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Palm Factory Circularity Indicators Based on Various Palm Oil Mills Effluent Processing Technologies

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ABSTRACT

Apart from Crude Palm Oil (CPO), which is the main product, the process of converting FFB to CPO also produces liquid waste known as liquid palm oil waste or Palm Oil Mill Effluent (POME). In the framework of this analysis, POME is also considered a product because it has economic value and benefits that allow it to be further processed into new products, so the circularity value will be calculated. The research approach uses the MCI circularity indicator developed by the Ellen MacArthur Foundation in assessing circularity indicators for various POME waste management scenarios in palm oil mill. From various POME processing governance scenarios, namely: 1) Processing POME with biogas technology lagoon system, 2) Processing POME with biogas technology with a CSTR system, and 3) Processing POME into with composting and 4) Based on government regulations regarding POME processing in palm oil mills with open ponds processing. Based on the assessment results based on these various scenarios, the MCI circularity values obtained are 1)0.5781; 2)0.6143 and 3)0.7065, and 4)0.5500;. The highest MCI circularity value is produced by processing POME into composting.

Keywords: circular economy; material circularity indicator; palm oil industry; pome

INTRODUCTION

From a physical perspective, the conceptualization of a sustainable circular economy can be interpreted as a strategy to minimize the outflow of material from the system, where in this context, biomass functions as the material and the palm oil industry as the system that involves it (Abidi, 2022). However, the current reality of the palm oil industry in Indonesia is that it tends to adopt a linear economic approach that follows a 'make-use-dispose' pattern (Yoochatchaval et al., 2011; Zulkifli, 2016).

Such a conventional approach can be considered less efficient because it does not fully utilize the potential economic benefits, implying that some resources are forgotten due to the 'make-use-dispose' model. In this case, the demand for effective utilization of biomass arises, where the idea of circularity can be introduced into the realm of the palm oil industry, forming a regenerative system that stands independently and produces a more sustainable continuation.

The results of other research, according to Susilawati (2015), the average amount of solid waste produced by factories is: (a) Empty bushes (JJK) are around 18% to 21% of the FFB processed, (b) Fiber is around 11% to 13% of processed FFB, (c) The shell is about 5% of the processed FFB, (d) The remainder is POME, around 60% of the FFB processed.

Solid waste consisting of palm shells and fiber is implemented as fuel in boilers in the Fresh Fruit Bunches (FFB) processing process at Palm Oil Mill facilities. At the same time, empty hemp residues are used as "organic fertilizer" by being applied to agricultural land through an application approach that complies with the recommendations set out by the Research Department (Ng et al., 2017). The method of applying empty leaf residue through the mulching technique is applied between the four main plants for each point on the mature plants (TM).

In order to turn this waste into an energy source, "conversion technology" is needed which is able to convert biomass into a useful form of energy (Janik & Ryszko, 2017; Parinduri & Parinduri, 2020). The use of biomass to produce heat in a "simple" way in a Palm Oil Mill environment involves directly burning the fibers or shells as biomass, which then produces heat.

According to Kirchherr, et al. (2017) in their research, the circular economy concept refers to an economic framework that integrates the product life cycle to the final stage, with main principles including reduction, reuse and improvement of materials in the production process, distribution and consumption (Repair). This approach can be implemented at various levels, including micro scale (companies, consumers), meso scale (eco-industrial areas), and macro scale (cities, regions, countries), with the main aim of achieving sustainable economic goals, as well as realizing optimal environmental quality, economic prosperity, and social justice. Developing a circular economy requires a transformation in business models and the adoption of responsible consumer behavior.

In a broader context, CPO is placed as the main product that is the focus, while other commodities are considered as derivative products that still have economic value and benefits that can be utilized or passed on to the next processing stage to become new products. Apart from the materials that have been described, the process of converting FFB to CPO also produces waste in liquid form known as liquid palm oil waste or Palm Oil Mill Effluent (POME). In the framework of this analysis, POME is also considered a product because it has economic value and benefits that allow it to be further processed into new products, and therefore, its circularity value will be calculated.

RESEARCH METHOD

Material Circularity Indicator

The Ellen MacArthur Foundation (2019) presents the concept of the "Material Circularity Indicator" or what is known as the Material Circularity Indicator (MCI) which aims to evaluate the extent to which the principle of linear flow has been suppressed and restorative flow returns have been increased for the component materials. In addition, this indicator also involves an analysis of the extent to which the intensity and duration of use compares with the average of products in similar industries.

This approach developed by Ellen MacArthur is an approach that is usually used in the manufacturing industry, but it is possible that this approach is used in the process industry.

The core structure of the Material Circularity Indicator is basically formed through the combination of three main product characteristics, which include:

1. mass of raw materials used in the factory,
2. the mass of waste associated with the product,
3. utility factors that explain the length and intensity of product use.

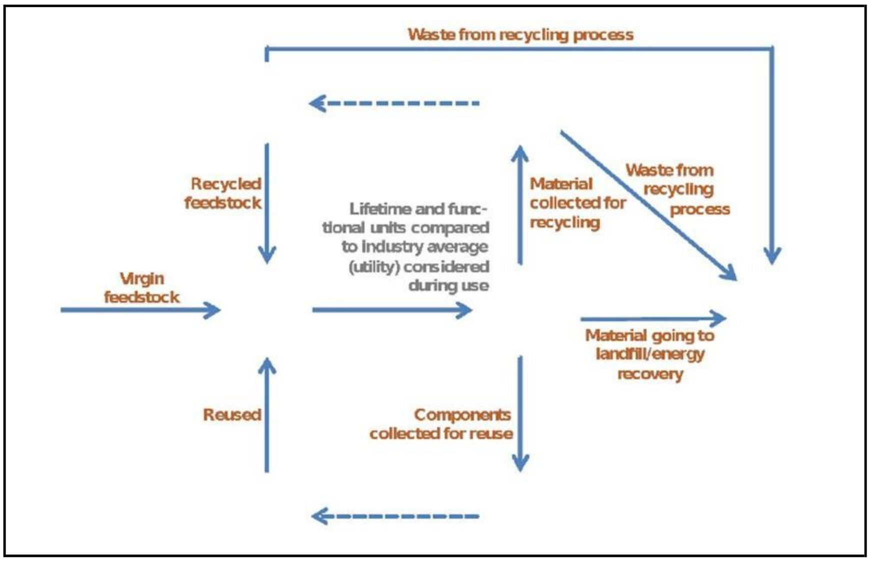

Figure 1. Material Circularity Model (MACARTHUR & HEADING, 2019)

This Material Circularity Indicator is an assessment tool for companies to (Budiarto & Agung, 2009; Safrizal, 2015):

a. Measures the circularity of material flow for selected products
b. Enabling companies to build from products to portfolios, this can be extended to an enterprise-level view of the circularity of material flows
c. Support decision making regarding business development

MCI approach

MCI is a circularity indicator measurement tool proposed by the Ellen MacArthur Foundation (Hasanudin et al., 2015; Kachapoch et al., 2020) which considers:

- recycling and reusing products
- waste generated by the manufacturing process.
- product usability
- average lifetime of the product
- functional units of industrial products

These are represented as a single value, ranging from 0-1, where 1 means a fully circular product and 0 means a fully linear product. MCI also functions as a tool that can evaluate product-level circularity performance by considering (WBCSD, 2021; Yacob et al., 2006):

- reuse and recycling in raw materials, expressed as a reuse to recycling ratio.
- waste generation by the manufacturing process and product utility calculated from the product's lifetime
- functional units compared with similar industrial products.

Perhitungan MCI mengacu pada dokumen metodologi Material Circularity Indicator dari Ellen MacArthur Foundation (Ellen MacArthur Foundation, 2019).

To calculate MCI, virgin raw materials (V) are first calculated. Virgin raw materials used in production are given by:

$$V = M(1 - F_R - F_U - F_S) \tag{1.1}$$

Where M is the mass of the final product, F_R is the fraction of recycled raw materials, FU is the fraction of raw materials that are reused, and F_S is the fraction of biological raw materials from sustainable production. Unrecoverable waste (W_0), namely waste sent to landfill or energy recovery is calculated as :

$$W_0 = M(1 - C_R - C_U - C_C - C_E) \tag{1.2}$$

Where C_R is the product fraction after use collected for the recycling process, C_U is the product fraction after use collected for reuse, C_C is the product fraction after use collected for the composting process, and C_E is the fraction of product after use collected for energy recovery. This generates waste from the recycling process (W_C) which depends on the efficiency of the recycling process (E_C).

$$W_C = M(1 - E_C)C_R \tag{1.3}$$

There is also waste generated to produce recycled raw materials (W_F) which depends on the efficiency of the recycling process used to produce recycled raw materials (E_F).

$$W_F = M\frac{(1-E_F)C_R}{E_F} \tag{1.4}$$

Therefore, the total amount of unrecoverable waste (W) is obtained

$$W = W_0 + \frac{W_F + W_C}{2} \tag{1.5}$$

The next stage is to calculate the Linear Flow Index (LFI) parameter which shows the level of linearity of a product. The value of this parameter has a range of 0 to 1, where a value of 1 represents full linearity and a value of 0 represents nonlinearity.

$$LFI = \frac{V+W}{2M+\frac{W_F - W_C}{2}} \tag{1.6}$$

The MCI parameter is a function of LFI and utility factor or F(X), where F(X) can be calculated based on the product lifetime and product functional units.

$$X = (\frac{L}{L_{av}})(\frac{U}{U_{av}}) \tag{1.7}$$

$$F(X) = \frac{0.9}{X} \tag{1.8}$$

$$MCI_P = 1 - LFI.F(X) \tag{1.9}$$

Where L represents the actual average lifetime of a product, Lav represents the average lifetime of products from the same industry, U is the actual average number of functional units of a product, and Uav is the average number of functional units of an industrial product the same one.

In the research of Muthita Kachapoch et al (2020), the unrecoverable waste calculation formula had to be modified to suit CPO. The calculation of modifications to the unrecoverable waste formula considers the product after use, including co-products, waste, and oil loss from the refining process (Safrizal, 2015; Sudaryanti, 2017). Co-products are considered part of a product that after use is collected for recycling because it is then used in the soap and oleochemical industry. Oil losses from the refining process are considered as part of the product after use which is collected for reuse. However, the modified MCI did not reach 1, even though the oil extraction rate increased. This is because virgin raw materials do not have reuse, recycling and biological material fractions, namely the mass of oil in FFB is still the same as the mass of CPO according to the Ellen MacArthur Foundation formula.

RESULT AND DISUCCION

Data Analysis

We can assess circularity using several parameters. that is (Yeo et al., 2020):

1. Mass of the product being analyzed
2. Composition of by-products, waste produced, and oil loss from the product being analyzed
3. Actual average shelf life of the analyzed product and of the same industrial product
4. Actual average value of the functional unit of the analyzed product and of the same industrial product

Analysis of results in the form of support in building current performance, can track performance over time and identify opportunities for improvement, by interpreting and visualizing the results obtained from calculations.

POME Circularity Value Calculation Results

This research calculates the circularity using the MCI calculation method and compares the circularity value obtained from the best practice conditions for liquid waste processing in palm oil mills and regulations relevant to palm oil liquid waste processing.

The MCI method is used to assess the level of circularity and evaluate the extent to which products related to the palm oil industry can be categorized as processes that adopt circular principles. The initial stage of this analysis begins with the use of Fresh Fruit Bunches (FFB) as the initial entity to be processed. The FFB processing process produces a number of commodities, including CPO, palm kernel kernels, empty palm fruit bunches (TKKS) which are better known as Empty Fruit Bunch (EFB), palm fiber (Palm Fiber), and coconut seed shells. palm oil (Palm Kernel Shell). Apart from the materials that have been described, the process of converting FFB to CPO also produces waste in liquid form known as liquid palm oil waste or Palm Oil Mill Effluent (POME).

Supporting data used to calculate the circularity value of POME is as follows:

- Total solids from POME is 4-5% (Ahmad et al., 2003; Irwansyah, 2016) which will be used to calculate Mwaste in MCI calculations.
- Oil loss from POME used in this study is 1%.
- The residence time of POME in open pond systems is 40-60 days (Jannah, 2018; Yoochatchaval et al., 2011).
- The functional unit of POME for land application is the FFB productivity value, so the actual average number of functional units (U) used for productivity using treated POME is 15,360.21 kg FFB/ha, while the average number of functional units of The same industrial product (Uav) uses productivity without using treated POME, namely 13,622.45 kg FFB/ha (Hasanudin et al., 2015; Szekely & Zhao, 2022).
- The functional unit of POME in the composting scenario to become fertilizer is the conversion value of POME which is equivalent to UREA fertilizer, so that the actual average number of functional units (U) used is 0.0023 kgurea/kgpome (Chong, et al., 2017), while the average number of functional units of the same industrial product (Uav) is 0.0015 kgurea/kgpome ¬ (AM, 2012; Nazir, 2011; Parinduri & Parinduri, 2020).

In the MCI calculation in this study, the value of V will be the same as M and the WF value is 0 because palm oil production does not involve a recycling and reuse process and there is no biological content from pure raw materials, namely FFB.

This study also uses several alternative scenarios for POME processing to compare the circularity value of several existing types of palm oil liquid waste management. The first and second scenarios are closed pond systems which are anaerobic in nature so they produce methane gas which has a higher utilization potential than POME, such as generating electricity to meet factory energy needs. The difference between these two scenarios is the material used as a POME storage container, in (1) the first scenario uses a covered laggon concept while (2) the second scenario uses a continuous stirred tank reactor (CSTR), (3) the third scenario is POME processing into fertilizer or compost using a composting process which is then used for fertilizing garden land. These three scenarios are referred to as best practices in managing POME (Iwuagwu & Ugwuanyi, 2014; Parinduri, 2018).

In this framework of this analysis, POME is also considered a product because it has economic value and benefits that allow it to be further processed into new products, and therefore, its circularity value will be calculated. This final product is used for land application on the plantation land of each Palm Oil Mill. Although there is no definite data from Palm Oil Mill regarding how much influence the use of processed POME has on land quality and plantation productivity, this study will use data from other sources that can be accounted for.

Regulations and policies from the government (of Republic Indonesia) have an important role in supporting existing POME governance and its development according to best practices, so in this study the calculation of the circularity value of regulations was also carried out as the fourth scenario, in this scenario, POME processing usually uses an open pond system.

The results of MCI calculations for POME in various scenarios are shown in Figure 2 and Table 1.

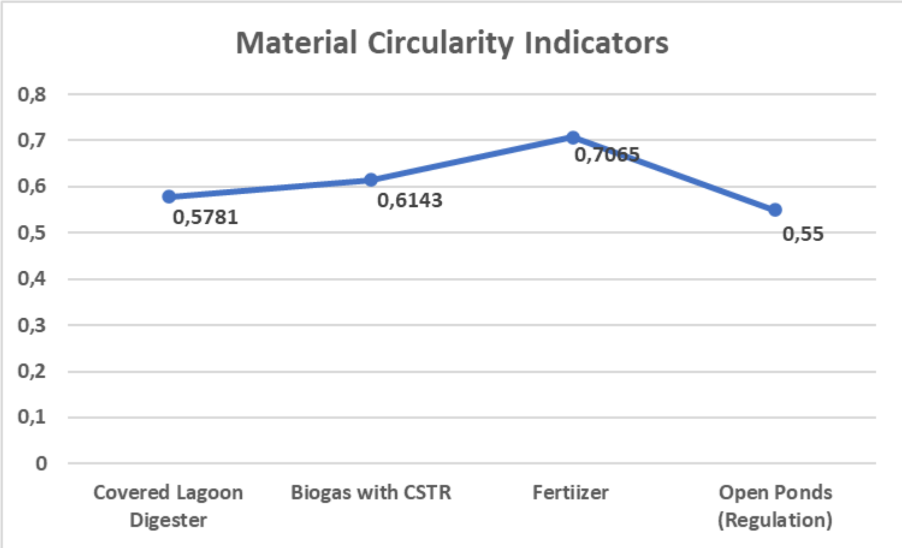

Figure 2. Circularity Values from Various Conditions

Table 1. MCI calculation results for POME under various conditions

Parameter	Covered Lagoon Biogas	CSTR Biogas	Fertilizer	Open Lagoon
M	45.360	45.360	45.360	45.360
V	45.360	45.360	45.360	45.360
$M_{Co\text{-}product}$	-	-	-	-
M_{Waste}	1.814,40	1.814,40	1.814,40	1.814,40
$M_{Oil\ loss}$	453,6	453,6	453,6	453,6
M*	2.268,00	2.268,00	2.268,00	2.268,00
W_0	-	-	-	-

C_R	-	-	-	-
C_U	0,2	0,2	0,2	0,2
C_C	0,8	0,8	0,8	0,8
C_E	-	-	-	-
W_C	-	-	-	-
E_C	-	-	-	-
W_F	-	-	-	-
E_F	-	-	-	-
W	-	-	-	-
L	40	20	20	1
L_{av}	40	20	20	1
U	25,6	28	0,0023	1
U_{av}	24	24	0,0015	1
X	1,067	1,167	1,533	1
F(X)	0,844	0,771	0,587	0,9
LFI	0,5	0,5	0,5	0,5
MCI	0,5781	0,6143	0,7065	0,55

DISCUSSION

From the results of the MCI calculations in this study, it was found that POME management using the composting process had the highest circularity value. This is possible because the fertilizer produced from POME management can increase soil fertility thereby increasing the productivity of fresh fruit bunches from oil palm so that CPO production, as the main product, can increase. A cycle like this really illustrates the implementation of a circular economy where all products produced can be reused, thereby increasing the economic value of the process itself without throwing away a product that still has economic value (dan Supijatno, 2015; Sudaryanti, 2017).

This value is slightly higher than the best practice scenario of using closed ponds as a methane capture method which has a value of 0.5781. This higher value can occur because the use of POME for land applications is directly related to increasing the productivity of virgin raw materials, while the use of POME into biogas has an impact on supporting parameters, namely substitution and energy fulfillment from the factory itself.

When compared with the same concept, the second scenario, namely the use of CSTR in managing POME into biogas, will have a higher circularity value than the first scenario which uses a closed pond, namely 0.6143. Basically, the biogas produced from CSTR will have better quality, such as the amount of biogas produced and its composition, compared to closed ponds (Rahayu et al., 2015; Rajani et al., 2019). A larger amount of biogas and better quality can produce a greater amount of energy so that it can increase the quality and quantity of production. Likewise with the third scenario, POME management using a composting system has a higher value than the use of POME for land application, namely 0.7065 even though they both have benefits for soil fertility and increasing the productivity of pure raw materials. This can happen because composting will use additional processes to increase the nutrients and quality of the fertilizer produced, so the impact will be greater than using POME for soil application which does not use further processes.

For the fourth scenario, where POME governance follows the directions of existing regulations, with open ponds processing, it will produce the smallest circularity value, namely 0.55. This value obtained is due to the absence of specific regulations governing POME management for further utilization and management of POME and there are only regulations regarding quality standards for liquid waste water discharged into land and other water sources. Therefore, POME governance based on existing regulations in Indonesia can be described as conventional POME governance, namely using an open pond system and without the use of POME so that POME that has been processed will be disposed of directly into water sources.

The importance of transitioning to more sustainable governance practices in the palm oil industry cannot be underestimated. Innovative steps, such as implementing an independent liquid waste management system, using biogas technology, and collaborative efforts between government, industry, and various stakeholders, have the potential to bring positive change. By increasing awareness of the long-term benefits of more environmentally friendly management, it is hoped that more mills in Indonesia will be encouraged to adopt more sustainable practices in managing palm oil wastewater.

CONCLUSION

The POME management that has the highest circularity value is in the fourth scenario, namely the composting process or utilization of POME into fertilizer with a circularity value of 0.7065, while the lowest circularity value is in POME management based on existing regulations in Indonesia, namely 0.55. From these results it was found that the management of liquid waste from palm oil mills generally still uses conventional methods, namely the open pond system. This is done only to meet the quality standards that have been determined by existing regulations.

There are several factors that can support the management of liquid waste from palm oil mills in realizing a circular economy, namely the implementation of the 5R principles (reduce, reuse, recycle, refurbish and repair), the use of technology and further utilization of waste, and more specific regulations. in determining and regulating good liquid waste management.

RECOMMENDATION

The existing Material Circularity Indicator values can be used as a comparison in making managerial decisions related to POME waste management.

Some of the findings from this research are that the value of the Material Circularity Indicator does not depend on the capacity of the palm oil mill, but is determined by the effort made to process the POME. Besides that, it was found that most industries in the field did not innovate to increase the value of the Material Circularity Indicator in POME processing, and only referred to government regulations regarding POME processing in the palm oil industry.

The weakness of this research is that there were no examples of palm oil mills that had processed POME to be processed into energy or fertilizer, so it could not provide a more complete and comprehensive picture, because the data used in the simulations for various scenarios 3,4 and 5 above were processed from various secondary sources. Therefore, we suggest conducting a study on palm oil mills that have processed POME with biogas technology and made fertilizer.

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