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A sustainability performance assessment framework for palm oil mills

Nabila Farhana Jamaludin [a, b], Haslenda Hashim [a, b], Zarina Ab Muis [a, b, *], Zaki Yamani Zakaria [b], Mazura Jusoh [b], Alafiza Yunus [a, b], Siti Mariah Abdul Murad [b, c]

[a] Process System Engineering Centre (PROSPECT), Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia
[b] Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia
[c] Sime Darby Berhad, Wisma Sime Darby, Jalan Raja Laut 50350 Kuala Lumpur, Malaysia

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A B S T R A C T

The palm oil industry has had to undergo rapid development in order to cope with the increasing demand from consumers year by year. The palm oil industry is receiving criticism from various parties on the issue of sustainability. This paper presents the development of a Palm Oil Mill Sustainability Index that enables millers to assess the sustainability performance of palm oil mills against benchmarks, and to differentiate between the performance of each mill. The assessment was performed via the adoption of a Proximity-to-Target approach that measures the current sustainability performance of the industry relative to policy targets. The industry's comparable performance was observed in terms of sustainability and indicators through a graphical method. The resulting Palm Oil Mill Sustainability Index scores were translated into a five-point rating system to describe the sustainability performance levels for different mills i.e. excellent, good, fair, poor, and very poor. Based on the Palm Oil Mill Sustainability Index scores and rating system, weak performance indicators were identified, for example, excessive use of water consumption due to inappropriate operation of hydrocyclones. By identifying the weak performance indicators, practical recommendations and measures for improvement can be proposed and the Palm Oil Mill Sustainability Index scores recalculated to evaluate the effectiveness of the proposed sustainability performance strategy. Selected palm oil mills in Malaysia were used as a case study to demonstrate the applicability of the framework. The results provide empirical evidence to support a decision-support-system for enhancing palm oil mill sustainability performance, so as to achieve a balance between environmental, economic, and social aspects in the palm oil mill sector.

1. Introduction

The Malaysian palm oil industry is a highly regulated industry. The industry's supply chain must adhere to more than 15 laws and regulations including the Land Acquisition Act 1960, Environmental Quality Act 1974, Environmental Quality (Clean Air Regulations) 1978, Pesticides Act 1974 (Pesticides Registration Rules), Occupational Safety and Health Act (1977), and Protection of Wildlife Act (1972). The industry must comply with Hazard & Critical Control Points (HACCP) and Environmental Impact Assessment (EIA) requirements. Increased sustainability issues arising from palm oil production have resulted in growing global concern and demand for more sustainable production (Rival and Levang, 2014). These sustainability issues introduce more pressure to the industry with major palm oil consumers such as Starbucks and Ferrero Corporation stating that they will only use sustainably certified palm oil in their production line (Vanessa, 2013).

To address the controversies surrounding the sustainability issues and to maintain a clean image, palm oil mills must now undertake certification schemes, which ensure that they keep track of their sustainability practices—from millers, transporters, and refiners to end users. (Schouten and Glasbergen, 2012). In order to enhance the sustainability of the industry, numerous certification schemes and sustainability practices have been adopted by the palm oil industry, namely through certification based on a set of pre-defined principles and criteria, which outline the best practices encompassing both the environmental and social aspects within the industry, as indicated in Table 1.

The explicit benchmarks and indicators have not been set as guidance for quality and verification criteria or for assessment of the sustainability performance of the palm oil industry. RSPO

* Corresponding author. Process System Engineering Centre (PROSPECT), Malaysia.
E-mail address: zarinamuis@utm.my (Z.A. Muis).

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Table 1
Current palm oil sustainable certification schemes.

Standard	Objective	Research gap	References
Roundtable Sustainable Palm Oil (RSPO)	The RSPO objective is to promote the growth and use of sustainable oil palm products through credible global standards and engagement of stakeholders.	- General guidelines without address the gap between current sustainability performance achievement with respect to national guidelines or industrial best practices[a]. - Emphasise on environmental and social aspects	Lim et al. (2015) Schouten and Bitzer (2015)
International Sustainability and Carbon Certification (ISCC)	The ISCC objective is to certify the biomass and bioenergy industries, sustainable land use, protection of the natural biosphere, and social sustainability, all oriented towards the reduction of greenhouse gas emissions.	- General guidelines without quantifiable indicators - Emphasise on carbon footprint assessment	International Sustainability and Carbon Certification (ISCC) (2015)
Rainforest Alliance/ Sustainability Agriculture Network (RA/SAN)	RA/SAN aims to change land-use and business practices to reduce their impacts on both biodiversity and local people. Also, to mitigate the environmental and social risks associated with agriculture.	- General guidelines without quantification assessment - Emphasise on plantation assessment	Sustainability Agriculture Network (2015)
Indonesian Sustainable Palm Oil (ISPO)	ISPO aims to improve the sustainability and competitiveness of the Indonesian palm oil industry and contribute to the Indonesian Government's objectives to reduce greenhouse gas emissions and draw attention to environmental issues.	- General guidelines without quantification assessment - Mandatory but the evaluation criteria are inconsistent - Emphasise on environmental aspect	Indonesia Sustainable Palm Oil Council (ISPOC) (2014)
Malaysian Sustainable Palm Oil (MSPO)	The Malaysian Sustainable Palm Oil (MSPO) Certification Scheme is the national certification scheme in Malaysia through which oil palm plantations, independent and organised smallholdings, and palm oil processing facilities are certified against MSPO Standards.	- General guidelines without quantification assessment - Emphasise on environmental and social aspects	Basiron (2015)
Accreditation Services International (ASI)	ASI is one of the accreditation bodies under RSPO that investigates the compliance assessment for already certified and not yet certified mills.	- Qualitative assessment analysis without quantification approaches	Zudrags et al. (2015)

[a] Refer Appendix 1 in Supplementary Material for comparison between RSPO and POMSI.

requires mills to monitor water usage per tonne of FFB without address the gap between current sustainability performance achievement with respect to national guidelines or industrial best practices (Lim et al., 2015), rendering the RSPO seemingly ineffectual. In contrast, Blackman and Rivera (2011) stated that benchmarks and indicators are essential criteria for generating more credible and successful performance assessments. These schemes also lack the balance between three sustainable aspects, which over emphasise environmental issues, carbon footprint (International Sustainability and Carbon Certification (ISCC), 2015) and are lacking specific and quantifiable targets for implementation, monitoring, and reporting (Schouten and Bitzer, 2015). According to Rival and Levang (2014), it is complicated to implement existing palm oil certification schemes, which rarely refer to numerical data. The framework in this study is developed using index-based approaches to address the above limitations.

The concept of sustainable development has gained more attention. It is used as a global focal point for decision-making and policy settings in the industry. One of the key challenges is the measurement of the level of sustainability from the aspect of society, e.g. the local, national governments, the industry, local communities, and individual efforts, to determine the directions of change geared towards sustainability. Numerous sustainability index assessments have been performed such as the Low Carbon City Indicator proposed by Tan et al. (2015), which focuses on evaluation, implementation, and standardisation of low carbon cities (LCC) by measuring waste management, environmental control, and the economic factor of municipal solid waste (MSW) at the country level. Ahamad et al. (2015) developed the Environmental Performance Index for Malaysia with a focus on Malaysia's environmental performance. The most relevant index study concerning palm oil mills was developed by Hashim et al. (2014). The authors largely neglected the economic and social aspects in determining the sustainability performance assessment of palm oil mills. Table 2 summarises various sustainability assessment tools and gaps found in different sectors. According to Hansen et al. (2015), the pattern of palm oil sustainability research mainly touches on the technical aspects of palm oil residue. Yusoff (2006) reported that sustainability indicators in a palm oil mill should consist of energy efficiency, emissions, and waste management.

It is anticipated that there is no comprehensive sustainability assessment framework subject to the regulation or policy standards of the palm oil industry. In this study, a systematic sustainability assessment framework for a palm oil mill is developed, namely the Palm Oil Mill Sustainability Index (POMSI), to provide insights into, and comprehension of the current standing of palm oil mill sustainability performance in regard to specific standards, regulations or policies. POMSI enables millers to assess the sustainability performance of palm oil mills against benchmarks and to differentiate each mill performance for continuous mill operational improvements.

2. Methodology

This chapter presents a detailed methodology for the development of a sustainability performance framework for palm oil mills. The overall POMSI framework is shown in Fig. 1. This research is divided into three stages; the development of a sustainability index for palm oil mills, a sustainability index assessment to identify areas of weaknesses (hotspot), and an improvements proposal to improve weak performance indicators. The sustainability performance will be recalculated to evaluate the effectiveness of the proposed improvement. A case study approach is adopted whereby operational data from an entire palm oil supply chain is analysed.

2.1. Stage 1: development of a sustainability index for palm oil mills

A comprehensive study on current practices is conducted to analyse the shortcomings of current index practices. The indicators are identified based on a literature review and discussion with

Table 2
Sustainability assessment tool for different sectors.

Researcher	Objective	Research Gap	Application
Humbert et al. (2009)	To compare the life cycle assessments of spray dried soluble coffee with alternative drip filter and capsule espresso coffee.	1 . Assessment limited to environmental performance	Coffee Industry
Hashim et al. (2014)	To develop a new systematic tool known as the Green Industrial Performance Scorecard (GIPS) to assess the greenness of the palm oil industry.		Palm oil industry
Ahamad et al. (2015)	To develop an Environment Performance Index in Malaysia at the State level.		State/Country
Rivera and Reyes-Carillo (2016)	To develop a life cycle assessment framework for the environmental evaluation and decision making of automobile paint shops.		Automobile paint shops
Geibler et al. (2016)	To integrate quantitative material input and semi-quantitative decisions on environmental weaknesses in the single-serve coffee value chain.		Coffee value chain
Robeco SAM AG (2013)	To develop Dow Jones Sustainability group indices.	1 . Assessment limited to economic performance.	Corporation
Rajala et al. (2016)	To assess environmental sustainability focusing on the economic scope of industrial manufacturing.	2 No specific standards, regulations or policies were defined.	Industrial manufacturing
Chand et al. (2015)	To develop an integrated sustainability index for small dairy farm holders in Rajasthan, India.	1 . Policies or regulations were not considered in the assessment.	Dairy farm
Salvado et al. (2015)	To develop a Sustainability Index for the Automotive Industry	2 No specific benchmarking or target for results comparison compared with regulations.	Automotive Industry
Jasinski et al. (2015)	To develop a Sustainability Assessment Model (SAM) to bring all sustainability aspects into a single method for the automobile industry.		Automobile
Feil et al. (2015)	To select and identify the indicators for quickly measuring sustainability in micro and small furniture industries.		Furniture Industry
Tan et al. (2015)	To develop a holistic low-carbon city indicator framework for sustainable development.	1 . No specific benchmarking or target for results comparison. 2 . Weightage used entropy method approaches. 3 The economic aspect was not taken into consideration.	Low carbon city
Ford and Despeisse (2016)	To discuss and determine the advantages, challenges, and implications of additive manufacturing on sustainability in terms of sources of innovation, business models, and the configuration of value chains.	1 The development of this index was based on questionnaires; no specific standards, regulations or policies were defined.	Additive manufacturing
Latif et al. (2017)	To develop a sustainability index for the manufacturing industry		Manufacturing
Manik et al. (2013)	To identify the weightage of social indicators for the palm oil biodiesel industry.	1 Assessment has been limited to social performance.	Palm Oil Biodiesel

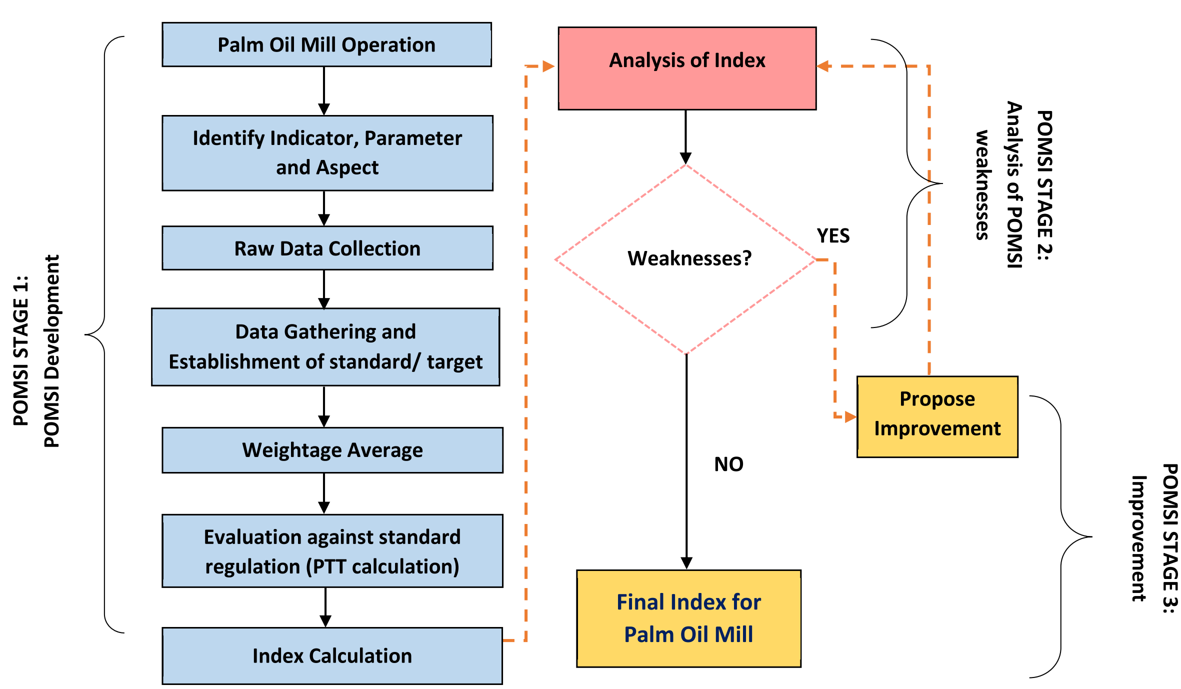

Fig. 1. Overall framework for the development of POMSI.

plant managers, staff, and subject experts. The final list of indicators is based on the data availability at the mill. The data is collected from selected palm oil mills after finalisation of the indicators. In the meantime, standards or targets are established based on policies from the Department of Environment of Malaysia (DOE), industry guidelines, targets set by the mills or existing best practices. As the data is different in terms of unit and scale, a normalisation method is performed using Eq. (1) or Eq. (2), as per the Proximity-to-Target (PTT), indicated in Section 2.1.6. The weightage of parameters is determined using an expert survey method. Once the weightage is obtained, the index is calculated using Eq. (3) to Eq. (6) to obtain the sustainability index performance score of each palm oil mill.

2.1.1. Palm oil mill operation

POMSI was developed to provide a quantitative and yet effective presentation approach of complex sustainability data for a palm oil mill. It is meant to inform related agencies as well as the public on the status of sustainability practice of mills. Palm oil mill operation is analysed to identify the mill component, system, and operational data prior to the selection of relevant indicators.

As shown in Fig. 2, fresh fruit bunches (FFB) are harvested and transported from the plantation to the palm oil mill. In order to maintain the freshness of the fruit, transportation of the fresh fruit bunches (FFB) from harvesting to sterilising should not exceed 72 h. In normal conditions, the palm oil of fresh fruits should contain about 1% free fatty acids (FFA). This content tends to increase rapidly with the maturation of the fruits and, could affect the value of the oil.

FFB are loaded into steriliser cages and are sterilised in order to deactivate natural enzymatic activity and loosen the fruit as well as to soften the mesocarp, resulting in easier extraction of oil. Sterilisation is carried out in autoclaves of 20- to 30-ton FFB capacity, with the application of live steam, at temperatures of 130 °C and a pressure of 3.1 bars, for 90 min. The sterilisation process produces wastewater, which is called steriliser condensate. Steriliser condensate is also known as steam condensate (Thani et al., 1999).

The sterilised FFB are then sent to rotary drum threshers to separate the sterilised fruits from the bunch stalks. The generated residues from this process include empty fruit bunches (EFB), which contain moisture. EFB can be used as an organic fertiliser and soil conditioner, as it maintains the humidity of the soil. Some mills introduce EFB pressing techniques to achieve lower moisture content in the EFB, which can subsequently be used as biomass fuel in suitable boiler systems for steam or electricity production.

The separated fruits are discharged into vertical steam-jacketed drums (digesters), treated mechanically to convert them into a homogeneous oily mash. Hot water is added to the digester to facilitate homogenisation. This mash is subsequently put into the oil extraction press (screw press). Screw pressing is a process that extracts palm oil from the mash. Later, the extracted oil is collected and discharged into the purification section while the solid parts, comprising fibre and nuts, are separated through physical means.

The process of oil purification is divided into four sub-processes, (during which the suspended matter is dissociated from the raw crude oil), which include the vibrating screen of raw crude oil, separation of suspended solids from oil, purification, oil drying, and cooling.

Fig. 2 shows the process flow diagram of the palm oil mill industry with the related indicators. This step is crucial for appropriate data collection and analysis. Identification of the parameters represented by symbols EN1, EN2, etc. in the process flow diagram (PFD) is outlined in Table 3. Table 3 also shows a list of aspects, parameters, indicators, and breakdown of parameters and indicator units and symbols.

2.1.2. Identify indicator, parameter, and aspect

POMSI aims to assess the sustainability performance of the palm oil mill using an index score. It consists of four assessment layers, which are indicator, parameter, aspect, and index layer. In order to obtain the index, the sustainability performance of palm oil mills is evaluated using three aspects, which are environment, economy, and social. Fig. 3 shows the level of POM sustainability index comprising aspect (the main category in this assessment), parameter (a division of aspect for the specific group of evaluation), and indicators (the components to measure).

The indicators are selected based on relevance, performance orientation, transparency, data quality, data sustainability, and data custodian (Ahamad et al., 2015). In this study, the selection of indicators are based on current palm oil schemes such as RSPO, ISPO, ISCC, regulations, policies, and mill best practices. The final decision is taken through a series of engagements with subject experts of palm oil mills including the plant manager, operations manager, plant engineer, and technicians.

The social aspect is still lacking certain important indicators such as forced labour, passport confiscation, child labour, gender discrimination (Amnesty, 2016; Neo, 2016; Manik et al., 2013; Obidzinski et al., 2012). These issues are not included in the list of indicators due to the difficulties and sensitivities of gaining access to this type of data. Future studies can extend the framework to improve upon the limitations of this study.

2.1.3. Data collection

Data collection was performed in four selected palm oil mills—mills A, B, C, and D— for the year 2015. Mill A operates 22 h/d, mill B and D operate for 18 h, while mill C for only 15 h. The basis of data collection is per metric ton of FFB. Table 4 shows the data collected in this study.

2.1.4. Data gathering and establishment of standard or target value

A standard value is obtained from related authorities such as DOE. The industry target can also be used as a standard value. If the company sets a target of increasing Oil Extraction Rate (OER) production annually by more than 21.94%, this same percentage can be used as a benchmark to be achieved by the indicator. By having a standard value, the performance of each indicator can be determined, as opposed to using the target or specific standard. In cases where indicators do not have any target or standard, historical data from the industry is used instead to determine the best performance to be set as the target. In summary, the hierarchy of standard development is: 1) local authorities, 2) industry target (IT), and 3) best performance (BP). Table 4 shows the standard data collected in this study.

2.1.5. Weightage determination

Assigning weight to parameters is important because of the different consequences, importance, and policy reasons associated with each parameter (Ahamad et al., 2015). Some parameters may be considered more responsive to changes from the aspect of interest, and deserve greater weightage. In this case study, it is assumed that all parameters bear the same weightage. As shown in Table 4, the environmental, economic, and social aspects encompass 6, 5, and 3 parameters. 100% is divided equally with the total number of parameters (14) resulting in 7.15% for each parameter. The environmental aspect weightage is 42.9%, the economic aspect is 35.75%, and the social aspect is 21.45%, as illustrated in Fig. 4.

2.1.6. Evaluation against standard regulations

The collected data vary according to terms of units and dimensions, as seen in Table 5. Each indicator can be categorised into type A or type B, where type A indicates a high value equal to good

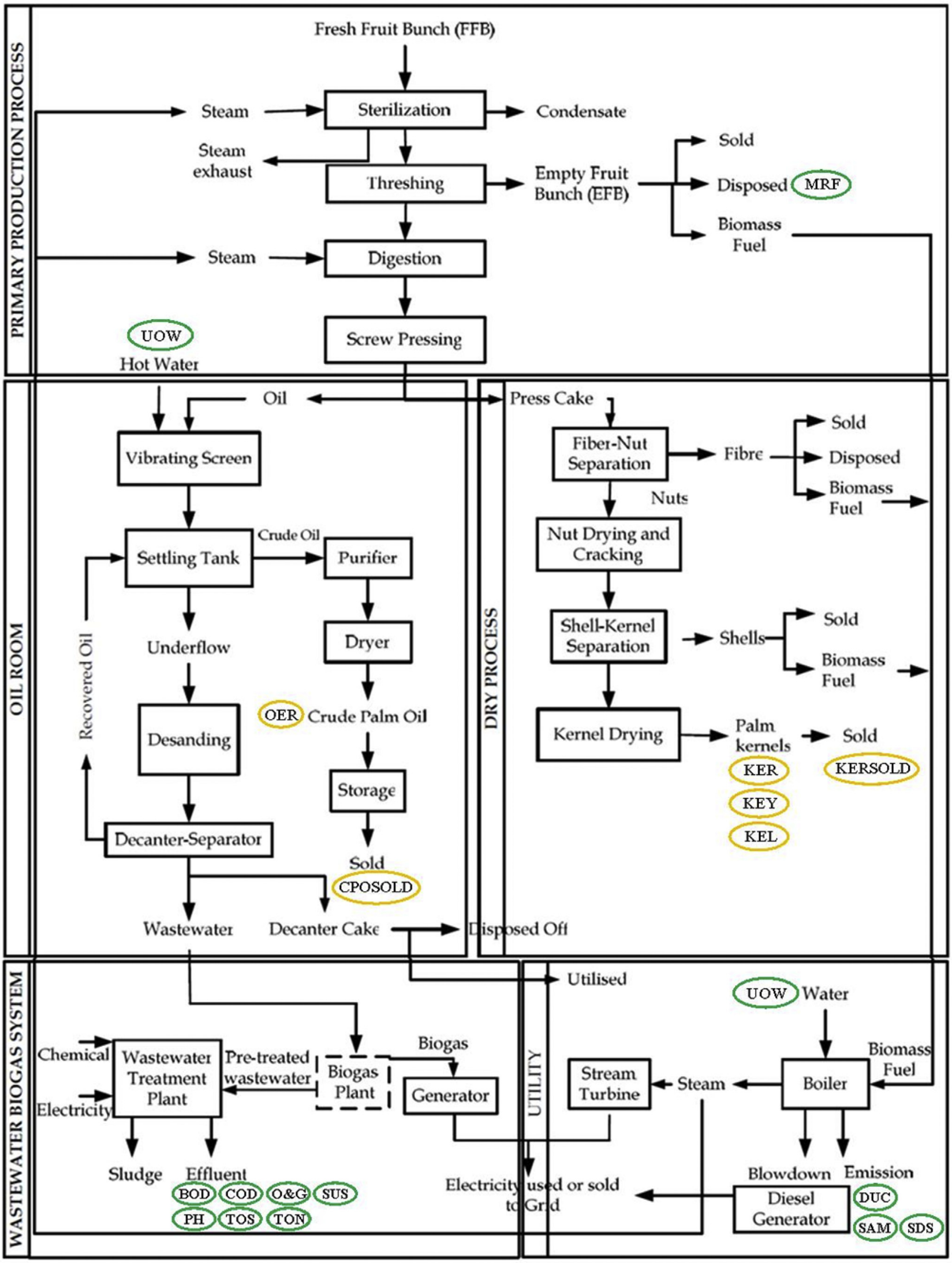

Fig. 2. Identification of indicators based on palm oil mill operation.

Table 3
List of aspects, parameters, and indicators.

	Aspect	Parameter	Symbol	Indicator	Symbol	Unit
Sustainability Index for a Palm Oil Mill	Environment	Water Consumption	EN1	Use of fresh water	UOW	m^3/MT
		Boiler Emission (Air Quality)	EN2	Dust Concentration @ 12% CO_2	DUC	g/Nm^3
				Sulphuric Acid Mist	SAM	g/Nm^3
				Sulphur Dioxide SO_2	SDS	g/Nm^3
		Air Surrounding	EN3	Total Suspended Particulate point A1	TSP A1	μg/m^3
				Sulphur Dioxide SO_2 point A1	SDS A1	ppm
				Nitrogen Dioxide point A1	NID A1	ppm
				Total Suspended Particulate point A2	TSP A2	μg/m^3
				Sulphur Dioxide SO_2 point A2	SDS A2	ppm
				Nitrogen Dioxide point A2	NID A2	ppm
		Waste	EN4	Mixed Raw Effluent	MRE	MT/MT
		Waste Water Quality of Effluent (final discharge)	EN5	BOD_3	BOD	mg/L
				COD	COD	mg/L
				Oil and grease content	O&G	mg/L
				Suspended Solid	SUS	mg/L
				pH	PH	–
				Total Solid	TOS	mg/L
				Total Nitrogen	TON	mg/L
		Diesel Consumption	EN6	Diesel used for Process	DIP	L/MT
				Diesel used for transportation	DIT	L/MT
	Economic	FFB	EC1	Oil Extraction Rate (OER)	OER	L/MT
		Kernel	EC2	Kernel yield	KEY	MT/MT
				Kernel extraction rate (KER)	KER	L/MT
				Amount of sold Kernel	KERSOLD	MT/MT
		CPO profit	EC3	CPO yield	CPY	MT/MT
				Amount of sold CPO	CPOSOLD	MT/MT
		Losses	EC4	Oil losses per FFB	OIL	L/ton
				Kernel losses per FFB	KEL	MT/MT
		Production Cost	EC5	Production cost	PC	RM/MT
				Margin	MARG	–
	Social	Risk Factor	SO1	Percentage of FFB from known source	KS	%
				Site verification of known FFB source	SV	%
				Percentage of FFB from peat soil	PS	%
		Occupational Poisoning and Disease Case	SO2	Fatality rate	FAR.OP	–
				Frequency Rate	FRR.OP	–
				Incident Rate	IR.OP	–
				Severity Rate	SR.OP	–
		Occupational accident case	SO3	Fatality rate	FAR.OA	–
				Frequency Rate	FRR.OA	–
				Incident Rate	IR.OA	–
				Severity Rate	SR.OA	–

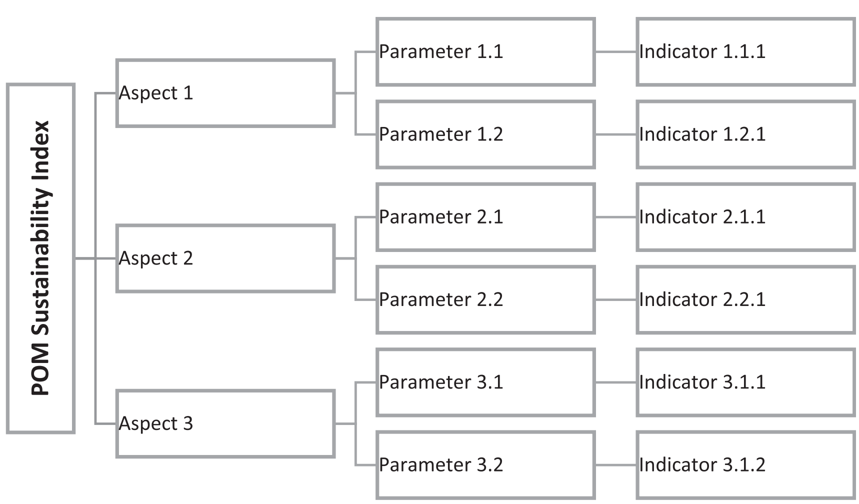

Fig. 3. The concept of POMSI.

performance, and type B indicates a high value equal to bad performance (Sieting, 2015). The data is normalised using the Proximity-to-Target (PTT) method, which measures the industry's raw data against targets. All variables are normalised from zero to 100, with zero indicating the industry as the worst competitor among all industries and 100 indicating that the industry has

Table 4
Collected palm oil mill data and standard value.

	Aspect	Parameter	Symbol	Indicator (i)	Symbol	Standard Value	Standard References	Mill Data (j)			
								A	B	C	D
Sustainability Index for a Palm Oil Mill	Environment	Water Consumption	EN1	Use of fresh water	UOW	1	IT	0.95	1.04	0.7	1.2
		Boiler Emission (Air Quality)	EN2	Dust Concentration @ 12% CO_2	DUC	0.4	DOE	0.01	0.5	0.41	0.6
				Sulphuric Acid Mist	SAM	0.2	DOE	0.0001	0.1	0.3	0.25
				Sulphur Dioxide SO_2	SDS	0.1	BP	0.0008	0.3	0.04	0.13
		Air Surrounding	EN3	Total Suspended Particulate point A1	TSP A1	260	DOE	33	261	280	295
				Sulphur Dioxide SO_2 point A1	SDS A1	0.04	DOE	0.001	0.06	0.05	0.05
				Nitrogen Dioxide point A1	NID A1	0.17	DOE	0.095	0.19	0.2	0.18
				Total Suspended Particulate point A2	TSP A2	260	DOE	25	268	265	270
				Sulphur Dioxide SO_2 point A2	SDS A2	0.04	DOE	0.001	0.05	0.07	0.03
				Nitrogen Dioxide point A2	NID A2	0.17	DOE	0.095	0.09	0.2	0.25
		Waste	EN4	Mixed Raw Effluent	MRE	0.65	BP	0.52	0.9	0.7	0.6
		Waste Water Quality of Effluent (final discharge)	EN5	BOD_3	BOD	50	DOE	43	51	81	60
				COD	COD	1000	DOE	500	800	1700	1200
				Oil and grease content	O&G	50	DOE	13	60	68	45
				Suspended Solid	SUS	400	DOE	229	600	750	300
				pH	PH	5-9 (7)	DOE	8.43	6	7.05	8
				Total Solid	TOS	1500	DOE	6674	4246	2982	5907
				Total Nitrogen	TON	50	DOE	59	66	73	51
		Diesel Consumption	EN6	Diesel used for Process	DIP	0.28	BP	0.3	0.53	0.47	0.2
				Diesel used for transportation	DIT	0.16	BP	0.21	0.17	0.19	0.15
	Economy	FFB	EC1	Oil Extraction Rate (OER)	OER	0.2	IT	0.21	0.2	0.18	0.22
		Kernel	EC2	Kernel yield	KEY	0.05	IT	0.055	0.049	0.051	0.052
				Kernel extraction rate (KER)	KER	0.05	IT	0.056	0.03	0.04	0.06
				Amount of sold Kernel	KERSOLD	1	IT	1	0.98	0.78	0.84
		CPO profit	EC3	CPO yield	CPY	0.2	IT	0.21	0.19	0.17	0.18
				Amount of sold CPO	CPOSOLD	1	BP	1	0.95	0.88	0.7
		Losses	EC4	Oil losses per FFB	OIL	0.014	IT	0.013	0.015	0.012	0.016
				Kernel losses per FFB	KEL	0.3	IT	0.23	0.31	0.4	0.25
		Production Cost	EC5	Production cost	PC	46.94	BP	46.94	60.04	57.87	57.66
				Margin	MARG	0.015	BP	0.011	0.008	0.009	0.002
	Social	Risk Factor	SO1	Percentage of FFB from known source	KS	100	IT	58	50	70	20
				Site verification of known FFB source	SV	100	IT	67	100	30	20
				Percentage of FFB from peat soil	PS	0	IT	0	0	0	30
		Occupational Poisoning and Disease Case	SO2	Fatality rate	FAR.OP	0	IT	0	0	0	0
				Frequency Rate	FRR.OP	0	IT	0	0	0	0
				Incident Rate	IR.OP	0	IT	0	0	0	3
				Severity Rate	SR.OP	0	IT	0	0	0	0
		Occupational accident case	SO3	Fatality rate	FAR.OA	0	BP	0	0	0	0
				Frequency Rate	FRR.OA	0	BP	0	0	0	5
				Incident Rate	IR.OA	0	BP	0	0	0	0
				Severity Rate	SR.OA	0	BP	0	0	0	4

IT – Industry Target, BP – Best Performance, DOE – Department of Environment.

already achieved its target. The PTT concept is illustrated in Fig. 5. PTT uses Eqs. (1) and (2) to normalise indicator data. A, B, and C in Fig. 5 show the distance of indicator data to the target. The shortest distance shows the performance of the indicator closest to the target value; the better the performance. In contrast, the longest distance shows the performance of the indicator further than target; the lower the performance.

Type A

$$\mathrm{PTT}_{ij} = \frac{\left[\left(t_i - min_{(m_{ij})}\right) - \left(t_i - m_{ij}\right)\right] X\, 100}{\left(t_i - min_{(m_{ij})}\right)} \tag{1}$$

Type B

$$\mathrm{PTT}_{ij} = \frac{\left[\left(max_{(m_{ij})} - t_i\right) - \left(m_{ij} - t_i\right)\right] X\, 100}{\left(max_{(m_{ij})} - t_i\right)} \tag{2}$$

PTT_{ij} is the normalised value for the jth mill, ith indicator, while m_{ij} is the data value of the jth mill, ith indicator. The $max_{(m_{ij})}$ and $min_{(m_{ij})}$ is determined from the maximum and minimum value of the m_{ij} data set, which indicates the lowest benchmark. Basically, type A uses $min_{(m_{ij})}$ and type B use $max_{(m_{ij})}$. t_i represents the standard or target value of the ith indicator. The use of water (UOW; $i = 1$) indicator for mill B ($j = 2$) is taken as an example to portray the concept of PTT, where UOW is a type B indicator. Because a higher usage of water equates to bad performance, Eq. (2) is used. The value of m_{ij} is 1.04 m^3/mt/month, the value of $max_{(m_{ij})}$ is 1.2 m^3/mt/month, and t_i is 1 m^3/mt/month. Table 5 shows the full results of PTT.

$$\mathrm{PTT}_{1,2} = \frac{[(1.2 - 1) - (1.04 - 1)]\, X\, 100}{(1.2 - 1)} = 80\%$$

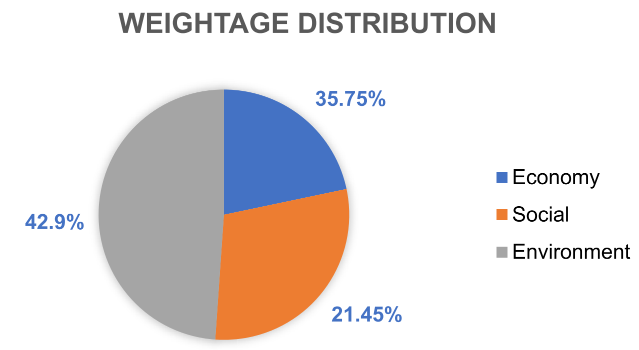

Fig. 4. Summary of parameter weightage distribution.

2.1.7. Index calculation

Eq. (3) is used to obtain the parameter score, $P_{j,k}$, by summing $PTT_{k(i,j)}$ for the kth parameter and with respect to the jth mill, ith indicator, and divided by *No of indicator*$_k$, kth parameter.

$$\mathrm{P}_{j,k} = \sum \frac{PTT_{i,j}}{No\ of\ indicator_k} \tag{3}$$

The concept of this index calculation can be referred to in Fig. 6. To enhance the understanding of this step, an example is shown where $P_{j,k}$ of EN2 is calculated for Mill A as an example using Eq. (3):

$$P_{1,2} = \sum \frac{100 + \ldots + PTT_{n,1} + PTT_{4,1}}{3}$$
$$= 100$$

The value $P_{j,k}$ above is then multiplied with $Weightage_k$for the kth parameter to obtain the Parameter Aggregation Score, $\mathrm{PAS}_{j,k}$ of the jth mill, kth parameter, as per Eq. (4):

$$PAS_{j,k} = \mathrm{P}_{j,k} x\ Weightage_k \tag{4}$$

The value above is used to obtain $\mathrm{PAS}_{j,k}$ with which Eq. (4) will be used. As mentioned in the previous sections, all values of weightage in this case study are assumed to be the same. Thus;

$$PAS_{1,2} = 100x\ 7.15\ \%$$
$$= 7.15$$

The score of $P_{j,k}$, $\mathrm{PAS}_{j,k}$, and weightage are shown in Table 6.

Based on Eq. (5), the $\mathrm{PAS}_{j,k}$ value is aggregated to obtain the aspect score, $\mathrm{A}_{j,l}$ for the jth mill, lth aspect.

Table 5
The normalisation results based on the PTT method.

	Aspect (l)	Parameter (k)	Symbol	Indicator (i)	Symbol	PTT			
						A	B	C	D
Sustainability Index for a Palm Oil Mill	Environment	Water Consumption	EN1	Use of fresh water	UOW	100.00	80.00	100.00	0.00
		Boiler Emission (Air Quality)	EN2	Dust Concentration @ 12% CO_2	DUC	100.00	50.00	95.00	0.00
				Sulphuric Acid Mist	SAM	100.00	100.00	0.00	50.00
				Sulphur Dioxide SO_2	SDS	100.00	0.00	100.00	85.00
		Air Surrounding	EN3	Total Suspended Particulate point A1	TSP A1	100.00	97.14	42.86	0.00
				Sulphur Dioxide SO_2 point A1	SDS A1	100.00	0.00	50.00	50.00
				Nitrogen Dioxide point A1	NID A1	100.00	33.33	0.00	66.67
				Total Suspended Particulate point A2	TSP A2	100.00	20.00	50.00	0.00
				Sulphur Dioxide SO_2 point A2	SDS A2	100.00	66.67	0.00	100.00
				Nitrogen Dioxide point A2	NID A2	100.00	100.00	62.50	0.00
		Waste	EN4	Mixed Raw Effluent	MRE	100.00	0.00	80.00	120.00
		Waste Water Quality of Effluent (final discharge)	EN5	BOD_3	BOD	100.00	96.77	0.00	67.74
				COD	COD	100.00	100.00	0.00	71.43
				Oil and grease content	O&G	100.00	44.44	0.00	100.00
				Suspended Solid	SUS	100.00	42.86	0.00	100.00
				pH	PH	100.00	100.00	100.00	100.00
				Total Solid	TOS	4.33	49.22	72.60	18.51
				Total Nitrogen	TON	60.87	30.43	0.00	95.65
		Diesel Consumption	EN6	Diesel used for Process	DIP	92.00	0.00	24.00	100.00
				Diesel used for transportation	DIT	0.00	80.00	40.00	100.00
	Economy	FFB	EC1	Oil Extraction Rate (OER)	OER	100.00	100.00	0.00	100.00
		Kernel	EC2	Kernel yield	KEY	100.00	0.00	100.00	100.00
				Kernel extraction rate (KER)	KER	100.00	0.00	50.00	100.00
				Amount of sold Kernel	KERSOLD	100.00	90.90	0.00	27.27
		CPO profit	EC3	CPO yield	CPY	100.00	66.67	0.00	33.33
				Amount of sold CPO	CPOSOLD	100.00	83.33	60.00	0.00
		Losses	EC4	Oil losses per FFB	OIL	100.00	50.00	100.00	0.00
				Kernel losses per FFB	KEL	100.00	90.00	0.00	100.00
		Production Cost	EC5	Production cost	PC	100.00	0.00	16.56	18.17
				Margin	MARG	69.23	46.15	53.85	0.00
	Social	Risk Factor	SO1	Percentage of FFB from known source	KS	58.00	50.00	70.00	20.00
				Site verification of known FFB source	SV	67.00	100.00	30.00	20.00
				Percentage of FFB from peat soil	PS	100.00	100.00	100.00	70.00
		Occupational Poisoning and Disease Case	SO2	Fatality rate	FAR.OP	100.00	100.00	100.00	100.00
				Frequency Rate	FRR.OP	100.00	100.00	100.00	100.00
				Incident Rate	IR.OP	100.00	100.00	100.00	97.00
				Severity Rate	SR.OP	100.00	100.00	100.00	100.00
		Occupational accident case	SO3	Fatality rate	FAR.OA	100.00	100.00	100.00	100.00
				Frequency Rate	FRR.OA	100.00	100.00	100.00	95.00
				Incident Rate	IR.OA	100.00	100.00	100.00	100.00
				Severity Rate	SR.OA	100.00	100.00	100.00	96.00

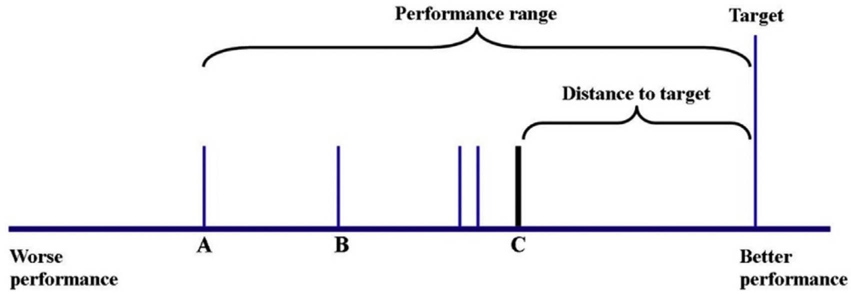

Fig. 5. Proximity-to-Target concept.

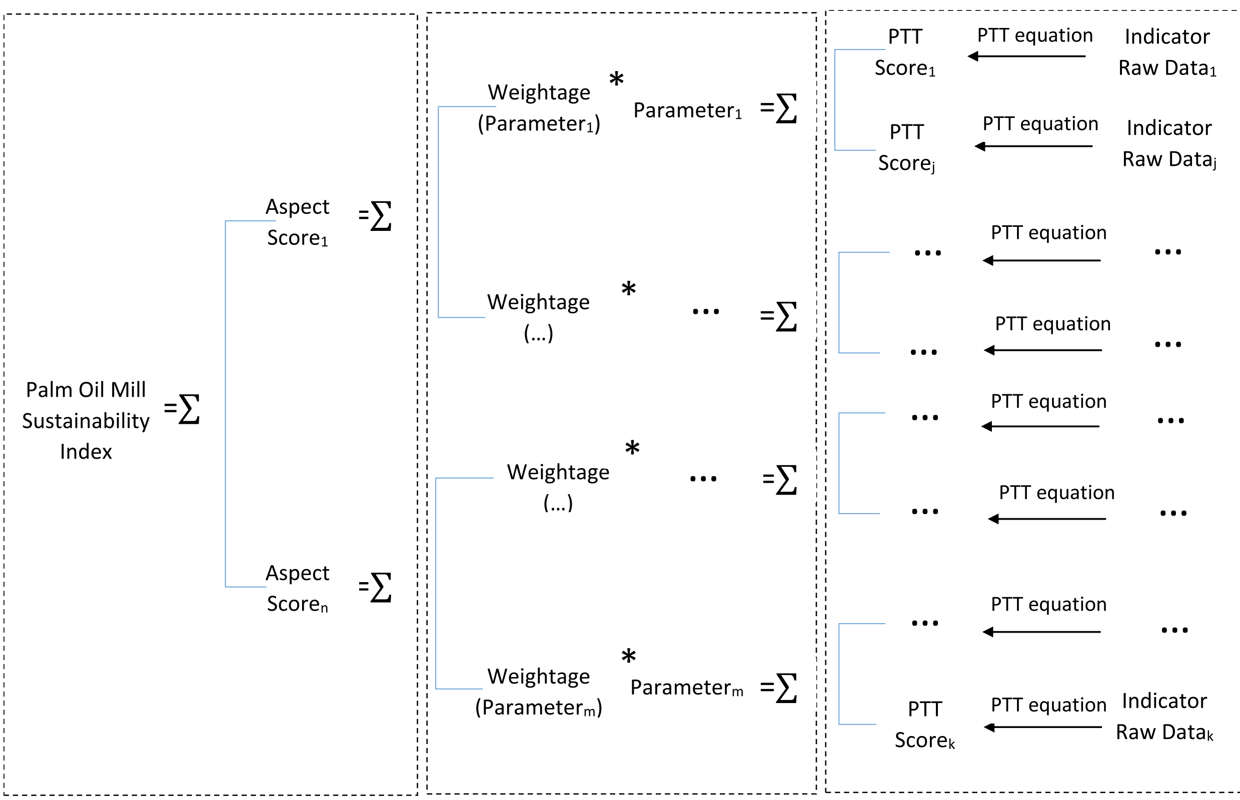

Fig. 6. Summary of the POMSI calculation.

Table 6
Parameter score, parameter aggregation score, and weightage value.

	Parameter Score, $P_{j,k}$				Weightage	Parameter Aggregation Score, $PAS_{j,k}$			
	Mill					Mill			
Parameter	A	B	C	D		A	B	C	D
EN1	100.00	80.00	100.00	0.00	7.15	7.15	5.72	7.15	0.00
EN2	100.00	50.00	65.00	45.00	7.15	7.15	3.58	4.65	3.22
EN3	100.00	52.86	34.23	36.11	7.15	7.15	3.78	2.45	2.58
EN4	100.00	0.00	80.00	100.00	7.15	7.15	0.00	5.72	7.15
EN5	80.74	66.25	24.66	79.05	7.15	5.77	4.74	1.76	5.65
EN6	46.00	40.00	32.00	100.00	7.15	3.29	2.86	2.29	7.15
EC1	100.00	100.00	0.00	100.00	7.15	7.15	7.15	0.00	7.15
EC2	100.00	30.30	50.00	75.76	7.15	7.15	2.17	3.58	5.42
EC3	100.00	75.00	30.00	16.67	7.15	7.15	5.36	2.15	1.19
EC4	100.00	70.00	50.00	50.00	7.15	7.15	5.01	3.58	3.58
EC5	84.62	23.08	35.21	9.08	7.15	6.05	1.65	2.52	0.65
SO1	75.00	83.33	66.67	36.67	7.15	5.36	5.96	4.77	2.62
SO2	100	100	100	99.25	7.15	7.15	7.15	7.15	7.10
SO3	100	100	100	97.75	7.15	7.15	7.15	7.15	6.99

Table 7
Aspect score and index value.

Mill	Aspect Score, $A_{j,l}$			Index, I_j
	Environment	Economic	Social	
A	37.66	34.65	19.66	91.97
B	20.67	21.33	20.26	62.26
C	24.02	11.81	19.07	54.89
D	25.75	17.98	16.68	60.42

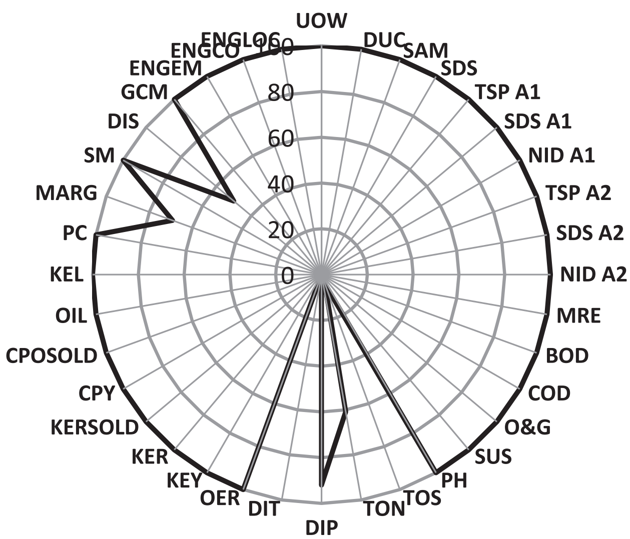

Fig. 7. Example of web chart.

$$A_{j,l} = \sum \mathrm{PAS}_{j,k}$$

$$A_{j,l} = \sum \mathrm{PAS}_{j,k} = 7.15 + 7.15 + 7.15 + \ldots + \mathrm{PAS}_{1,n} + \mathrm{PAS}_{1,14} = 37.66 \quad (5)$$

Using Eq. (6) $A_{j,l}$ for the jth mill, the lth aspect will be aggregated to obtain the index score I_j for the jth mill. The full result of $A_{j,l}$ and I_j can be referred to in Table 7.

$$Ij = \sum A_{j,l}$$

$$I_j = 37.66 + 34.65 + 19.66 = 91.97 \quad (6)$$

2.2. Stage 2: analysis of sustainability performance

In the second stage, index, aspect, and parameter scores are analysed using a bar chart to illustrate the performance of palm oil mills, whereas the indicators are analysed using a web chart, as shown in Fig. 7. A web chart was used because it is a simple diagram to quickly analyse the performance of multiple indicators. The outer to inner ring web chart shows better performance to bad performance with a scale of 100%–0%. The web charts allow industries to quickly recognise performance weaknesses and identify areas for improvement. A five-star rating is given based on their performance score. The performance category of the rating score can be referred to in Table 8.

2.3. Stage 3: palm oil process improvement

After the hotspot is identified, an appropriate improvement to overcome the process weaknesses is proposed. Suggestion for improvement will be based on recent studies related to the problematic area. To prove the improvement to the weak area, there will either be an enhancement on the performance or vice versa. Index recalculation could also be done starting from the calculation of PTT using the new data until the final index is obtained.

3. Results and discussion

According to the data of each palm oil mill in Table 4 with the methodology presented in Section 2.1.5, the index, aspect, parameter, and indicator performance scores are calculated and the result presented in Sections 3.1 until 3.4. The sustainability index performance of each mill is evaluated based on 20 indicators and 6 parameters under the environmental aspect, 10 indicators and 5 parameters under the economic aspect, and 11 indicators and 3 parameters under the social aspect. A rating is then given based on the performance score of each mill. The resulting guideline for the

Fig. 8. Sustainability index score for palm oil mills A, B, C, and d.

Table 8
Star Rating score range.

Performance	% Score	Star Rating
Excellent	90.0≤PTT<100.0	5
Good	80.0≤PTT<90.0	4
Fair	60.0≤PTT<80.0	3
Poor	40.0≤PTT<60.0	2
Very Poor	0≤PTT<40.0	1

palm oil mill rating scores can be referred to in Table 8. Further explanation is given in the next subsection.

3.1. Index score of mill

The sustainability index score, I_j, as calculated using Eq. (6) and outlined in Table 7, are presented in a bar chart for ranking and in-depth analysis. In Fig. 8, the index score, I_j, of four palm oil mills is presented. Mill A tops the rankings as the most sustainable palm oil mill with a score of 91.85%. Mill D ranks second place with a 63.62% score, slightly higher than Mill B's score of 63.62%. Mill C ranks lowest with a total score of 54.82%. From the results, it is interesting to observe that the new mill (established after the 2000s), Mill A, is more sustainable compared to the older mills i.e. Mill B, C, and D. Further breakdown analysis by aspect, parameter, and indicator to identify the weak performance indicators leading to each mill performance is shown in Figs. 9–11 and further discussed in the next section.

3.2. Performance breakdown of each aspect, parameter, and indicator

This section highlights the sustainable performance for the assessed mill based on aspect, parameter, and indicator, as shown in Figs. 9–11. Fig. 9 shows the aspect reflecting the concept of sustainable performance fo the palm oil mills. Fig. 10 illustrates the parameter score while Fig. 11 shows the detailed breakdown of each indicator score, which is more presentable and easy for hot-spot identification.

Despite the low ranking in terms of environmental score, Mill A

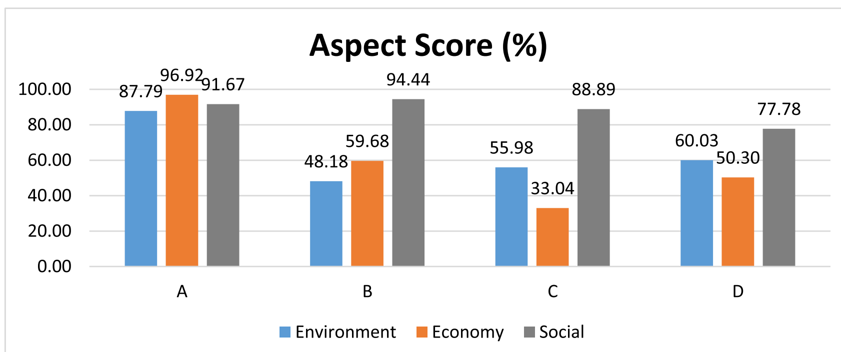

Fig. 9. Aspect score for palm oil mills A, B, C, and d.

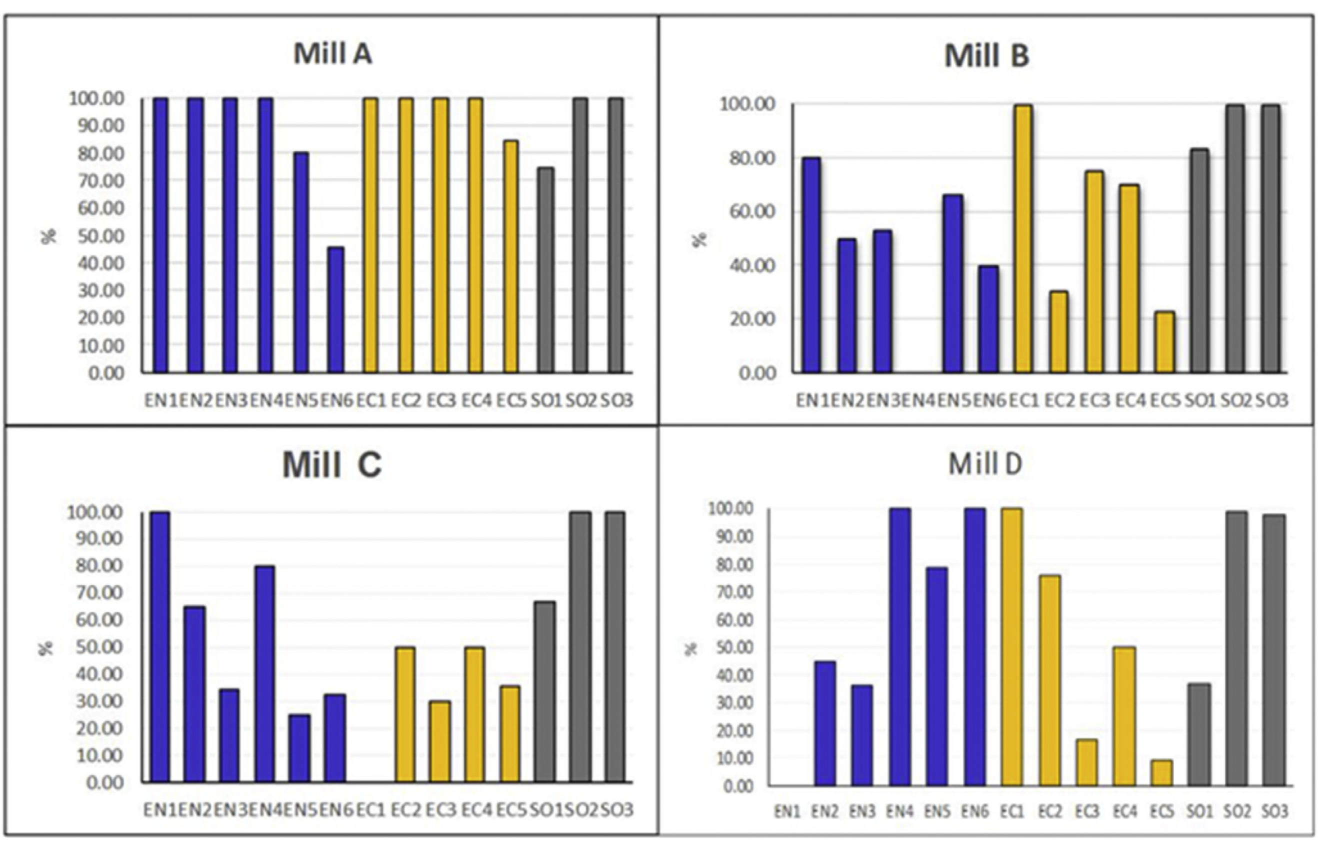

Fig. 10. Detailed score of the parameters for palm oil mills A, B, C, and d.

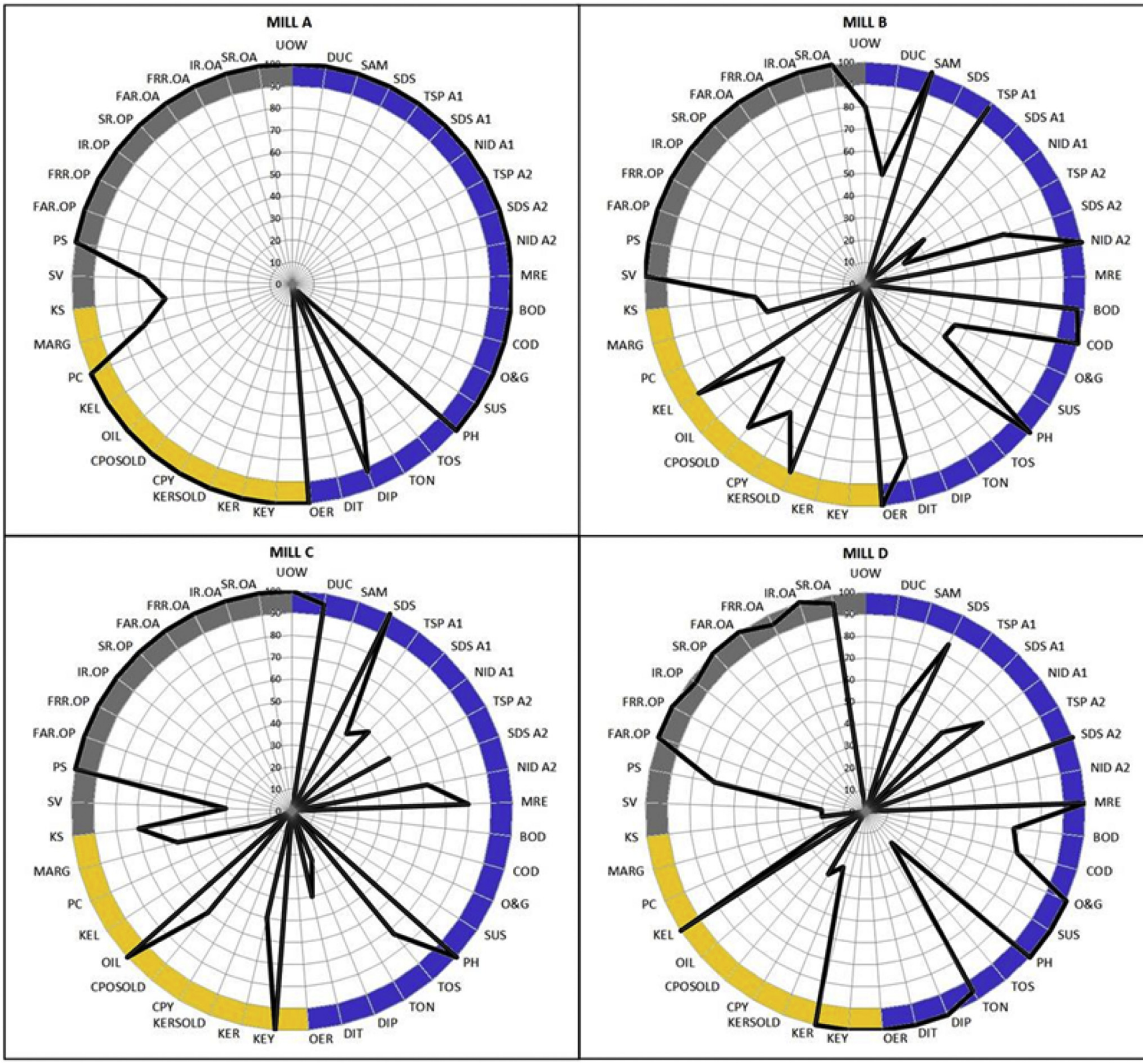

Fig. 11. Indicator Analysis using Web Chart for Palm Oil Mills A, B, C, and D.

achieved a high score in this aspect with 87.79%, as shown in Fig. 9. The Mill A parameter rating is excellent (100%) for EN1, EN2, and EN3 but not EN5 and EN6, as shown in Fig. 10. This is not surprising because Mill A is considered to be a new palm oil mill (operated after 2000). The efficiency, advancements in technology, and sustainability practice for Mill A is better than the other mills. This is not surprising because Mill A's parameter rating is excellent (100%) for EN1, EN2, and EN3 but not EN5 and EN6, as shown in Fig. 10. Mill C and D performed moderately compared to the other mills while Mill B performed poorly with an environmental score of only 48.18%, due to it achieving lower than average scores for most of the environmental parameter scores, which are EN1, EN2, EN3, EN4, and EN6.

Mill B has issues with the UOW indicator under the EN1 parameter, due to the low efficiency of its hydrocyclone. The EN2 score for Mill B is only 50% because of its low efficiency boiler as compared to Mill A. This boiler releases a high emission of dust concentration (DUC) and suspended solids (SUS), effecting its PTT score, as shown in Fig. 11. The EN3 score for Mill B is 52.86% due to its low PTT score for the SDSA1, NIDA1, TSPA2, SDSA2 indicators. The same above scenario is observed to happen, which affects the air quality surrounding the mill.

For EN4, Mill B only has one indicator under this parameter with a score of 0%, as shown in Fig. 11. The EN4 score is also 0%, due to the low quality of the mill's waste system in comparison to other mills. Altogether, this makes Mill B the lowest benchmark for this indicator. It is important to note that, as per Eq. (1), if the low benchmark is equal to mill data value, the mill's indicator score will become 0%.

Meanwhile, Mill B's poor rating (40%) for EN6 is due to its Diesel use for Process (DIP), as shown in Fig. 10. The high usage of diesel in Mill B is because Mill B supplies power using a diesel generator to generate electricity not only for the mill consumption, but also for the worker's housing area and other facilities surrounding the mill.

In comparison with Mill B, the high usage of diesel in Mill A is due to the consumption for transport (DIT). Mill A has the lowest score for DIT, which means the diesel consumption for transport for Mill A is higher than the that of other mills because the capacity of Mill A is larger and it uses many more vehicles for the transportation of fresh fruit bunches (FFB). The other factor affecting the high usage of diesel in Mill A is due to long operating hours as compared to the other mills and this has resulted in a longer duration of vehicle usage. The same problem also occurs for the EN6 score of Mill C but instead of having a low score only for one of the indicators, Mill C obtained low scores for both indicators DIT and DIP, making Mill C's EN6 parameter score the lowest of all the mills.

As for the economic aspect, Mill A maintains its first-place ranking (96.62%) followed by Mill B and Mill D with only 59.68% and 50.30%, as illustrated in Fig. 9. It seems that Mill A can operate at a lower cost and obtain a higher profit since Mill A obtained higher scores for all parameters EC1 to EC5 compared to the rest of the mills. This is due to the high oil extraction rate (OER) of Mill A. With a higher OER, POM will produce more crude palm oil (CPO) per tonne of FFB. This reduces the production cost of CPO. Nevertheless, the other mills have low OER, meaning that they use more tonnes of FFB when producing the same amount of CPO as Mill A. Meanwhile, Mill C appears to be the lowest ranked with only 33.04%, which indicates the very poor performance (rating 1) category, as defined in Table 8. The low score for Mill C is expected since most of the parameters scores of Mill C are below the rating of 3, as shown in Fig. 10. The breakdown of parameters in Fig. 11 shows that OER, KER, KERSOLD, CPY, KEL, and PC scored 0%. The low score of KEL means high kernel losses during the process, which reduces the kernel extraction rate (KER) and amount of kernel that can be sold (KERSOLD). Besides that, Mill C also has a low oil extraction rate (OER), which increases its oil production cost (PC).

In Fig. 9, for the social aspect, Mill A still performs excellently with a score of 91.67%. Mill A is second to Mill B, which acquired the first ranking with a score of 94.44%. Most of the mills obtained a more than good rating for their performance except for Mill D.

3.3. Rating

The final stage for evaluating the sustainability performance of a palm oil mil involves the transformation of the score into a rating. This rating simplifies the performance comparisons between the mills. This in turn pushes the competitiveness level among the mills. In this step, the aspect score from Fig. 9 is translated into the data in Table 9 to obtain the overall rating score for each palm oil mill. Table 9 also shows the breakdown percentage score for each aspect together with its corresponding rating. The rating is between 1 and 5, for which 1 indicates very poor performance and 5 indicates excellent performance, as described in Table 8. This rating determines the level of performance of the index, aspect, parameter, and PTT score. The results show that Mill A still leads in terms of overall rating score with a rating of 5 followed by Mill B, with the poorest performance belonging to Mill C.

3.4. Example of improvement of the weak performance indicators

As discussed in Section 3.3, the diesel consumption for transportation (DIT) of Mill A was found to be one of the lowest performance indicators with a score of 0%, which indicates the highest diesel consumption. The score of 0% is due to Mill A being the lowest benchmark among the other mills. In order to reduce this consumption, substitution of diesel with natural gas fuel is proposed. Based on Table 4, the current DIT for Mill A is 0.21 L/mt FFB. Substitution of natural gas would result in a 99% reduction of diesel consumption (The Climate Registry, 2014)—down to 0.002 L/mt FFB consumption. This improvement is inversely proportionate to the production cost (PC) indicator, where PC increases due to the higher cost of natural gas. The PTT score of DIT increases to 100% whereas PC slightly decreases to 90% (refer to Fig. 12). The final index was calculated as 95.55% compared to the former index, which is 92%, as per Table 10. This method helps the user to observe the balance between cost and proposed improvement and wisely take necessary actions.

4. Conclusions

In this study, a new sustainability assessment for the palm oil mill known as POMSI was developed and applied to selected palm oil mills. POMSI is a comprehensive tool to evaluate palm oil mill performance, which considers three principles of sustainability: the environmental, economic, and social aspects. POMSI provides decision-makers with overall sustainability performance and pinpoints weak performance operation to assist and ascertain the activities that should or should not be taken in order to move towards a more sustainable palm oil mill.

POMSI helps the industry to continuously measure and keep

Table 9
Palm oil mill rating score.

	Palm Oil Mill Index		Aspect								
			Environment			Economy			Social		
Mill	Score (%)	Rating	Score	%	Rating	Score	%	Rating	Score	%	Rating
A	91.97	5	37.66	87.79	4	34.65	96.92	5	19.66	91.66	5
B	62.26	3	20.67	48.18	2	21.33	59.66	2	20.26	94.45	5
C	54.89	2	24.02	55.98	2	11.81	33.04	1	19.07	88.89	4
D	60.42	3	25.75	60.03	3	17.98	50.30	2	16.68	77.78	3

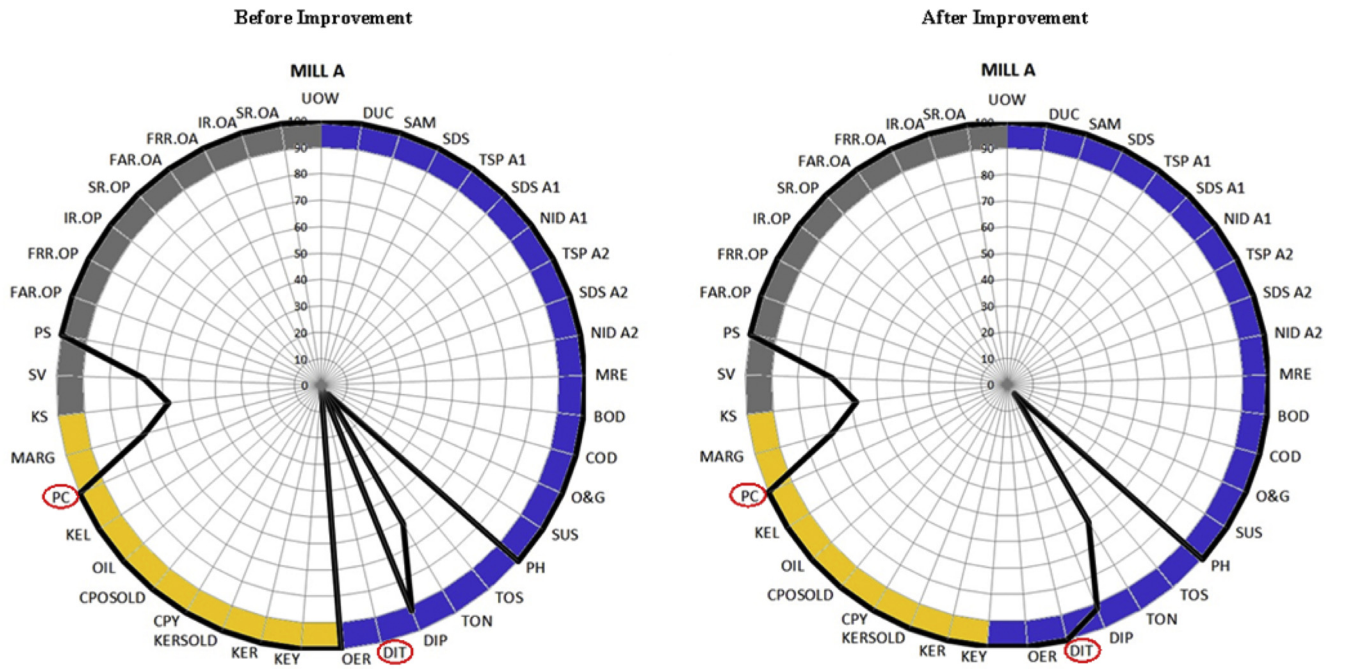

Fig. 12. Comparison of before-and-after implemented improvements and changes to PTT score for Mill A.

Table 10
Before and after improvement results.

	Improvement is done by replacing diesel for transport (DIT) with natural gas					
	Mill data		PTT score (%)		Index Score	
Aspect	Before improvement	After improvement	Before improvement	After improvement	Before improvement	After improvement
Environment	0.21 L/mt	0.002 L/mt	0%	100%	92%	95.55%
Economy	46.94 Rm/mt	50 Rm/mt	100%	90%		

track of sustainability practices and perform continuous operational improvement. The results provide an impetus to every mill to compete for better improvement and learn from each other as well as help to improve sustainability performance. More holistic improvement effectiveness and the overall effect of POMSI will be further discussed in future publications. The POMSI framework is generic and can be implemented in other sectors by adjusting the parameters and indicators related to the study undertaken.

Parameter weightage may differ because of different consequences, importance, and policy reasons associated with each parameter. Some parameters may be considered more responsive to changes from the interest aspect and deserve greater weightages. A more detailed weightage study will be conducted in the future works.

Acknowledgement

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jclepro.2017.11.028.

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