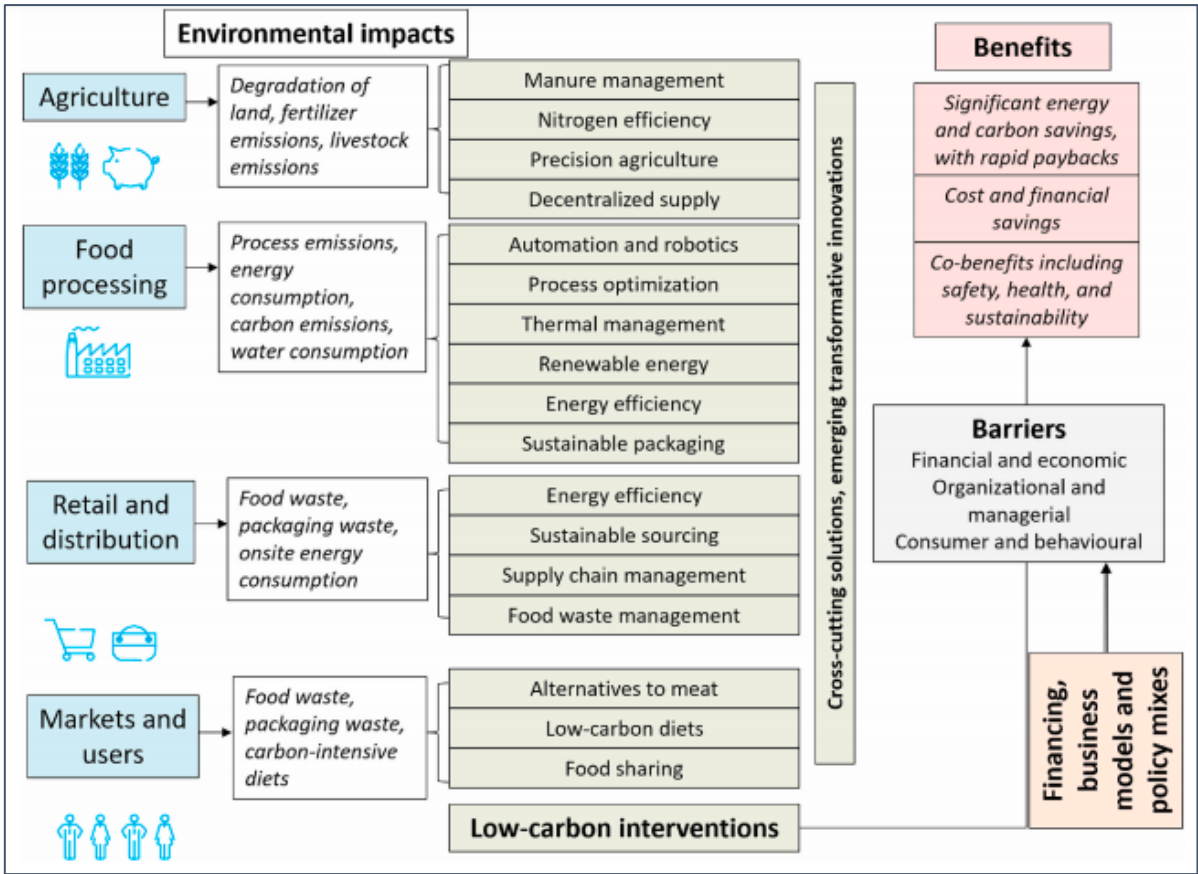


Figure 9 Interventions, Benefits, Barriers, and Policies for Decarbonizing the Food and Beverage Sociotechnical System ¹⁴

¹⁴ Sovacool BK, Bazilian M, Griffiths S, Kim J, Foley A, Rooney D (2021) Decarbonizing the food and beverages industry: A critical and systematic review of developments, sociotechnical systems and policy options. Renewable and Sustainable Energy Reviews, 143, 10856.

3. Life Cycle Assessment

Life cycle assessments have been conducted for five value chains (i.e., cultivation, mill, refinery, packaging and distribution, as well as consumption and disposal). For plantation and mill, there are four scenarios' approaches (i.e., software assessment using Indonesian background database including LULUC, software assessment using Indonesian background database excluding LULUC, software assessment using foreground data excluding LULUC, and manual assessment using foreground data excluding LULUC). For refinery, there is an assumption of 21% CPO refined for palm cooking oil production. Packaging and distribution assess only the 2L PET bottled – palm cooking oil. While consumption and disposal assessment were conducted with premise that vegetable cooking oil is carbon neutral meaning CO₂ released when it burned is the same as CO₂ taken by plant to grow. Thus, the approach come from the utilization of used cooking oil as raw material for biodiesel production.

3.1 Plantation/Cultivation Value Chain

The cultivation process of Oil palm fruit in Indonesia considering seeding, plantation, fertilizer, lime and pesticide application rates and their production, capital goods depreciation, energy use for field management and irrigation (see Figure 10). The elementary flows include field emissions to the air, water and soil, direct land use change emissions and emissions due to pesticide use and heavy metal emissions.

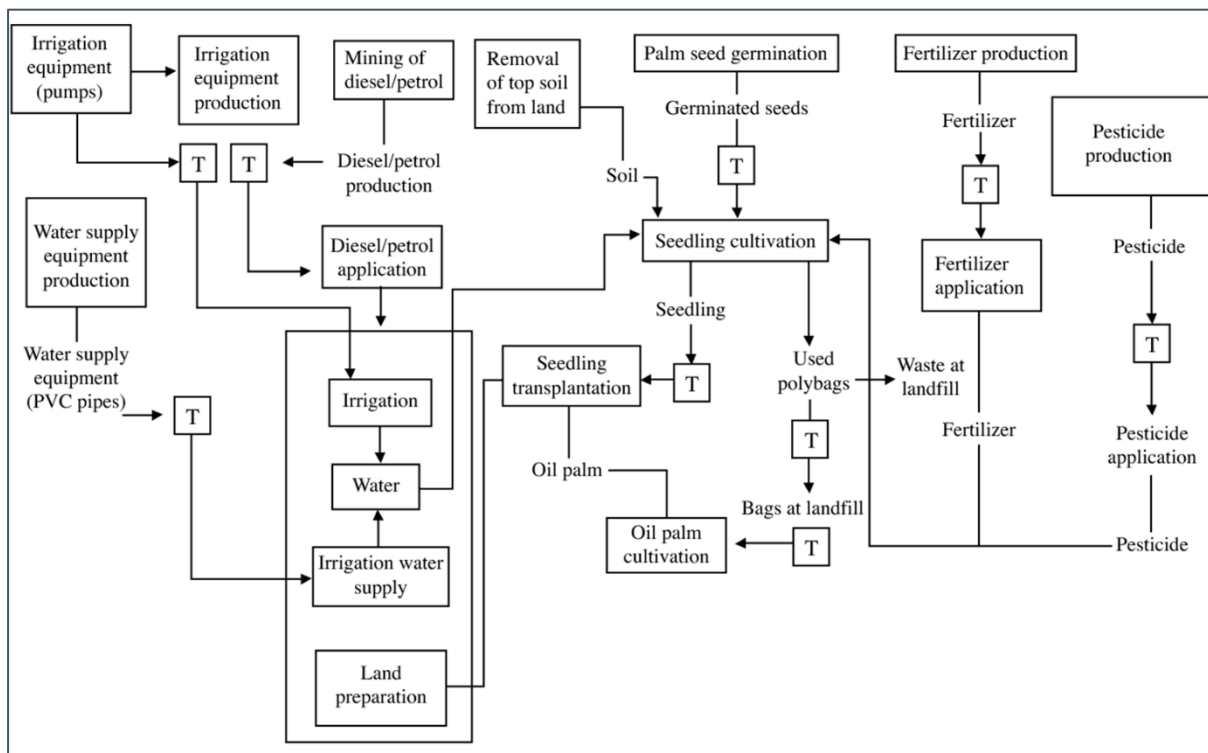


Figure 10 Flow Chart for Palm Oil Cultivation/Plantations ¹⁵

For the first and second scenarios, the LCI are taken from Agri Footprint 5 – mass allocation background data. Crop yields are derived from FAO statistics using a 5-year average (2012-2016).

¹⁵ Halimah, et al. (2010). Journal of Oil Palm Research 22:878-886.

Possible co-production is in line with Agri-footprint methodology. Synthetic fertilizer use is: 86.77 kg N, 59.97 kg P₂O₅ and 134.26 kg K₂O equivalents, based on NPK model. Specific fertilizer amount is quantified based on total NPK and relative amounts of fertilizer consumed by type for the region Indonesia.¹⁶

For arable cultivations, animal manure is applied for soil maintenance based on the methodology described in Appendix 4 of Vellinga et al (2013).¹⁷ Nutritional input from manure for this type of cultivation is: 0.00 kg N and 0.00 kg P₂O₅ equivalents, based on data from FAOSTAT (2012-2016). Seven heavy metal emissions due to synthetic fertilizer, manure and lime use have been calculated based on adapted methodology.¹⁸ It is taken in account the heavy metal balance as a function of deposition, use of fertilizer and crop uptake using literature concerning heavy metal contents of manure (Amlinger et al. 2004) and fertilizers and lime (Mels, Bisschop & Swart, 2008)¹⁹ and crop uptake (Delahaye et al. 2003).²⁰

Total water use is based on the 'blue water footprint' of Oil palm fruit in Indonesia, which is 0.00 m³/ton.²¹ It was chosen not to include 'green water footprint' of 904.04 m³/ton or total rain water of 15441.56 m³/ha to the dataset.

Energy use for arable and orchard cultivations were calculated based on 'Energy model for crop cultivation', which include energy requirements for nine different agricultural activities. Various inputs are used for the energy model including yield, irrigation water use and different type of tillage techniques applied around the world. For horticultural cultivations the amount of energy is based on 'Energy model for horticulture' which includes climate conditions to estimate heat and electricity demand for cultivation.

Total pesticide use is based on 'Pesticide model' which determines the amount of insecticide, fungicide and herbicide specific for crop country combination. Pesticide emissions are based on the most common active ingredients for the global region. LCI for Plantation scenarios 1 and 2 are available as Supporting Information.

Land transformations are responsible for 770 kg CO₂-eq/100 kg produced CPO (96.4%wt of total CO₂ emission). By excluding the land transformations from the assessment, the total CO₂ emissions from plantation reduce to 28.7 kg CO₂-eq/100 kg produced CPO and Fertilizers take the first major responsibility of about 20.8%, while energy for machineries comes second with 3.77% and plantation infrastructure comes third with 3.56%. Figure 11 and Figure 12 show the network assessment of the plantation scenarios 1 and 2, respectively.

¹⁶ IFA (2011). Personal communication. Director Agriculture and Environment, Fertilisers Europe, Brussels.

¹⁷ Vellinga, T. V., Blonk, H., Marinussen, M., Zeist, W. J. Van, Boer, I. J. M. De, & Starmans, D. (2013).

Methodology used in feedprint: a tool quantifying greenhouse gas emissions of feed production and utilization.

¹⁸ Nemecek & Schnetzer (2012). Methods of assessment of direct field emissions for LCIs of agricultural production systems.

¹⁹ Mels, A., Bisschops, I., & Swart, B. (2008). Zware metalen in meststoffen - vergelijking van urine en zwart water met in Nederland toegepaste meststoffen.

²⁰ Delahaye, R. Fong, P. Van Eerd, M. (2003). Emissie van zeven zware metalen naar landbouwgronden.

²¹ Mekonnen, M. M., & Hoekstra, A. Y. (2010). The green, blue and grey water footprint of crops and derived crop products - Volume 1: Main Report (Vol. 1).

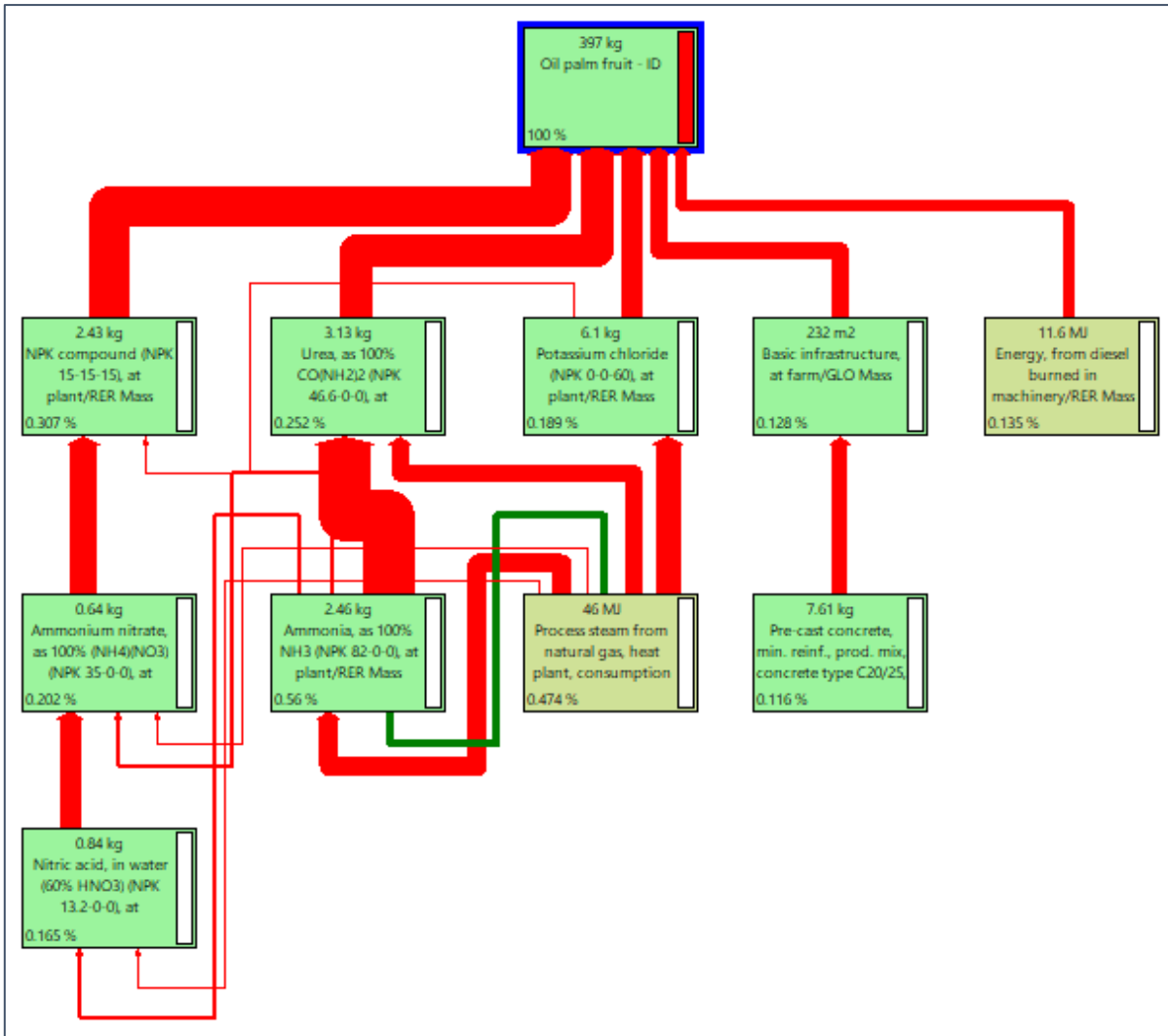


Figure 11 Network Assessment of the Plantation Scenario 1 (Background Data with LULUC)

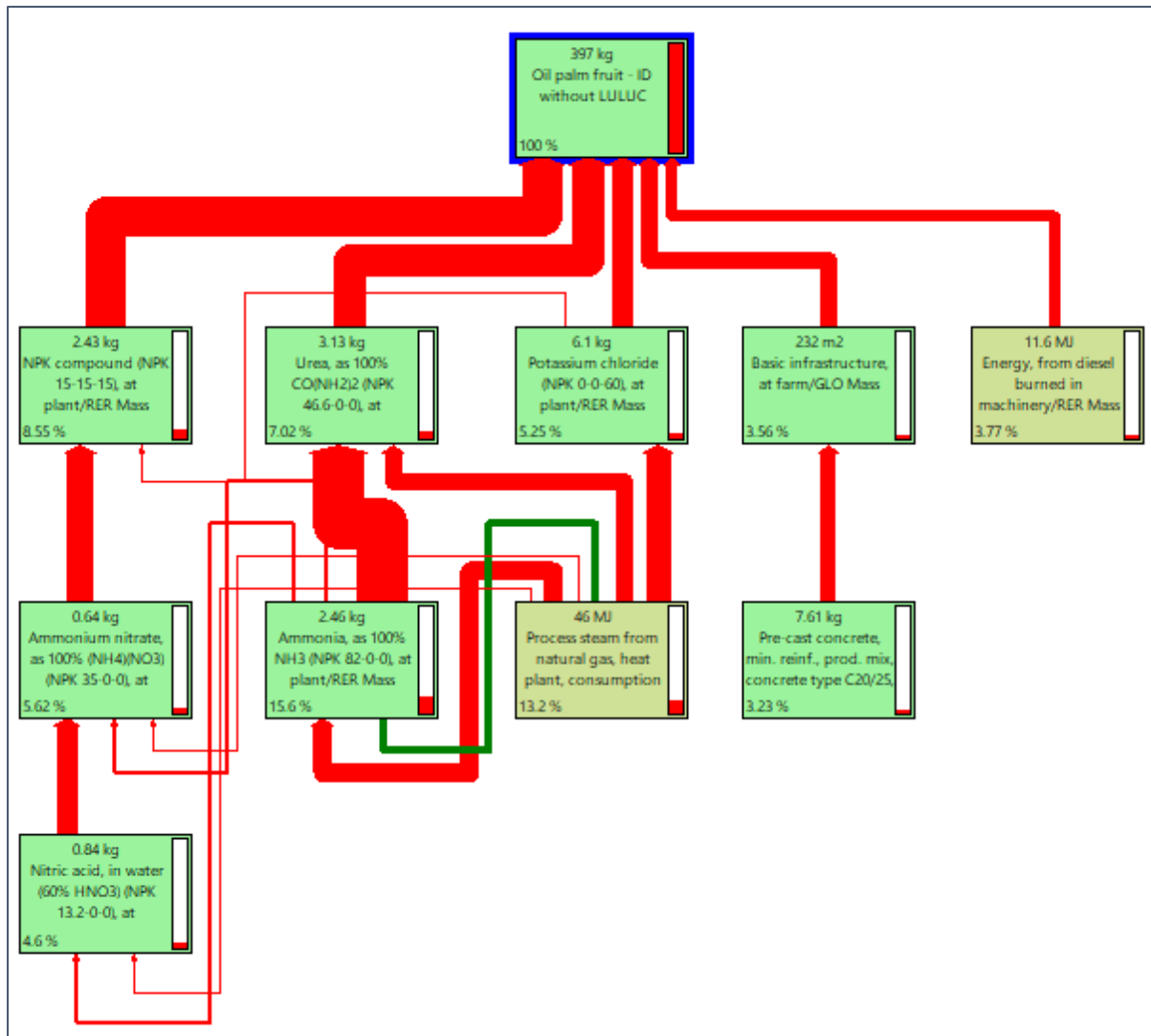


Figure 12 Network Assessment of the Plantation Scenario 2 (Background Data without LULUC)

3.2 Mill Value Chain

The palm oil mill in Indonesia considers palm fruit sterilization, stripping, crushing, palm oil extraction and CPO drying and purification. In modern mill stations, steam and electricity are generated from boiler through heat recovery from fiber and shell collected from the process solid waste. Treatment on palm oil mill effluent (POME) sludge has also been developed to recover the methane. Figure 13 shows the flow chart for palm oil mills. LCI for Mill scenarios 1 and 2 are available as Supporting Information.

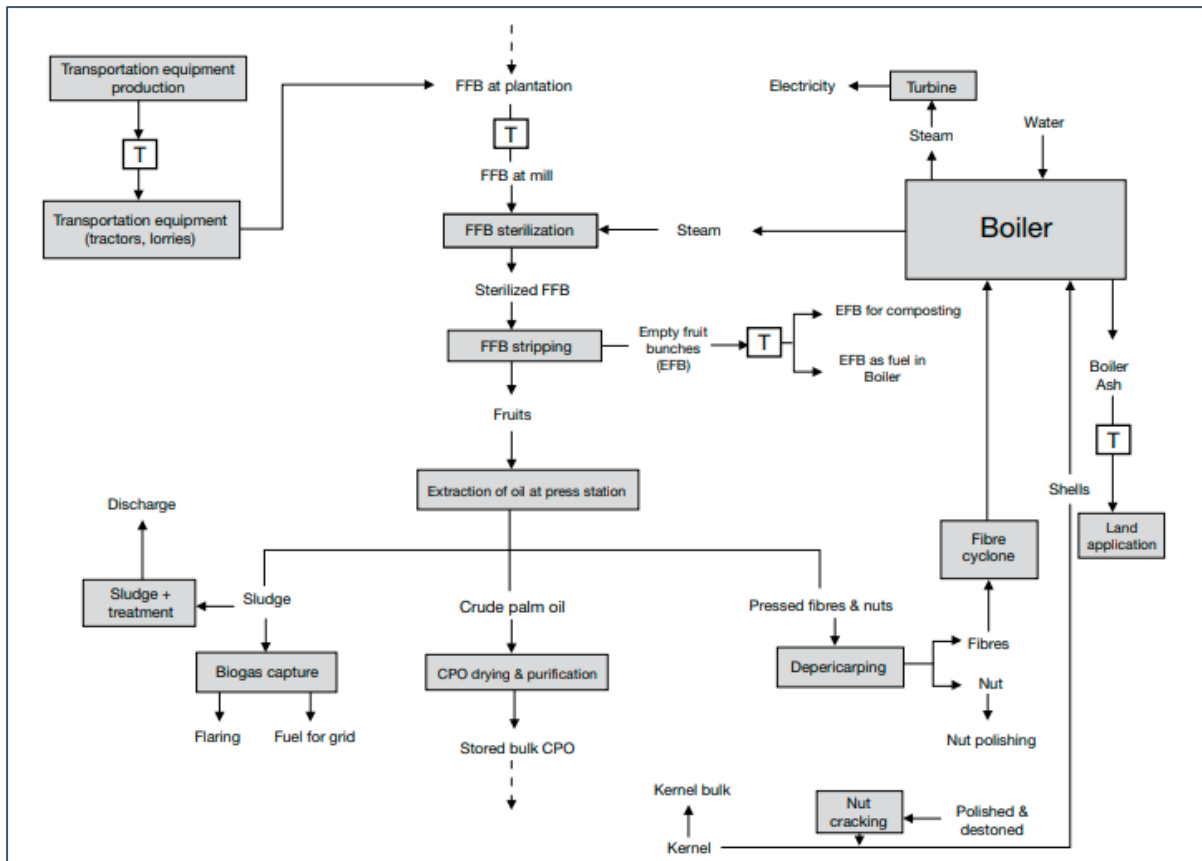


Figure 13 Flow Chart for Palm Oil Mills²²

Palm oil mills contribute to 207 kg CO₂-eq/100 kg produced CPO, comprising of landfill of biodegradable solid waste (44.9%) and wastewater treatment (4.9%). Figure 14 and Figure 15 show the network assessment of the plantation scenarios 1 and 2, respectively.

²² Vijaya, et al. (2010). Journal of Oil Palm Research 22:895-903.

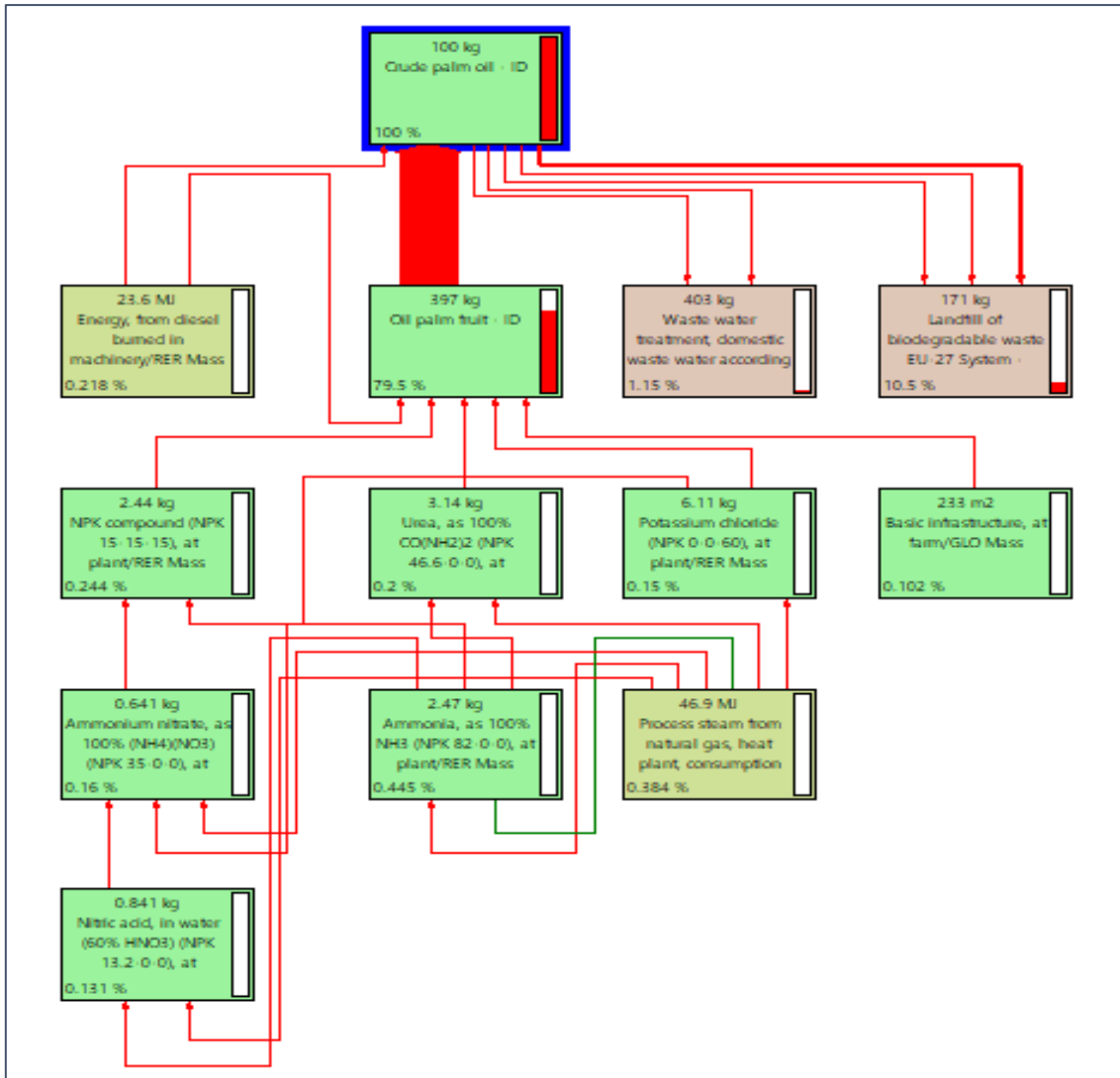


Figure 14 Network Assessment of the Mill Scenario 1 (Background Data With LULUC)

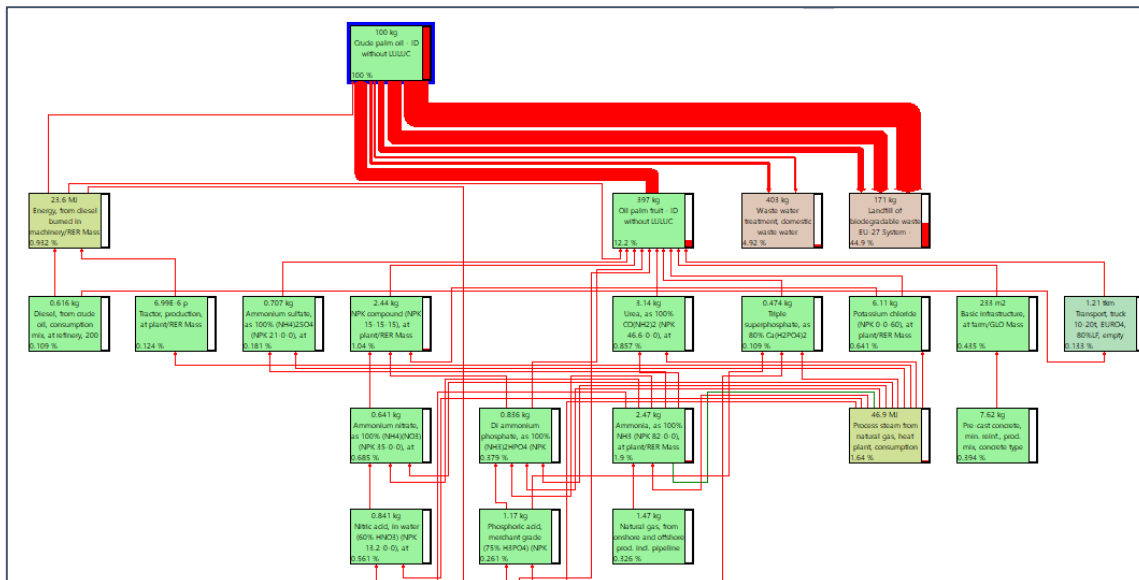


Figure 15 Network Assessment of the Mill Scenario 2 (Background Data Without LULUC)

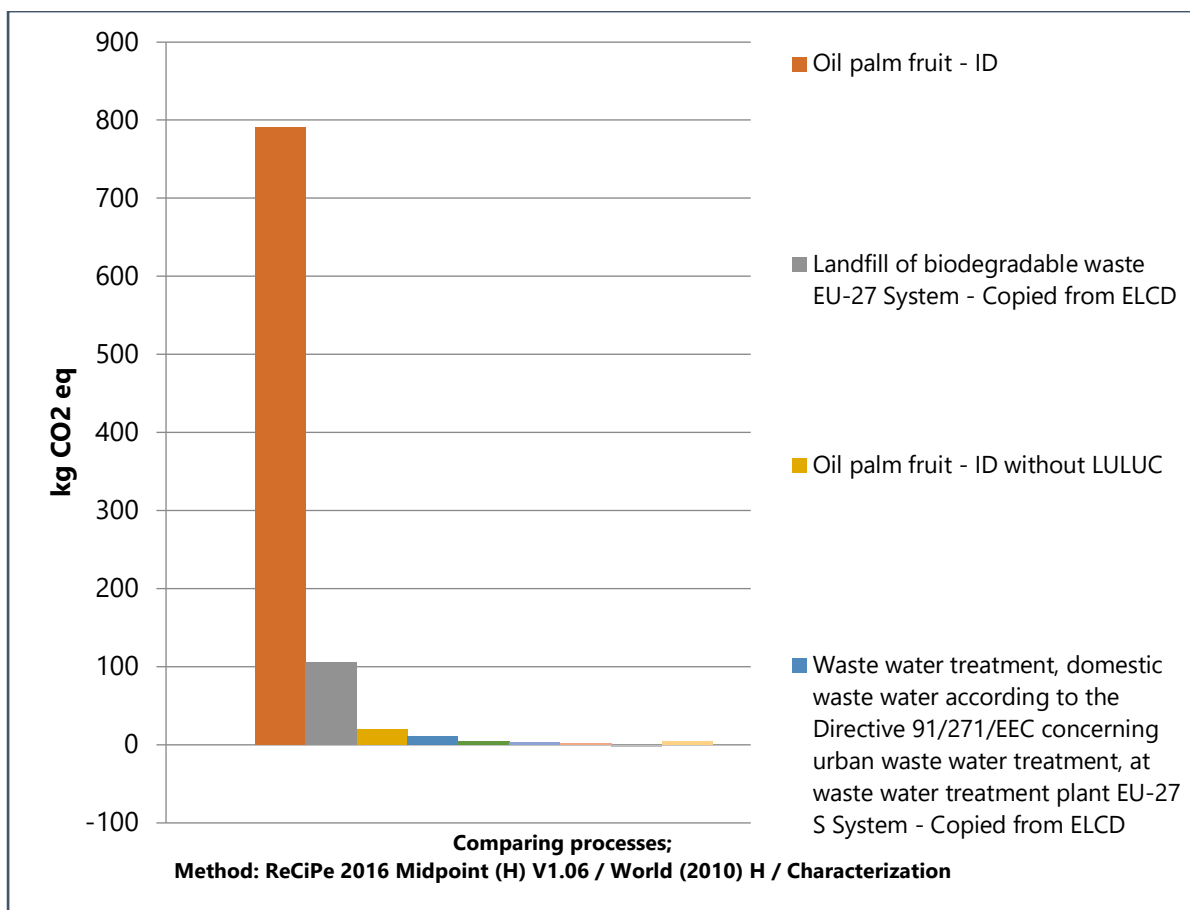


Figure 16 Life Cycle Impact Assessment of Plantation and Mill on Global Warming

One of the targeted government stakeholders for this study is PT Perkebunan Nusantara V, commonly abbreviated as PTPN V. PTPN V is a PTPN III subsidiary engaged in oil palm and rubber plantations. PTPN V is headquartered in Pekanbaru, Riau. To process palm oil commodities, the Company has 12 units of Palm Oil Mills (PKS) with a total installed processing capacity of 570 tons of fresh fruit bunches (FFB) per hour with processed products in the form of palm oil and palm kernel. Then to further process palm kernel commodity, the Company has 1 unit of Palm Kernel Oil Mill with an installed capacity of 400 tons of palm kernel/day with processed products in the form of Palm Kernel Oil (PKO) and Palm Kernel Meal (PKM).

Plant area management is currently entering the transition from the first crop cycle (Gen-1) to the second crop cycle (Gen-2). The first cycle began in the 1980s through plantation development projects for former PT Perkebunan (PTP) II, IV, and V in Riau Province. The transition from Gen-1 to Gen-2 started in 2003, marked by replanting areas of old/old plants whose economic value has decreased. The transition phase from Gen-1 to Gen-2 is estimated to be completed in 2017. At that time, all of the Company's plants were Gen-2 plants expected to be more productive than Gen-1, as the fruit of continued innovation in the field of plant cultivation.

PTPN V provided the data from each of 12 units of PKS, including:

- Production amount of Crude Palm oil.
- Energy used (diesel, electricity, and energy intensity).
- Materials and chemicals used (fertilizer, pesticides, and other chemicals).
- Water used (water sources and water intensity).
- Existing mitigations strategies for waste and CO2 reduction

The detailed aggregate data of the following parameters for each PKS in 2021 can be seen in Table 2 with aggregated inventory data as follows:

Table 2 Aggregate Inventory Data of PKS in 2021

Plantation area	1,933	Ha
Total Palm	274,551	palm
Unit Functional	100	kg CPO
Productivity	23	ton/Ha/year
Potential production of TBS	0.004	100 kg CPO/palm/year

Table 3 Foreground Data Inventory from 12 Oil Palm Plantations in 2021

No	Process	Mass	Substance	Unit	Total
1	Plants produce	Energy	Diesel fuel	Liter	99,343
			Electricity	kWh	2,023,333
			Energy intensity	kW/Production amount	12
		Fertilizer	1. Urea	Kg	241,681
			2. Dolomite	Kg	295,905
			3. MOP	Kg	57,270
			4. Kieserit	Kg	2,346
			5. Borate	Kg	246,80
		Pesticide	1. Amcofur	Kg	43,25
			2. Nara Up	Kg	3,273
			3. Racumin	Kg	228,25
			4. Marshall	Kg	1,000
			5. Santrino	Kg	133,46
Transportation	Distance	km	1,292,608		
2	Extraction of CPO	Water	Surface Water (River)	m ³	502,018
			Water intensity	m ³ /Production amount	3
			Diesel fuel	liter	99,343
			Production of CPO	ton	30,672

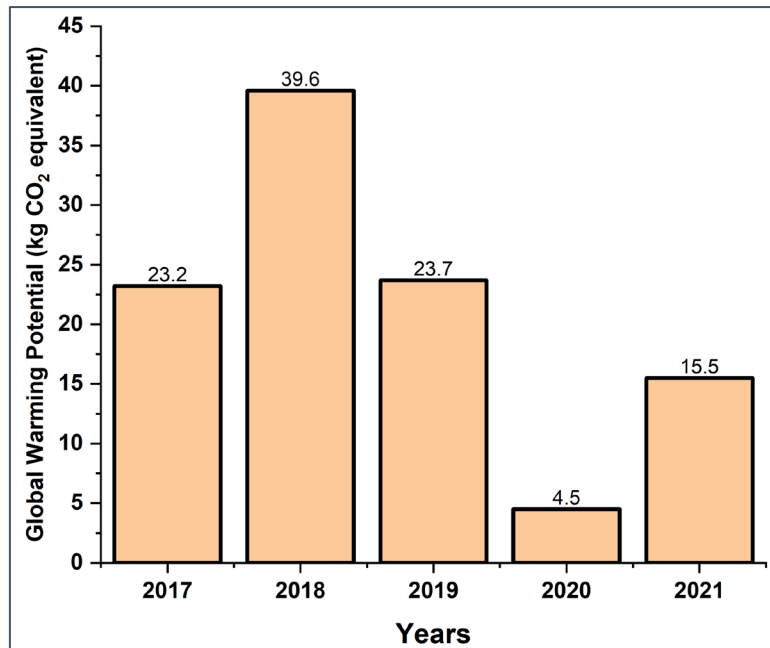


Figure 17 GWP of Oil Palm Plantation and Mill Value Change – Software Calculated from Foreground Data Without Consideration to LULUC

Scope of manual LCA calculation is cradle to gate, system boundary starts from palm seedling (12 months) continue to planting process, immature palm (36 months), mature palm, harvesting and CPO extraction. The data used primary data from PTPN 5 PKS TPU. The CO₂ equivalent is calculated by a manual formula using the number of substances from system product cycle, multiplied by the emission factor, and by the characterization factor. The number of substances used as primary data from PTPN V. With functional unit of 100 kg CPO, it is found that plantation and mill are responsible for 27.4 and 100.5 kg CO₂ eq emissions, respectively. Thus, the manual calculation results are in line with the software background data calculation.

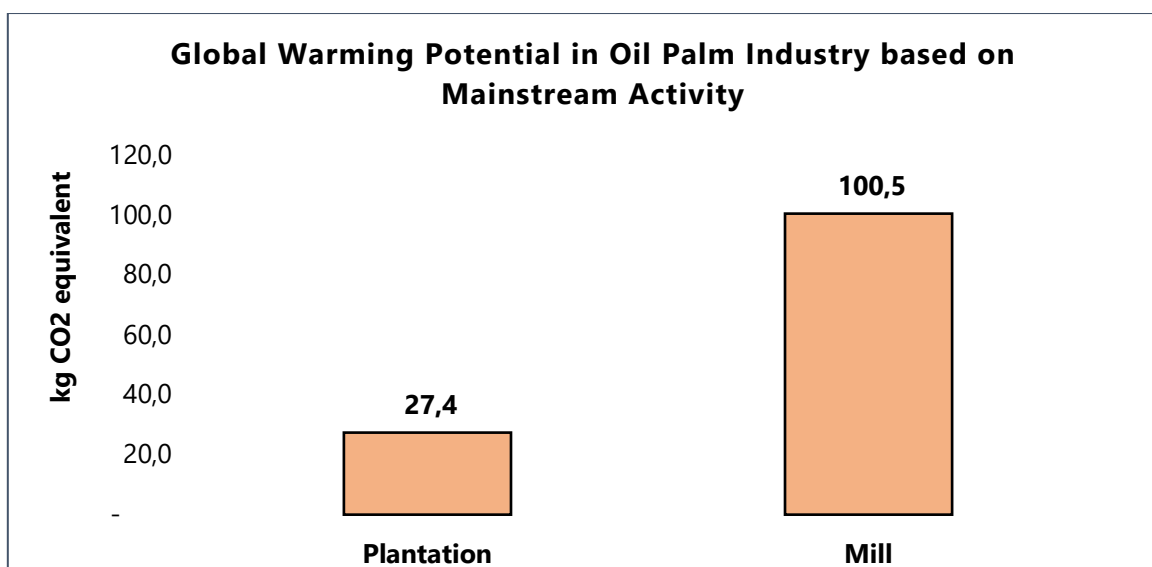


Figure 18 GWP of Oil Palm Plantation and Mill Value Change – Calculated Manually from Foreground Data Without Consideration to LULUC

3.3 Refinery Value Chain

The palm oil refinery in Indonesia considers. Figure 19 shows the flow chart for palm oil mills. LCI for Mill scenarios 1 and 2 are available as Supporting Information.

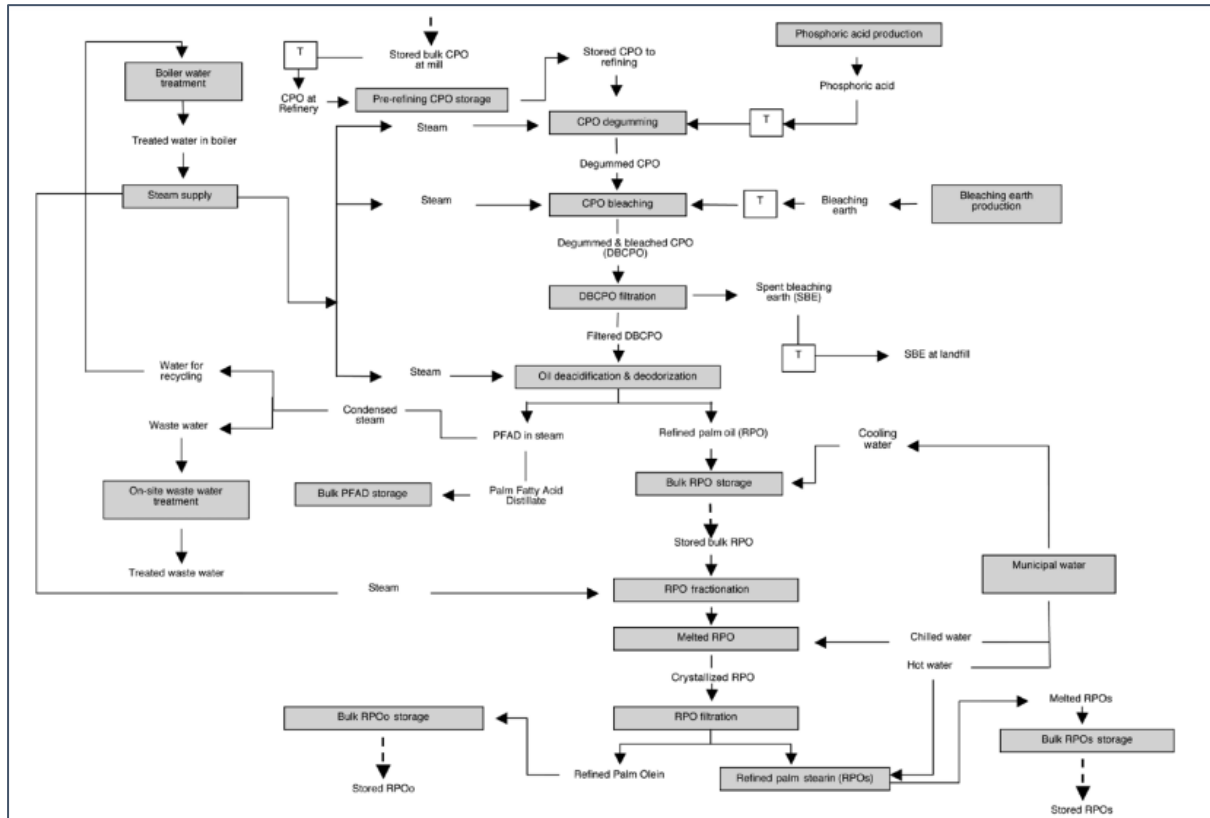


Figure 19 Flow Chart for Palm Oil Refinery²³

3.4 Packaging and Distribution Value Chain

Palm cooking oil packaging available in several forms such HDPE jerrycan, PET bottle, standing pouch, plastic glass, sachet, etc. (see Figure 20). Specifications of each packaging are shown in Table 4. For the sake of this study, we focus on the use of 2L bottle packaging which comprises of PET bottle and PP closure.

²³ Yewai, et al. (2010) Journal of Oil Palm Research 22:913-926.



Figure 20 Palm Cooking Oil Packaging

Table 4 Plastic Packaging Form for Palm Cooking Oil

Packaging type	Material	Volume	Weight	Lifetime
Sachet	LDPE	60 mL	2 g	Single-use
Glass	PET	150 mL	8 g	Single-use
Standing pouch	PE	1000 mL	18g	Single-use
Bottle	PET & PP	2000 mL	86 g & 2 g	Single-use
Jerrycan	HDPE	5000 mL	200 g	

Indonesian population distributions are shown in Figure 21. Similar to the palm oil refinery profile, the population are concentrated in Java and Sumatra Island. Therefore, the study was focused in Jakarta as the capital of the country with most of population as well as refinery could be zoomed in as a representative case study.

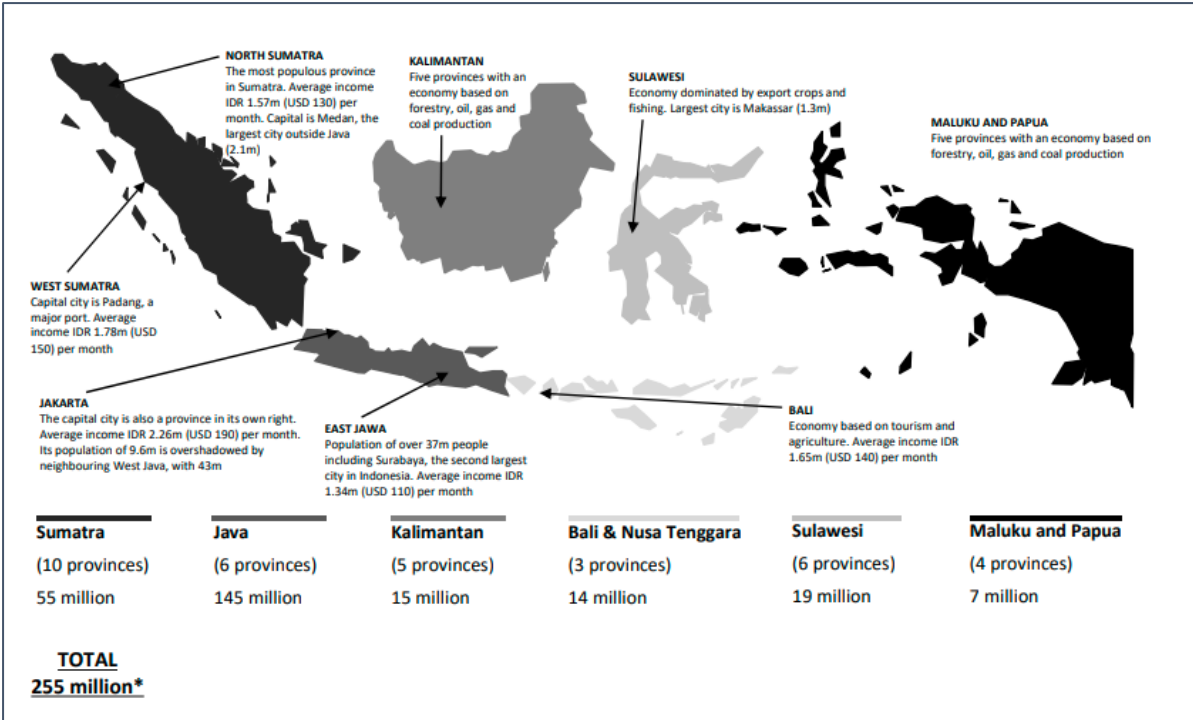


Figure 21 Indonesian Population Distributions

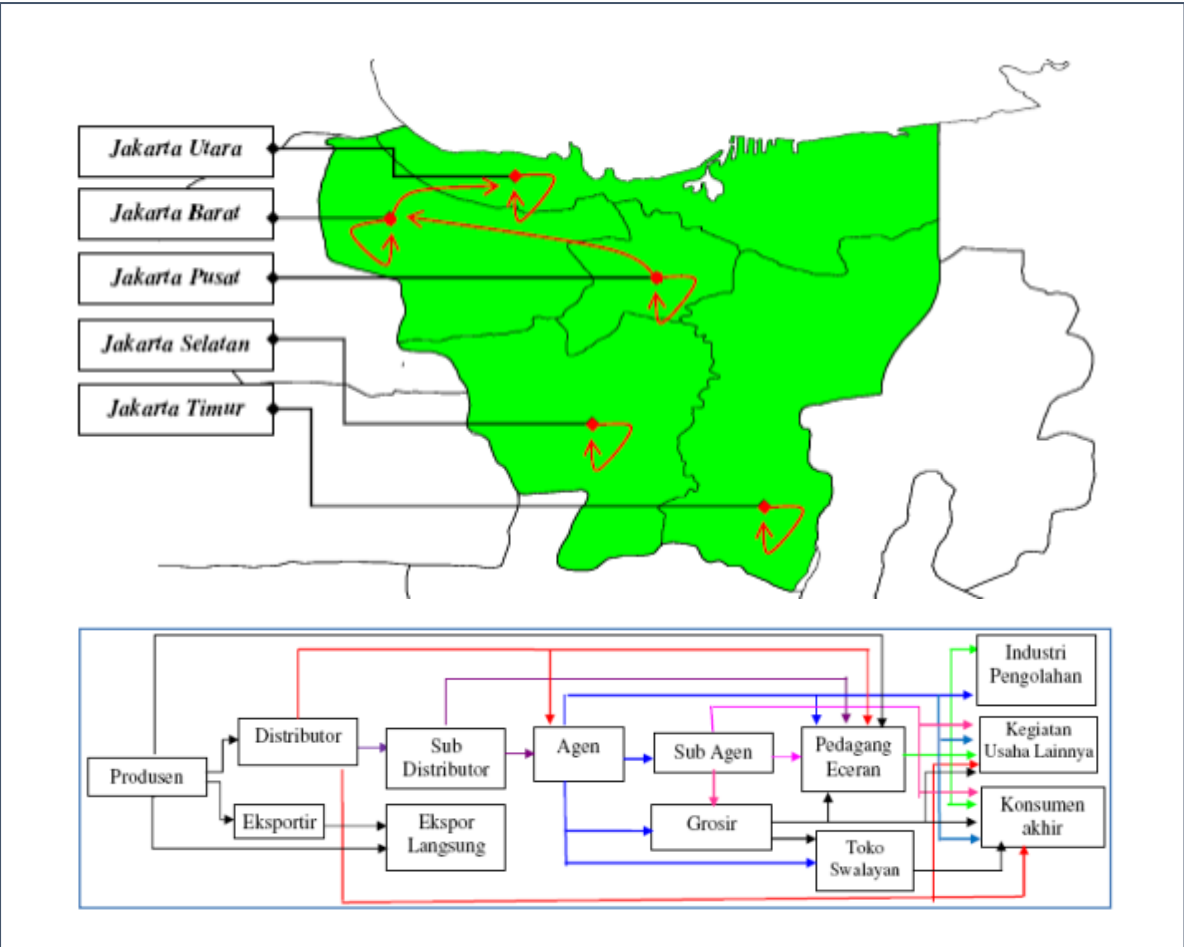


Figure 22 Palm Cooking Oil Distribution Map (top) as well as Stakeholders (bottom) – Case Jakarta

With assumption that the packaged palm cooking oil are distributed using Freight lorry 16-32t, with average distribution distance = 100 km, the global warming potentials that come from the palm cooking oil packaging and distributions are still dominated by the refined palm olein (93.97%). Even without LULUC, GWP from PET packaging is only 5.22%, while transportation and PP bottle cap take 0.71% and 0.1%, respectively.

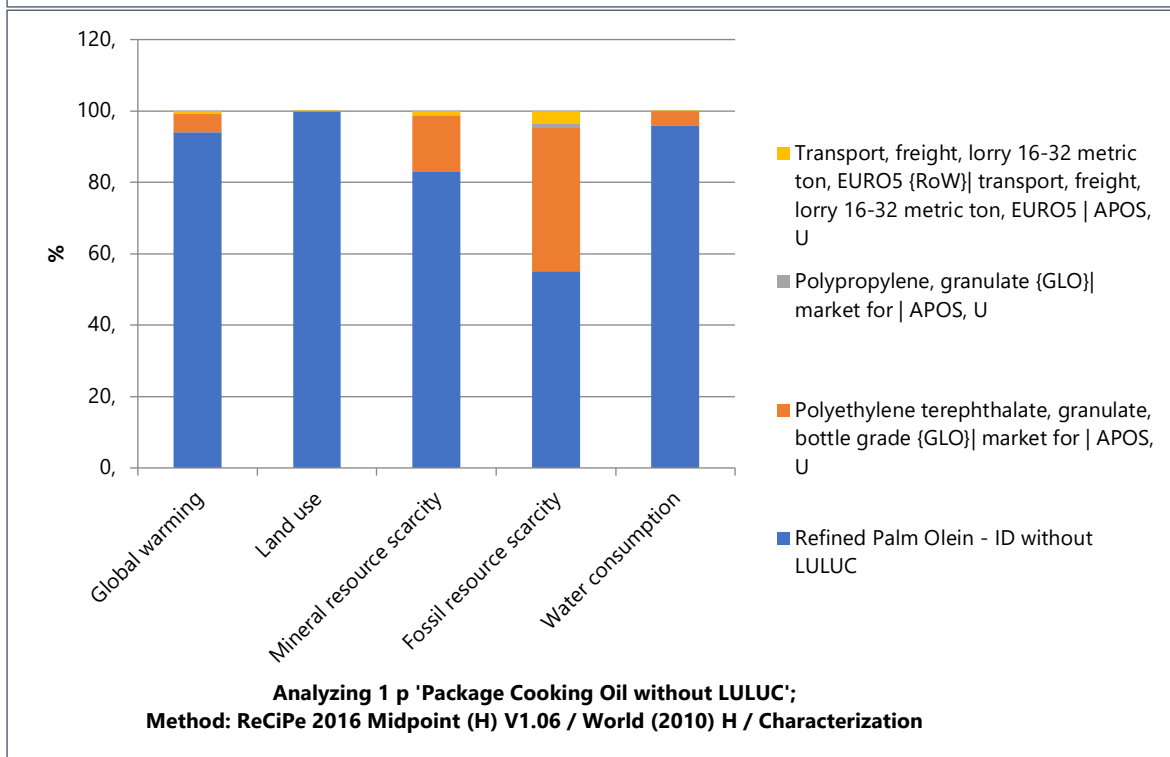
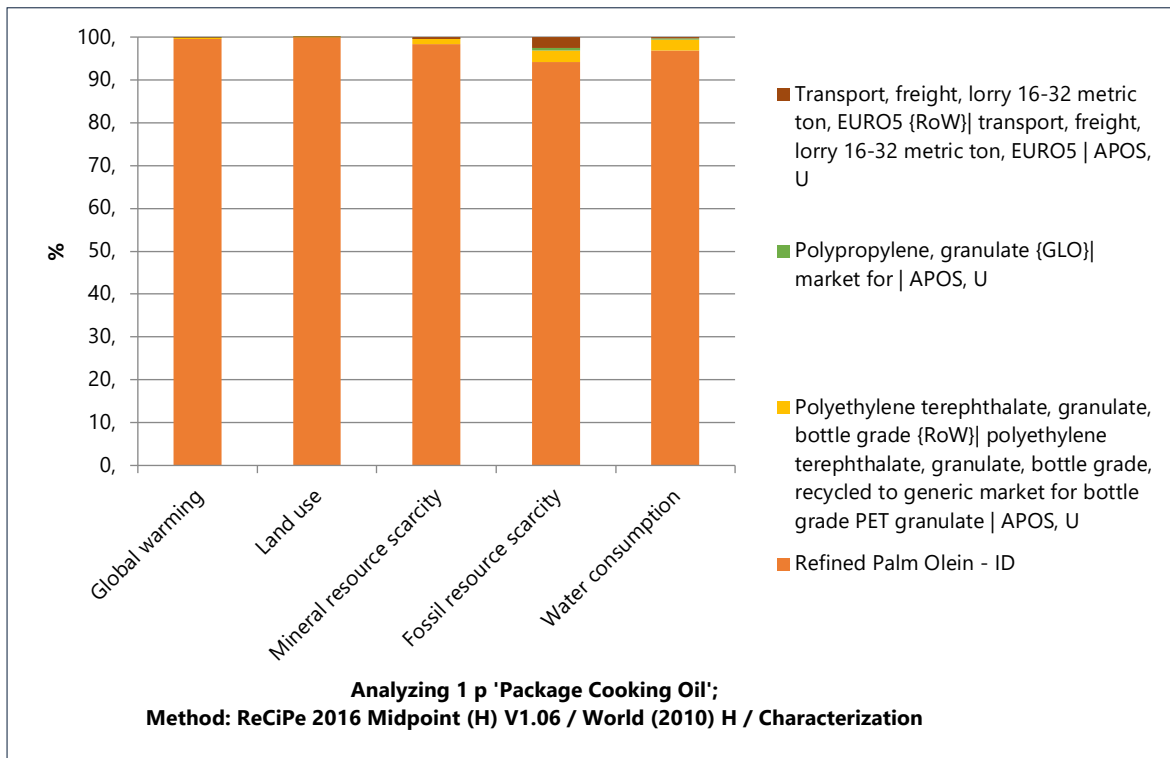


Figure 23 Analysis of Package Cooking Oil with (top) and without (bottom) LULUC

3.5 Consumption and Disposal Value Chain

The consumption of vegetable cooking oil can be considered carbon neutral. Meaning CO₂ released when it burned is the same as CO₂ taken by plant to grow. Indonesian cooking oil consumption per capita in 2019 is 11.58 kg or equals to 6 MMt (6.6 MM³). Through purification, refinement, and transesterification, 1.8 MM³/year used cooking oils could produce 1.38 MM³ (35% of yearly biodiesel demand), reduce 6 MT GHG, save 1.16 MT CPO/year, and save 321 thousand ha forestation. Besides, the used cooking oil could cause a lot of environmental issues. When it is poured down the drain, it hardens and infiltrates into local sewer, water and waste management facilities. When tossed in the trash or carelessly littered in the dirt or grass outside, fats, oils, and greases seep into our ecosystems and affects our food supply.

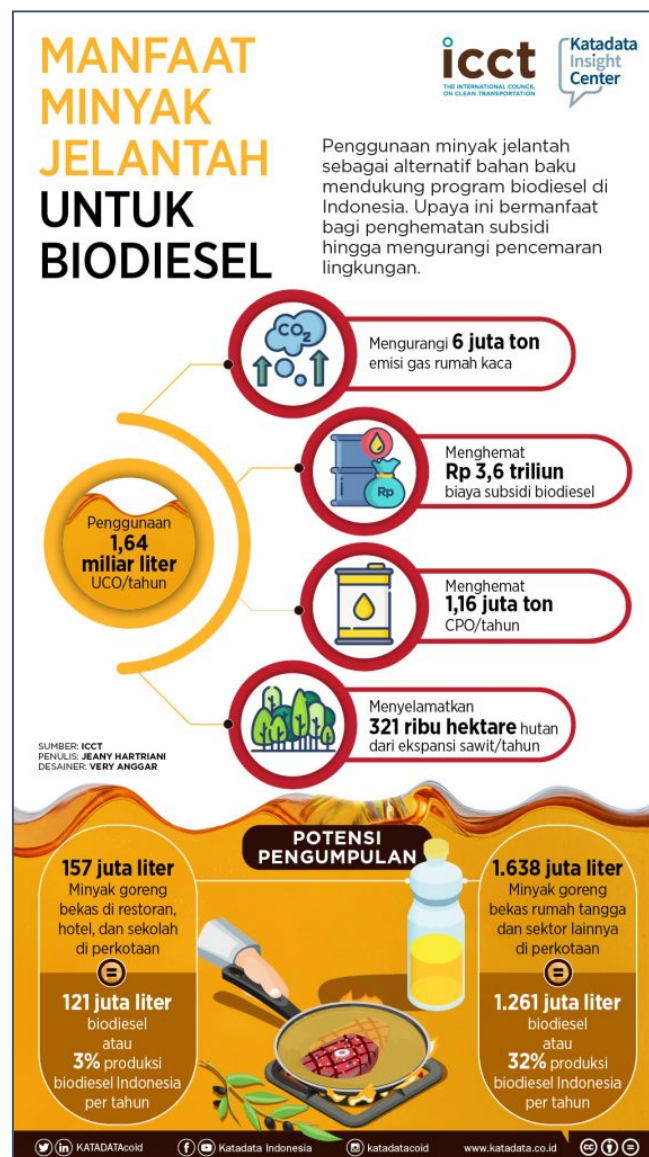


Figure 24 The Potential of Incorporating Used Cooking Oil into Indonesia’s Biodiesel ²⁴

In the production of palm cooking oil (RPO olein), the impacts are mainly associated with upstream activities at the oil palm plantation and the palm oil mill. The upstream impacts resulting from FFB and

²⁴ Katadata.co.id, 2020. *Manfaat Minyak Jelantah untuk Biodiesel*; based on: ICCT, 2018. *The Potential Economic, Health, and Greenhouse Gas Benefits of Incorporating Used Cooking Oil into Indonesia’s Biodiesel*.

CPO production are propagated down to the production of RPO/RPOo/RPOs, while the refinery activities confined to the production of RPO, RPOo and RPOs as well as packaging and distributions are found to have minor impacts on the environment in comparison. The consumptions are considered neutral in carbon emission; thus, approach has been made through its utilization as a raw material for biodiesel production to support B30. The main contributor to the fossil fuels category is the production and use of fertilizers for the cultivation of oil palm, with minor inputs from the refining and fractionation processes through the transport of raw and waste material and distribution of products as well as the use of boiler fuel. The hotspots in relation to respiratory inorganics and climate change are mainly from upstream activities, e.g., the application of nitrogen fertilizers for cultivation of the palms, and the emissions of methane as well as carbon dioxide from landfill of biodegradable waste activity and POME ponds at the mill.

4. Sociotechnical Options of Waste and CO₂ Reduction Strategies

There are several mitigation strategies for POME treatment that have been developed by PTPN V in collaboration with ITB:

1) Conversion of POME into biogas for electricity production

Palm oil mills produce liquid waste known as palm oil mill effluent (POME) in the production process of crude palm oil (CPO). POME is wastewater produced by palm oil mills, mainly from boiled condensate, hydro cyclone water, and sludge separator. The Decree of the State Minister of the Environment Number 28/2003 regulates the quality standards for POME applications on the land. POME characteristics and environmental quality standards are shown in Table 5.

Table 5 Characteristics and Environmental Quality Standards of POME

Parameter	Unit	Unprocessed POME		Quality standards	
		Interval*	Average	River**	Land Application
BOD	mg/L	8,200-35,000	21,280	100	
COD	mg/L	15,103-65,100	34,370	350	
TSS	mg/L	1,330-50,700	31,170	250	
Ammonia	mg/L	12-126	41	50***	
Oil and fat	mg/L	190-14,720	3,075	25	
pH		3.3-4.6	4	6-9	6-9
Maximum of POME generated	m ³ /ton CPO			2.5	

* Palm Oil Industry Waste Management Guidelines, 2006 Ministry of Agriculture, Ministry of Environment Regulation No. 3 of 2010

** Minister of Environment Decree No. 51/1996

*** Total nitrogen = organic nitrogen + total ammonia + NO₃ + NO₂

2.5-3 m³ of POME is produced for every tonne of CPO production. Thus, POME needs to be processed since it contains organic carbon with a COD value of more than 40 g/L and nitrogen content of around 0.2 and 0.5 g/L as ammonia nitrogen and total nitrogen. One potential alternative to improve POME management in this mill is to process POME into biogas in an anaerobic pond. The decomposition of organic waste (POME) into biogas utilizes microorganisms, producing biogas and residue that can be used as fertilizer. In this process, POME (organic waste) serves as a substrate or growing medium for organisms. This process has two main advantages: the biogas produced from the degradation process can be utilized and has economic value. In addition, PKS can treat waste to avoid negative environmental impacts and comply with regulations safely and quickly. Biogas generally contains 60% methane (CH₄) and 40% carbon dioxide (CO₂). Therefore, a palm oil mill with a processing capacity of 60 tons per hour of fresh oil palm fruit bunches, such as the Terantam Palm Oil Mill

in Riau, has the potential to produce POME, which can be processed into biogas for power plants with a power of about 2 MW.²⁵



Figure 25 Schematic Illustration of POME Conversion to Biogas for Electricity Production ²⁶

2) Conversion of POME into biomethane for fuel of palm oil plantation trucks

Biogas can be purified into biomethane through CO₂ separation technology. This purification is carried out to increase the added value of the resulting fuel, converted into vehicle fuel (BBG). The potential process technology for purifying biogas into biomethane in this mill is CO₂ absorption with water (water scrubbing). This technology is relatively simple and economical compared to other CO₂ separation technologies. Moreover, it only requires process water as a working fluid, making it suitable for application in rural areas or oil palm plantations. This technology has also been proven because it has been used in other applications (non-biogas) for decades.

The collaboration between the Department of Chemical Engineering ITB, BPPT (BRIN), PTPN V, BPDPKS, and Aimtop Indo Nuansa Kimia has successfully implemented the demonstration of biogas purification technology into biomethane for gas fuel via CO₂ absorption with water. From November to December 2021, biomethane product testing has been carried out on CNG converter trucks. Biomethane is put into a tube up to a pressure of 200 bar, which is used as fuel for vehicles/trucks with a gas converter installed in the combustion system. Trucks with biomethane fuel were tested in plantation areas and roads with a total distance of 250 km without problems, with an average CNG consumption of 3.4-3.5 kilometers per Liter of Premium Equivalent (LSP) with a load-carrying condition of 5-6 tons. The results of this study represent a breakthrough in the utilization of POME produced by Palm Oil Mills, which can be used as a renewable energy source and simultaneously reduce greenhouse gas emissions. The resulting CNG can be used as fuel for oil palm plantation trucks by installing a gas converter like CNG from natural gas. A palm oil mill with a capacity of 60 tons/hour has the potential to produce 600 Nm³/hour of biogas, which can be processed into 360 Nm³/hour of biomethane, which is equivalent to 8,350 LSP/day.²⁷

²⁵ BPPT, 2019. *PLT Biogas POME, Olah Limbah Cair Sawit Menjadi Listrik*. <https://bppt.go.id/berita-bppt/plt-biogas-pome-olah-limbah-cair-sawit-menjadi-listrik>.

²⁶ Raksajati, 2020.

²⁷ BPDKS, 2021. *ITB Berhasil Mendemonstrasikan Pemurnian Biogas Menjadi Biometana Untuk Bahan Bakar Gas (BBG)*. <https://www.bpdp.or.id/itb-berhasil-mendemonstrasikan-pemurnian-biogas-menjadi-biometana-untuk-bahan-bakar-gas-bbg>



Figure 26 Schematic Illustration of POME Conversion to Biomethane for Fuel of Palm Oil Plantation Trucks²⁸

Other product Improvement specifically to reduce emission from fertilizers:

1) Precision agriculture in fertilizing

The current fertilization recommendation must refer to the needs of the plant so that the dose given tends to be optimum and reduces the conditions where fertilizer is excessive and causes environmental damage such as high emissions, decreasing of soil health, and causes damage to the aquatic environment. Fertilization recommendations can refer to the analysis of plant (Leaf sampling Unit) and soil health (Soil Sampling unit), where leaf and soil samples are taken periodically so that dosing will be more accurate and precise.



Figure 27 Leaf Sampling Unit



Figure 28 Soil Sampling Unit

²⁸ Raksajati, 2020.

2) Optimalization of by-product utilization

The oil palm plantation industry is efforting to reduce the potential for contamination and environmental damage is applied the concept of zero waste. All palm oil waste products can be utilized and have a favorable economic value. In this case, solid waste including of Empty Fruit Bunch (EFB) can be used as a source of organic fertilizer to the planting area, either given directly or composted first. Another product, including palm oil mill effluent (POME), can be channeled into plantation areas as a source of liquid organic fertilizer, of course, before being channeled, it must be processed first until it reaches quality standards. During the processing, several industries build methane capture installations which will later be used as raw material for methane-powered power plants (Biogas). Other wastes, such as fiber, are generally composted or used as raw material for combustion in boiler furnaces, while palm kernel shells are used as plant mulch, road pavers, and boiler waiting raw materials. Overall, utilization of by-product especially for organic fertilizers can contribute to substitution the inorganic fertilizer and also increasing soil health. Finally, the industry will save the cost especially from fertilizer purchasing and implementing the circular economy, and applied the sustainability of oil palm practice.



Figure 29 Palm Oil Mill Effluent for Organic Liquid Fertilizers



Figure 30 Direct EFB Utilization (left) and Composting (right)

3) Legume cover crops optimizing

Soil health is one of the most important factors in improving plant health and increasing productivity. Soil health includes optimum and mutually supportive physical, chemical and biological properties of the soil. One way to maintain soil health needs to be maintained by minimizing the use of chemical fertilizers. There is one cultivation technique (technical culture) in utilizing several biological agents that are naturally able to supply several important elements for plants, one of which is by utilizing legume cover crops. Legume cover crops store nitrogen in nodules on the roots. The plant harvests nitrogen gas from the air and combines it with hydrogen. The process creates ammonia, which is converted by bacteria into nitrates, a usable form of nitrogen. Legumes on their own can offer many benefits, including fixing atmospheric nitrogen, providing a nitrogen source for the soil to be used by future crops, as well as protection from soil erosion along with building soil structure and organic matter.



Figure 31 Legume Cover Crops in Oil Palm Plantation

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Appendix 1: System Boundaries for LCA Analysis

SEEDLING

Processing Category	Included	Excluded
Production of polyvinylchloride for pipes	v	
Production, maintenance, and replacement of capital equipment		v
Transportation of capital goods		v
Production of agricultural inputs, e.g., polybags, fertilizers, insecticides, herbicides and fungicides	v	
Disposal of small polybags (15 cm × 23 cm)		v
Transportation of polybags, fertilizers, insecticides, herbicides and fungicides	v	
Water supply	v	
Agricultural activities, e.g. application of fertilizers, insecticides, herbicides and fungicides; use of polybags	v	
Transportation of germinated seeds to nursery	v	
Land occupation by nursery		v
Transportation of seedlings to plantation	v	
Electricity generation	v	
Diesel for running water pump	v	
Production of top soil		v
Partitioning of pesticides in different compartments	v	
Emissions from the application of pesticides	v	

PLANTATION

Processing Category	Included	Excluded
Production, maintenance, and replacement of capital equipment		v
Production of kieserite fertilizer, borate fertilizer, NPK compound fertilizer		v
Indirect land use change		v
Disposal of polybags at the plantation		v
Production of urea	v	
Production of ammonium sulphate	v	
Production of phosphate rock	v	
Production of muriate of potash	v	
Impact of heavy metals to the environment		v
Usage of pesticides	v	
Capital goods	v	
Production of plantation pesticides	v	
Transportation of raw materials from the port to plantation	v	
Transportation of FFB to mill	v	
Plantation input e.g. fertilizers and pesticides	v	
Seedling from the nursery	v	
land use change	v	

PLANTATION

Processing Category	Included	Excluded
Energy use of machinery in the plantation	v	
Output to air	v	
Output to water	v	
Output to soil	v	

MILL

Processing Category	Included	Excluded
Production, maintenance and replacement of capital equipment	v	
Transportation of capital goods		v
Water treatment and supply	v	
Extraction of crude palm oil from FFB	v	
Transportation of diesel to mill	v	
Management of solid waste in mill	v	
Electricity generation	v	
Production of fuel for boilers	v	
Processing of co-products e.g., palm kernels, palm shells		v
Capital goods	v	
Wastewater treatment	v	

REFINERY

Processing Category	Included	Excluded
Production, maintenance and replacement of capital equipment	v	
Transportation of capital goods		v
Transportation of CPO from mill to refinery	v	
Electricity generation	v	
Fuel oil production		v
Transportation of fuel oil from supplier to refinery	v	
Water treatment	v	
Water supply (for steam and chilled water supply)	v	
Phosphoric acid production	v	
Transportation of phosphoric acid to refinery (includes intermediate storage and retailing)	v	
Bleaching earth production	v	
Transportation of bleaching earth to refinery (includes intermediate storage and retailing)	v	
CPO degumming and earth bleaching	v	
Solid waste handling (includes transportation)	v	
Solid waste recycling (includes transportation)	v	
Palm oil deacidification and deodorization	v	
Recovery of palm fatty acid distillate (PFAD) from waste water		v

REFINERY

Processing Category	Included	Excluded
<i>On-site waste water treatment</i>	v	
<i>Capital goods use including steel and concrete in buildings and processing plant equipment</i>	v	
<i>RPO fractionation</i>	v	
<i>Storage of PFAD</i>		v
<i>Storage of RPO (on tank farm)</i>		v
<i>Storage of refined palm olein and refined palm stearin</i>		v

PLANTATION					
Unit process	Process starts	Nature of transmission	Process ends	Data type (B/F*)/Data source	
Electricity production	Mining and extraction of fossil fuels	Energy conversion	Distribution to the grid at the point of use	B/Malaysian data from SIRIM	
Irrigation water supply	Water from surface water	Physical	Water at nursery	F/site specific data	
Irrigation	Water at nursery	Physical	Water applied to germinated seeds/seedlings	F/site specific data	
Fertilizer production N, P2O5 and K2O	Acquisition of raw materials	Chemical processing	Fertilizers at the production unit gate	B/Ecoinvent database	
Transportation of fertilizers N, P2O5 and K2O to nurseries (includes intermediate storage and retailing)	Collection of fertilizers from port in Malaysia to nursery	Physical	Delivery of fertilizers to nursery	B/reference to other site specific data	
Application of fertilizers N, P2O5 and K2O (includes incorporation into soil at the recommended dosage)	Fertilizers stored at nursery	Physical	Fertilizers into soil	F/site specific data	
Production of insecticides thiocarbamate, pyrethroid and organophosphate	Acquisition of raw materials	Chemical processing	Pesticides at the production unit gate	B/Ecoinvent database	
Transportation of insecticides thiocarbamate, pyrethroid and organophosphate to nurseries (include intermediate storage and retailing)	Collection of pesticides from port in Malaysia to nursery	Physical	Delivery of pesticides to nursery	B/reference to other site specific data	
Application of insecticides thiocarbamate, pyrethroid and organophosphate (including preparations for application at the recommended dosage)	Pesticides stored at nursery	Physical	Pesticides applied to seedlings	F/site specific data	

Unit process	Process starts	Nature of transmission	Process ends	Data type (B/F*/Data source)
Herbicide production; unspecified herbicide (glufosinate ammonium, urea/sulfonylurea and glyphosate)	Acquisition of raw materials	Chemical processing	Herbicides at the production unit gate	B/Ecoinvent database
Transportation of herbicides; unspecified herbicide (glufosinate ammonium, urea/sulfonylurea and glyphosate) to nurseries (includes intermediate storage and retailing)	Collection of herbicides from port in Malaysia to nursery	Physical	Delivery of herbicides to nursery gate	B/reference to other site specific data
Application of herbicides; unspecified herbicide (glufosinate ammonium, urea/sulfonylurea and glyphosate) (including preparations for application at the recommended dosage)	Herbicides stored at nursery	Physical	Herbicides applied to soil	F/site specific data
Fungicides production: dithiocarbamate	Acquisition of raw materials	Chemical processing	Fungicides at the production unit gate	B/Ecoinvent database
Transportation of fungicides; (dithiocarbamate) to nurseries (includes intermediate storage and retailing)	Collection of fungicides from port in Malaysia to nursery	Physical	Delivery of fungicides to nursery gate	F/reference to other site specific data
Application of fungicides (dithiocarbamate) (including preparations for application at the recommended dosage)	Fungicides stored at nursery	Physical	Fungicides applied to soil	F/site specific data
Polybag production	Acquisition of raw materials	Chemical processing	Polybags at the production unit gate	B/SIRIM database
Transportation of polybags to nurseries (includes intermediate storage and retailing)	Collection of polybags from port in Malaysia to nursery	Physical	Delivery of polybags to nursery gate	B/reference to other site specific data

Unit process	Process starts	Nature of transmission	Process ends	Data type (B/F*/Data source)
Use of polybags	Polybags stored at nursery	Physical	Polybags used at nursery	B/reference to other site specific data
Top soil supply	Acquisition from land	Physical	Soil for seedling cultivation	B/reference to other site specific data
Transportation of top soil to nurseries (includes intermediate storage and retailing)	Collection of top soil from estate or contractor to nursery	Physical	Delivery of top soil to nursery gate	B/reference to other site specific data
Oil palm seedling cultivation	Acquisition of oil palm germinated seeds	Biological	10- to 12-month-old oil palm seedlings for planting in plantations	B/reference to other site specific data
Transportation of FFB to mill	Collection of FFB from the plantation unit gate	Physical	Delivery of FFB to milling unit gate	F/site specific data
Transportation of diesel to mill	Collection of fuel from supplier gate	Physical	Delivery of fuel oil to refining gate	F/site specific data
Extraction of crude palm oil from FFB	FFB as delivered and stored at mill	Physical and Chemical processing	Crude palm oil Palm Oil Mill Effluent (POME)	F/site specific data
Water treatment	Extraction of water from aquifers or surface water (river)	Physical, chemical and biological processing	Potable water at water works gate	B/Ecoinvent database
Water supply (for steam and chilled water supply)	Potable water at water works gate	Physical	Potable water at refining and fractionation unit gate	B/Ecoinvent database
Management of solid waste in mill	EFB, Kernel with retained oil and moisture	Physical, chemical and biological processing	solid waste processing unit	F/site specific data
Biogas capture	POME	Physical	Biogas	F/site specific data
Wastewater treatment	POME after Biogas capture	Chemical and biological processing	Treated waste water (to be discharged)	F/site specific data

MILL

Unit process	Process starts	Nature of transmission	Process ends	Data type (B/F*/Data source)
Electricity generation	Mining and extraction of fossil fuels	Physical	Distribution to grid at the points of use	B/Ecoinvent database
Production of fuel for boilers	Biogas	Energy conversion	fuel for boilers	B/reference to other site specific data
Capital goods	FFB at mill gate	Physical/chemical processing	CPO at mill gate	B and F/Ecoinvent data base, reference to other site specific data
Transportation of CPO from mill to refinery	Collection of CPO from the milling unit gate	Physical	Delivery of CPO to refining unit gate	B and F/Ecoinvent data base, reference to other site specific data
Electricity production	Mining and extraction of fossil fuels	Physical	Distribution to grid at the points of use	B/Ecoinvent database
Electricity usage	Refining gate	Energy conversion	Points of use at the refining and fractionation unit gate	B/reference to other site specific data
Fuel oil production	Mining and extraction of fossil fuels	Physical	Fuel at supplier gate	B/Ecoinvent database
Transportation of fuel oil from supplier to refinery	Collection of fuel from supplier gate	Physical	Delivery of fuel oil to refining gate	B/reference to other site specific data
Fuel usage	Boiler in refinery	Energy conversion	Fuel use for boiler	B/reference to other site specific data
Water treatment	Extraction of water from aquifers or surface water (river)	Physical, chemical and biological processing	Potable water at water works gate	B/Ecoinvent database
Water supply (for steam and chilled water supply)	Potable water at water works gate	Physical	Potable water at refining and fractionation unit gate	B/Ecoinvent database

REFINING AND FRACTIONATION PROCESS

Unit process	Process starts	Nature of transmission	Process ends	Data type (B/F*/Data source)
Phosphoric acid production	Acquisition of raw materials	Physical and chemical processing	Phosphoric acid at the production unit gate	B/Ecoinvent database
Transportation of phosphoric acid to refinery (includes intermediate storage and retailing)	Collection of phosphoric acid from production unit gate	Physical	Delivery of phosphoric acid to refining unit gate	B/reference to other site specific data
Phosphoric acid usage	Phosphoric acid store at refinery	Physical	Phosphoric acid for degumming CPO	B/reference to other site specific data
Bleaching earth production	Acquisition of raw materials	Physical and chemical processing	Bleaching earth at the production unit gate	B/Ecoinvent database
Transportation of bleaching earth to refinery (includes intermediate storage and retailing)	Collection of bleaching earth from production unit gate	Physical	Delivery of bleaching earth to refining unit gate	B/reference to other site specific data
Bleaching earth usage	Bleaching earth store at refinery	Physical	Bleaching earth for adsorptive cleansing of CPO	B/reference to other site specific data
CPO degumming and earth bleaching	CPO as delivered and stored at refinery	Physical and Chemical processing	Degummed, bleached palm oil Solid waster - spent bleaching earth (SBE)	B/reference to other site specific data
Solid waste handling (includes transportation)	SBE with retained oil and moisture	Physical	SBE at landfill	B/reference to other site specific data
Solid waste recycling (includes transportation)	SBE with retained oil and moisture	Physical	SBE and spent earth oil at SBE processing unit gate	B/reference to other site specific data
Palm oil deacidification and deodorization	Degummed, bleached palm oil	Physical processing	Refined palm oil (RPO)	B/reference to other site specific data
Recovery of palm fatty acid distillate (PFAD) from waste water	Waste water from processing of CPO	Physical	Waste water and PFAD	B/reference to other site specific data

Unit process	Process starts	Nature of transmission	Process ends	Data type (B/F*/Data source)
On-site waste water treatment	Waste water after recovery of PFAD	Chemical/chemical processing	Treated waste water (to be discharged)	B/reference to other site specific data
Storage of PFAD	PFAD ready	Physical	PFAD at refining unit gate	B/reference to other site specific data
Storage of RPO (on tank farm)	RPO ready	Physical	RPO at the refining unit gate	B/reference to other site specific data
Capital goods use including steel and concrete in buildings and processing plant equipment	CPO at RPO gate	Physical/chemical processing	RPO at refining and fractionation gate	B and F/Ecoinvent data base, reference to other site specific data
RPO fractionation	Refined palm oil at refining gate	Physical processing	Refined palm olein and palm stearin	B/reference to other site specific data
Storage of refined palm olein and refined palm stearin	Refined palm olein and refined palm stearin ready	Physical	Refined palm olein and refined palm stearin at fractionation unit gate	B/reference to other site specific data

Appendix 2: Inventory Background Data for LCA Analysis

Life Cycle inventory for Plantation Scenario 1 & 2

Output	incl. LULUC	excl. LULUC	Unit	Comment
FFB	17080	17080	kg	Dry matter: 0.30 kg/kg, Gross Energy 24.60 MJ/kg
Input	incl. LULUC	excl. LULUC	Unit	Comment
Water	0	0	m ³	
Occupation, permanent crop	10000	10000	m ² a	
Transformation, from forest, unspecified	365.1	0	m ²	
Transformation, from grassland	12.04	0	m ²	
Transformation, from permanent crop	2.439	0	m ²	
Transformation, from annual crop	50.32	0	m ²	
Transformation, to annual crop	429.9	0	m ²	
Di ammonium phosphate, as 100% (NH ₃) ₂ HPO ₄ (NPK 22-57-0), at plant/RER Mass	8.378	8.378	kg	
Ammonium sulfate, as 100% (NH ₄) ₂ SO ₄ (NPK 21-0-0), at plant/RER Mass	30.4	30.4	kg	
NPK compound (NPK 15-15-15), at plant/RER Mass	104.7	104.7	kg	
Urea, as 100% CO(NH ₂) ₂ (NPK 46.6-0-0), at plant/RER Mass	134.8	134.8	kg	
Phosphate rock (32% P ₂ O ₅ , 50% CaO) (NPK 0-32-0), at mine/RER Mass	75.82	75.82	kg	
Single superphosphate, as 35% Ca(H ₂ PO ₄) ₂ (NPK 0-21-0), at plant/RER Mass	25.87	25.87	kg	
Triple superphosphate, as 80% Ca(H ₂ PO ₄) ₂ (NPK 0-48-0), at plant/RER Mass	20.39	20.39	kg	
Potassium chloride (NPK 0-0-60), at plant/RER Mass	236.3	236.3	kg	
Potassium sulfate (NPK 0-0-50) (Mannheim), at plant/RER Mass	0.6649	0.6649	kg	
Insecticide, at plant/RER Mass	0.003992	0.003992	kg	
Fungicide, at plant/RER Mass	0.01447	0.01447	kg	
Herbicide, at plant/RER Mass	0.02821	0.02821	kg	

Insecticide emissions, at farm/GLO	0.003992	0.003992	kg	
Fungicide emissions, at farm/GLO	0.01447	0.01447	kg	
Herbicide emissions, at farm/GLO	0.02821	0.02821	kg	
Basic infrastructure, at farm/GLO Mass	1	1	ha	
Transport, truck 10-20t, EURO4, 80%LF, empty return/GLO Mass	51.87	51.87	tkm	
Energy, from diesel burned in machinery/RER Mass	331.3	331.3	MJ	
Emission	incl. LULUC	excl. LULUC	Unit	Comment
Carbon dioxide, fossil	176	176	kg	Lime and dolomite emissions based on tier 1 calculations described in Guidelines for National Greenhouse Gas Inventories (IPCC, 2006)
Carbon dioxide, fossil	98.88	98.88	kg	Fertilizer emissions based on tier 1 calculations described in Guidelines for National Greenhouse Gas Inventories (IPCC, 2006)
Dinitrogen monoxide	1.363	1.363	kg	Direct Fertilizer emissions based on tier 1 calculations described in Guidelines for National Greenhouse Gas Inventories (IPCC, 2006)
Dinitrogen monoxide	0.4431	0.4431	kg	Indirect Fertilizer emissions based on tier 1 calculations described in Guidelines for National Greenhouse Gas Inventories (IPCC, 2006)
Ammonia	14.3	14.3	kg	Fertilizer emissions based on tier 2 ammonia emissions described in Air Pollutant Emission Guidebook (EMEP/EEA, 2016)

Nitrogen monoxide	0.6074	0.6074	kg	Fertilizer emissions based on NO emission based on global mean fertilizer-induced NO emission (EMEP/EEA, 2016)
Dinitrogen monoxide	7.543	0	kg	Direct Emissions from peat oxidation based on peat land emissions described in Guidelines for National Greenhouse Gas Inventories (IPCC, 2006)
Carbon dioxide, fossil	22000	0	kg	Emissions from peat oxidation based on peat land emissions described in Guidelines for National Greenhouse Gas Inventories (IPCC, 2006)
Carbon dioxide, land transformation	8893	0	kg	Land use change impacts based on Direct Land Use Change Assessment Tool 2018, Blonk Consultants, Gouda
Dinitrogen monoxide	0.08611	0.08611	kg	Direct Crop residues emissions based on tier 1 calculations described in Guidelines for National Greenhouse Gas Inventories (IPCC, 2006)
Dinitrogen monoxide	0.01938	0.01938	kg	Indirect Crop residues emissions based on tier 1 calculations described in Guidelines for National Greenhouse Gas Inventories (IPCC, 2006)

Life Cycle inventory for Plantation Scenario 3 & 4

REFINERY		
Base: RPO	ton	1
Electricity	kWhr	11.94
Boiler fuel	MJ	476.91
Boiler fuel	kg	11.09
Water	litre	113.39
Crude palm oil (CPO)	ton	1.05
Phosphoric acid	kg	0.59
Bleaching earth	kg	9.11
Road Transport		
CPO transport (distance) from mill to refinery (28-t truck)	km	120
Transport of CPO to refinery tkm	tkm	126
Fuel oil transport (distance) from supplier to refinery (28-t truck)	km	500
Transport of fuel oil to refinery	tkm	5.545
Phosphoric acid transport (distance) from chemical plant to refinery (28-t truck)	km	500
Transport of phosphoric acid to refinery	tkm	0.3
Bleaching earth transport (distance) from chemical plant to refinery (16-t truck)	km	100
Transport of bleaching earth to refinery	tkm	0.91
Spent bleaching earth transport (distance) from refinery to landfill (16-t truck)	km	15
Transport of spent bleaching earth to landfill	tkm	0.17
Sea Transport		
Phosphoric acid sea transport (distance)	km	15000
Transport of phosphoric acid	tkm	8.85
Bleaching earth sea transport (distance)	km	3000
Transport of bleaching earth	tkm	27.33
Waste water	litre	42.16
Palm fatty acid distillate	kg	45.62
Spent bleaching earth	kg	11.09
Waste water biochemical oxygen demand (BOD)	kg	1.12
Waste water chemical oxygen demand (COD)	kg	3.26
Fractionation		
Electricity	kWhr	9.84
Water	litre	76.27
Cooking oil (Olein)	kg	715
Stearin	kg	239.38

Appendix 3: Detailed Foreground Data for LCA Analysis

No	Item Data	Year					Unit	Information
		2017	2018	2019	2020	2021		
1	TOTAL PRODUCTION							
	CPO (Crude Palm Oil)	33,791,000	30,141,000	29,757,000	34,892,000	30,672,000	kg	
	PKO (Palm Kernel Oil)	7,615,000	8,116,000	7,469,000	9,510,000	7,641,000	kg	
2	ENERGY USE							
	Source of Energy							
	Diesel fuel	0.3148	0.3219	0.2955	0.0124	0.3239	Litre	per 100 kg CPO
	Electricity	16.59	14.48	20.97	2.35	6.60	kWh	per 100 kg CPO
	Energy intensity	0.000443	0.000345	0.000561	0.000047	0.000163	kW	per 100 kg CPO
3	USE OF MATERIALS AND CHEMICALS							
	FERTILIZERS							
	1.Urea	0.621	1.762	0.213	0.861	0.788	Kg	per 100 kg CPO
	2.Dolomite	0.878	2.309	0.523	-	0.965	Kg	per 100 kg CPO
	3.MOP	0.610	1.398	0.156	0.960	0.187	Kg	per 100 kg CPO
	4.Kieserit	0.051	-	-	-	0.008	Kg	per 100 kg CPO
	5.Borate	0.027	0.095	0.052	0.071	0.001	Kg	per 100 kg CPO
	6.TSP	0.275	0.682	0.452	0.502	-	Kg	per 100 kg CPO
	7.LCKS	-	-	-	0.991	-	Kg	per 100 kg CPO
	8.RP	0.196	0.195	0.614	-	-	Kg	per 100 kg CPO
	9.NPK	0.056	0.027	-	-	-	Kg	per 100 kg CPO
	10.Tankos	-	-	-	5.269	-	Kg	per 100 kg CPO
	PESTICIDE							
	1.Amcofur	0.00044	0.01308	0.00030	0.00023	0.00014	Kg	per 100 kg CPO
	2.Nara Up	0.01005	-	-	0.02416	0.01067	Kg	per 100 kg CPO
	3.Racumin	-	-	-	0.00023	0.00074	Kg	per 100 kg CPO
	4.Marshall	0.00194	0.01663	0.00855	0.00861	0.00326	Kg	per 100 kg CPO
	5.Santrino	0.00249	0.00474	0.00144	-	0.00044	Kg	per 100 kg CPO
	6.Klerat	-	0.01108	0.00254	0.00093	-	Kg	per 100 kg CPO
	7.Beta Sipermatine	-	-	-	0.00002	-	Kg	per 100 kg CPO
8.Dithane	-	-	-	0.00005	-	Kg	per 100 kg CPO	

No	Item Data	Year					Unit	Information	
		2017	2018	2019	2020	2021			
	9.Methil Metsulfuron	-	-	-	0.00014	-	Kg	per 100 kg CPO	
	10.Starane 480 ec	0.00089	0.00108	0.00049	0.00041	-	Kg	per 100 kg CPO	
	11.Asefat	-	-	-	0.00012	-	Kg	per 100 kg CPO	
	12.Rexroot	-	0.04002	0.00831	-	-	Kg	per 100 kg CPO	
	13..Zhipos	-	0.00040	0.00168	-	-	Kg	per 100 kg CPO	
	14.Koller	-	0.00161	0.00039	-	-	Kg	per 100 kg CPO	
	15.Konidin Klamidospora	-	0.07197	-	-	-	Kg	per 100 kg CPO	
	16.Herb.Sun Up	0.00831	-	-	-	-	Kg	per 100 kg CPO	
	17.Herb.Crash	0.00468	-	-	-	-	Kg	per 100 kg CPO	
	CHEMICALS								
	1. Aluminium sulphate	0.09692	0.08162	0.10115	0.07996	0.09928	Kg		
	2. soda ash	-	0.01294	-	0.00766	0.04018	Kg		
	3. BWT 2041	0.01332	0.01468	0.01227	0.01304	0.01206	Kg		
	4. BWT 2200	0.01003	0.00938	0.00665	0.00929	0.00952	Kg		
	5. BWT 2430	0.00644	0.00705	0.00571	0.00473	0.00424	Kg		
	6. BWT 2520	-	-	-	-	0.00359	Kg		
	7. Caustic Soda	0.00044	0.01145	0.00546	0.00645	0.00473	Kg		
8. Sulphuric acid	0.00024	0.00637	0.00309	0.00413	0.00261	Kg			
9. Alcohol	0.00065	0.00075	0.00195	0.00136	0.00220	Kg			
10. Shell sholl	0.00052	0.00050	0.00084	0.00093	0.00057	Kg			
4	WATER USE								
	Source of water:								
	Surface water (River)	0.48396	0.71508	0.61132	0.04262	1.63673	m ³	per 100 kg CPO	
	Water intensity	2.9 x 10 ⁻⁶	3.48 x 10 ⁻⁶	4.1 x 10 ⁻⁶	3.55 x 10 ⁻⁶	1.01 x 10 ⁻⁶	m ³	per 100 kg CPO	
5	AIR EMISSIONS								
	Source: Genset								
	Total of Particulate	101.10	21.90	11.19	117.00	129.00	mg/Nm ³		
	CO	125.50	82.51	200.40	332.00	436.00	mg/Nm ³		
	NO ₂	58.77	74.64	191.80	42.00	63.00	mg/Nm ³		
	SO ₂	38.00	58.45	26.00	12.00	37.00	mg/Nm ³		
	O ₂	9.20	9.50	9.10	9.10	9.40	%		
	Flow speed	20.30	21.19	21.20	4.56	5.68	m/s		
Percentage of Isokinetic	100.05	101.10	100.05	99.89	101.17	%			
6	LIQUID WASTE (PermenLH 5/2014)								
	Debit (Q)						m ³		

No	Item Data	Year					Unit	Information
		2017	2018	2019	2020	2021		
	pH	7.87	7.93	6.76	7.44	7.9		
	BOD5	112.94	39.81	5.37	6.77	6.38	kg	
	COD	203.61	223.52	18.06	27.17	21.26	kg	
	TSS	63.18	96.99	7.41	8.56	0.44	kg	
	oil and fat	7.38	0.72	1.22	1.26	0.44		
	N - Total						mg/l	
	POME (<i>Palm Oil Mill Effluent</i>)	0.29526	0.30162	0.30021	0.31693	0.31686		per 100 kg CPO
6	SOLID WASTE							
	Domestic waste (Non B3)	0.00047	0.00056	0.00056	0.00048	0.00047	Kg	per 100 kg CPO
	Limbah B3	0.00487	0.00056	0.00056	0.00048	0.00047	Kg	per 100 kg CPO

