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AGRO-INDUSTRIAL WASTE SUSTAINABLE MANAGEMENT – A POTENTIAL SOURCE OF ECONOMIC BENEFITS TO PALM OIL MILLS IN MALAYSIA

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Abstract: Over the decades the palm oil industry has managed some challenging environmental concerns regarding land transformation and degradation, increase in eutrophication, changing habitats of wildlife, pesticides runoff into inland watercourses, and probable climate change. Countries producing palm oil desire to do so in a more sustainable way that will leave the environment evergreen. Therefore this paper aims to encourage sustainable management of agro-industrial waste and its potential in making financial returns from the same waste. Hence, the study was conducted with the participation of seven local palm oil mills having different capacities and operation age. Attention was given to milling waste as they could cause serious environmental menace if unattended to properly. Milling waste includes lignocellulosic palm biomass namely the empty fruit bunches (EFB), oil palm shell (OPS), mesocarp fibres, palm oil mill effluent (POME), and palm oil mill sludge (POMS), as well as solid waste generated from the further processing of these biomass into the palm oil fuel ashes (POFA) and palm oil clinkers (POC). The opportunities available to the Malaysian palm oil industry and the financial benefits which may accrue from waste generated during palm oil production process cannot be over emphasized.

Keywords: Palm oil; waste; bioenergy; sustainability; economic benefits

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INTRODUCTION

The green urbanization process towards a sustainable city requires an appropriate balance between urban growth, economic and political factors and environmental protection with respect to the quality of life of the citizenry (Zhou and Wang, 2011). Every component in the process of city development is crucial and needs to be planned in order to enable the city achieve sustainability. The development that meets the needs of the present without compromising the ability of future generations to meet their own needs is the basic definition of sustainability (World Bank, 1987). Developing a sustainable city or a "green urbanism" can be noticeably implied through an appropriate interaction of the following three pillar components, namely the (i) energy and materials, (ii) water and biodiversity, and (iii) urban planning and transport (Das, 2005). In order to transform a city into a sustainable one, Lehmann (2010), developed strategies named the triple-zero framework (triple-bottom line), which are the zero fossil-fuel energy use, zero waste, and zero emissions (aiming for low-to-no-carbon emissions). As such, we find the principle 'zero' discharge as one of the key component in green urbanism. The idea to move towards becoming green cities in Malaysia will not be successful without looking at every single urban design component in the process of development and their interaction. As the backbone of Malaysia economy, greening the palm oil industry became a key step to achieve the goal of transforming the nation's economy alongside environmental considerations. Realizing zero-waste in the palm oil industry is a driver for improved business performance and important for the environment.

The palm oil industry in Malaysia has flourished since the 1970's. Traveling across the nation, oil palm plantations are seen in most rural and sub-urban areas. The nation has approximately 5 million oil palm trees planted area as at December 2011 (MPOB, 2012). She has surpassed Nigeria as the world top producer of palm oil in 1974 and became the second largest producer after Indonesia in 2006. In 2011, Malaysia produced 18.8 million tonnes of crude palm oil (CPO) worth approximately $25 billion of sales (Sovacool and Drupady, 2011). Seeing the fascinating monetary returns, another aspect that should be given attention is the receiving environment. An oil palm plantation can produce massive amount of total dry matter (TDM). The TDM production rate is about 55 tonnes per hectare annually. In palm oil processing mills, utilization of the TDM for palm oil and palm kernel oil constitutes 5.5 tonnes per hectare annually (10% of the TDM) whilst the remaining 90% large amount of TDM or biomass in the form of lignocellulose are available to be exploited (Chan, 1999; Jalani *et al*., 1999).

This paper reports a survey conducted in seven local palm oil mills. The objective is to study the availability of by-products as a result of the milling activity and their reuse or in generation of extra monetary returns to the existing palm oil mill. Agro-industrial waste generated during 13 year period by the respective mill was used for this study. Where there is availability of agro-industrial waste, reuse, and renewal by-products, zero-discharge is necessary for achievement of zero-waste. Successful implementation of zero-discharge plan in the palm oil industry would help the sector to play its role in green urbanism and to meet the vision towards development of green cities nationwide.

METHODOLOGY

The study was conducted using the information collected from the local palm oil mills visited. Seven palm oil processing mills with different background have participated. Mills selection were advised by the Malaysian Department of Environment (DOE) officer in accordance with the background, processing capacity, age of mill, and more importantly their voluntarily participation in the survey. Visits to the palm oil processing mills were facilitated by the participating palm oil mills' supervisors, chemists, engineers, or treatment plant operators. Detailed explanations were given on the mill operation from upstream to downstream processing of palm oil, sources of water and wastewater during the production, solid and liquid waste generation handling and processing, and disposal systems. All managerial and technical information on the palm oil mill organization and how by-products are handled were obtained. Production or economic performances of all palm oil mills were studied. Thirteen years fresh fruit bunches (FFB) processed data from 2000 – 2012 were obtained both from the millers and completed through the MPOB's online database (www.mpob.gov.my). The FFB data is vital for estimation of the oil palm by-products generation through a compilation of calculation methodologies from different literatures (Chan, 1999; POTIM, 1985; DOE, 1999; Robani and Chan, 2009; Borhan *et al*., 2010; Ng *et al*., 2011; Ng *et al*., 2012).

Sampling

POME samples were collected from the local palm oil mills where possible. Untreated wastewater samples were obtained, transported to the laboratory and preserved in a cold room at temperature of 4ºC until analysis was done. It is important to mention that POPM

4 and 7 were not analysed because those processing mills discharge POME directly into land.

Analytical procedure

Some parameters of the POME were measured in-situ including dissolved oxygen (DO) and pH whereas others were performed in the laboratory. Dissolve oxygen (DO) was measured using YSI 5000 dissolved oxygen meter. Biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD) were measured according to the Standard Methods (APHA, 2005). Oil and grease was measured according to method 5520B of the Standard Methods (APHA, 2005). The suspended solids (SS) and volatile suspended solids (VSS) were measured according to methods 2540D and 2540E of the Standard Methods, respectively (APHA, 2005). Ammonia-nitrogen–NH_3-N, total phosphorus (TP) and total nitrogen (TN) were measured according to HACH handbook for water analysis (Hach, 2002).

RESULTS AND DISCUSSION

Waste generation

In Malaysia, 426 palm oil processing mills are reported to be in operation in the year 2011. Out of this number, 250 mills are located in the Peninsular with the Pahang state having the highest number of mills (70) in operation (MPOB, 2012). Most study sites in this survey are located in the Johore state, which has the second highest amount of palm oil processing mills in the Peninsular (64 mills) in operation as at year 2011. The agro-waste quantity and analysis is anticipated to be adequate to give a rudimentary conception and insights on the amount of by-products, or potential renewable resources accessible in the palm oil processing mills nationwide. This is based on the amount of by-products available from the FFB processed. In addition, the mills have similar handling practices on the by-products and thus they are virtually comparable.

In order to attract interest in the potentials of the palm oil processing by-products, the availability is often a concern in order to ensure that the new application/reuse purpose is practicable. An abundant amount of biomass by-product and solid waste are generated in this industry. Intensive research and exploration on the beneficial reuse are encouraged in all palm oil producing countries and especially across the Malaysian state. The following discussion enumerates the by-products available in the palm oil mills and their accessibility for potential renewable resources.

Participating palm oil mills

There were seven palm oil processing mills which participated in this study as shown in **Table 1**. The various mills have been abbreviated as POPM-1, POPM-2, POPM-3, POMP-4, POMP-5, POPM-6 and POPM-7.The POPM-4 has the highest capacity with 79,984 tonnes CPO/year, but it started its operation in 2006 and it is the latest among the 7 mills. POPM-3 in contrast has the lowest capacity of 22,800 tonnes CPO/year and was the earliest to commence its operation in the year 1968. POPM-1 is the only company in the central region (Selangor) while the rest are situated in southern region (Johore). POPM-4 is the only public-listed corporation. The POPM-1, 2 and 3 are operated by private organizations whereas the rest of them (POPM-5 to 7) belong to organizations which are supported by the government.

Palm oil processing waste

The estimation of palm oil waste or by-products is based on the amount of FFB processed by each mills. In other words, high FFB processing mills will generate higher amount of by-products which offer better advantage on the availability of these resources to seek for beneficial returns. A number of studies on the mass flow and balance of palm oil processing have provided important information on how to estimate the availability of several by-products in the palm oil mills. **Table 2** presents an estimation of fresh and dry weight of the process waste and/or by-products. Fresh weight is an estimation of the fresh sample directly from the FFB processed with the moisture content and all the fluids in the weight are included in the calculation. Dry weight is considered as a more precise and consistent estimation of organic matter as it represents only the sample weight without any water content. Hence, dry weight is used to eventually estimate the availability of these by-products.

The oil palm industry generates a high amount of waste such as the lignocellulosic palm biomass and the solid waste associated with it. Lignocellulosic palm biomass consists of empty fruit bunches (EFB), oil palm shell (OPSh), mesocarp fibres, palm oil mill effluent (POME) and palm oil mill sludge (POMS) while solid waste are palm oil fuel ash (POFA) and palm oil clinker (POC). Chan (1999) summarizes several applications of the EFB and POME which are prevalent reuse preferences in the 1990’s. Take EFB for an example, it can be utilized in many ways. It can be used as pulp for paper making, as bunch ash after incineration, as mulch and recycling of nutrient for palms, as an adjunct to improve efficiency in fertilizer uptake, as a fuel after dewatering to 40% moisture and become value-added products like medium density fibre board and wood composite products. POME can be also used as fertilizer; they become cellulose and single cell protein from sterilizer condensate and in the generation of biogas.

Table 1. Basic information of the inspected palm oil mills

Company	State[a]	District	Region	Capacity (tonnes CPO per year)	Year[b]	Management Background[c]
POPM-1	S	Sepang	Central	41,800	1986	IND
POPM-2	J	Kota Tinggi	Southern	67,640	1996	IND
POPM-3	J	KulaiJaya	Southern	22,800	1968	IND
POPM-4	J	Kluang	Southern	79,984	2006	PA
POPM-5						
	J	Kluang	Southern	51,300	2004	GOV
POPM-6	J	KulaiJaya	Southern	42,729	1977	GOV
POPM-7	J	Segamat	Southern	29,260	1986	GOV

[a] Location of the palm oil mills by state (S: Selangor; J: Johore).
[b] Year of operation commencement of the palm oil mills.
[c] Categories of management background (IND: individual millers; PA: public-listed corporation; GOV: government-backed organizations/companies).
POPM: Palm Oil Processing Mill

Table 2. Availability of the oil palm processing wastes (fresh and dry weight) [7; 10-15]

No.	Types of By-Products	Availability / Calculation Method
1	Empty fruit bunches (EFB)	EFB is assumed to be 22% of the FFB; dry weight is 35% of the total weight
2	Oil palm shell (OPSh)	OPSh is estimated to be 5.5% of the FFB; dry weight is 85% of the total weight
3	Mesocarp fibres	Mesocarp fibre is estimated to be 13.5% of the FFB; dry weight is 60% of the total weight
4	Palm oil mill effluent (POME)	When 1 tonne of FFB is processed in the mill, 0.67 tonnes of POME is generated
5	Palm oil mill sludge (POMS)	POMS is assumed to be 18% of the FFB
6	Palm oil fuel ash (POFA)	Burning the mesocarp fibres and the OPSh produce 5% of POFA
7	Palm oil clinker (POC)	Burning the mesocarp fibres and the OPSh produce 15% of POC

Legend

EFB	Empty fruit bunches	MESO	Mesocarp fibres	POMS	Palm oil mill sludge	POC	Palm oil clinker
OPSh	Oil palm shell	POME	Palm oil mill effluent	POFA	Palm oil fuel ash		

Biomass production in the seventh palm oil processing mills is shown in **Fig. 1**. Each mill produces different amount of oil palm waste namely the empty fruit bunches (EFP), oil palm shell (OPSh), mesocarp fibres, palm oil mill effluent (POME) and palm oil mill sludge (POMS) while solid waste are palm oil fuel ash (POFA) and palm oil clinker (POC) as well as fresh fruit bunch (FFB) are processed each year. The amount of each type of waste was based on the average amount of FFB in 13 years from 2000 to 2012 and the amount of FFB processed monthly throughout all these years did not differ so much. There are however low and high crop seasons in a year, but generally the differences are found to be less than 10%. Each palm oil processing mill is designed to handle certain loading of FFB to be processed into crude palm oils and other palm products. Unless major upgrade of facility was conducted, the FFB processed data presented do not differ considerably. The EFB is a renewable organic material which is generated during the processing of FFB at palm oil processing mills. It is an important biomass resource which can be converted into energy [18]. EFB is assumed to be 22% of FFB where 35% of that 22% is the dry weight (Chan 1999). From the bar chart in **Fig. 1**, POPM-2 has the highest EFB which is 31,196.26 tonnes due to the high amount of FFB processed. POPM-4 also produced high amount of EFB. Interestingly both palm oil processing mills have bigger capacity to store the CPO. POPM-3 produced the lowest amount of EFB due to the small capacity to store the CPO.

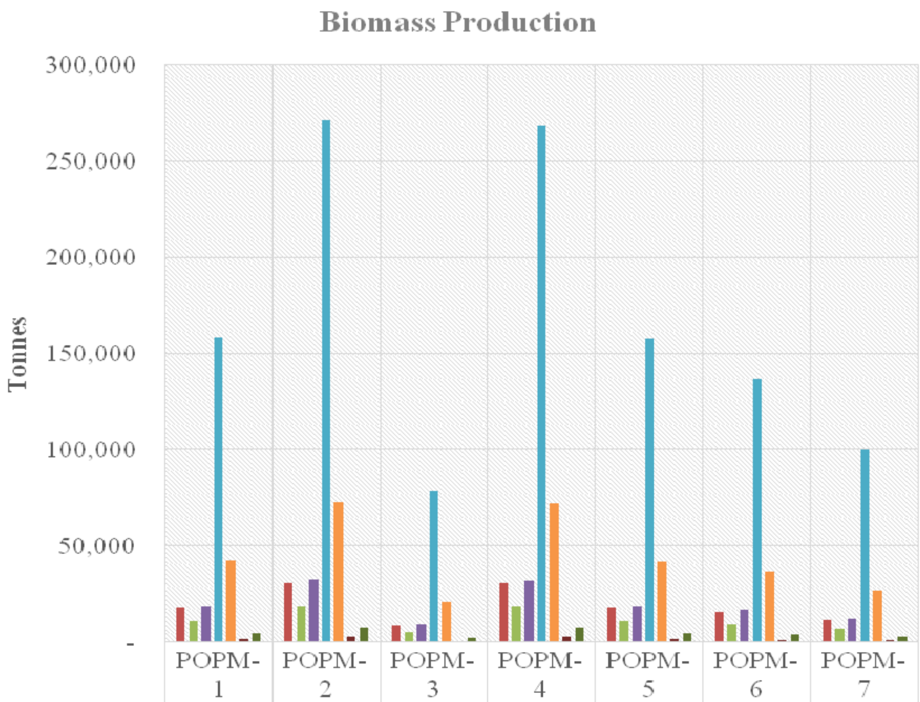
POME is the highest waste amongst all the waste generated in the palm oil processing mill. For every tonne of FFB processed in the mill, there are 0.67 tonnes of POME produced (Chan, 1999). That is why POME has the highest amount in every palm oil mill investigated in this study. Since the more FFB used the higher amount of POME would be generated. POME is a wastewater produced from palm oil milling activities which has high polluting properties. It needs proper and effective treatment before it is released into the watercourse (Poh *et al.*, 2010). POPM-2 and POPM-3 have quite very high amount of POME while POPM-1 and POPM-5 had about the same amount of POME.

The second highest waste from palm oil processing is palm oil mill sludge (POMS) and it is assumed to be

18% of FFB (Chan, 1999). Huge amount of sludge is generated in palm oil processing mills during wastewater treatment or biogas production every year (Tanawut *et al*., 2011). The POPM-2 had the highest amount of POMS (72,926 tonnes) while the lowest amount was held by POPM-3 (21,233.49 tonnes). POFA and POC are both solid wastes generated during the process, but are little compared to the rest of the other by-products. POFA is a waste product produced from burning the palm oil husk or fibre and palm kernel as fuel in the boiler where it is obtained in the form of ash (Abdul Awal & Hussin, 2011). POC is another by-product produced from the same burning process like POFA. By burning mesocarp fibre and oil palm shell, 5% of POFA and 15% of POC can be produced (Chan, 1999). The amount of POFA generated is less compared to the POC. A combination of both (POFA and POC) is also less than each of the lignocellulosic palm biomass weight.

Fate of palm oil waste and economic benefits

Although there are seven types of oil palm by-products reported in this study, we have selected three types of waste which come from both the lignocellulosic palm biomass and solid waste categories to further highlight their fates in the surveyed local palm oil processing mills. The EFB is very commonly reported in most literatures especially because of their wide range application and reuse options in the mills. EFB is considered of interest as it is about the most available and utilisable by-product from the palm oil industry. Sparse reports are available where EFB is discarded to landfills.



	POPM-1	POPM-2	POPM-3	POPM-4	POPM-5	POPM-6	POPM-7
EFB	18,161	31,196	9,083	30,833	18,108	15,719	11,489
OPSh	11,027	18,941	5,515	18,720	10,994	9,544	6,976
MESO	19,105	32,817	9,555	32,434	19,048	16,535	12,086
POME	158,02	271,44	79,036	268,28	157,56	136,77	99,972
POMS	42,455	72,926	21,233	72,076	42,330	36,746	26,858
POFA	1,507	2,588	753	2,558	1,502	1,304	953
POC	4,520	7,764	2,260	7,673	4,506	3,912	2,859

LEGEND

EFB	Empty fruit bunches
OPSh	Oil palm shell
MESO	Mesocarp fibres
POME	Palm oil mill effluent
POMS	Palm oil mill sludge
POFA	Palm oil fuel ash
POC	Palm oil clinker

Fig.1 An approximation of the oil palm processing wastes generated per annum in the inspected palm oil mills

POC and POFA are solid waste and have received the least attention in research. Both POC and POFA are produced from burning of lignocellulosic palm biomass to generate steam which is often related to the emission of intermittent dark smoke (carrying remainder of soot and partially carbonised fibrous particulates).

Most reports mentioned that these two by-products can be useful in civil engineering works such as in construction and transportation, while it prospects in broader applications is yet to be discovered. In local palm oil processing mills, these by-products are disposed to nearby landfill or more befitting dumpsites. The POFA is non-crystalline silicone dioxide and it is about 57% in amorphous form with high specific area and pozzolanic activity (Karim *et al.*, 2011). While the POC has silicone dioxide content of approximately 82% (Robani & Chan, 2009). Despite some thorough reports on the characterization of both materials, there is sparse literature on further research and development (R&D). **Table 3** shows waste handling methods and related economic benefits from their disposal.

The waste enumerated in **Table 3** is of interest not only because of the sustainable methods in their disposal, but also for their economic benefits. These are basically the empty fruit bunches, palm oil clinker and palm oil fuel ashes. For empty fruit bunch, POPM-3, 4 and 7 returned the EFB to the plantation estates for mulching. POPM-1 shredded and sold their wastes to other factories as a fuel resource for RM22/tonnes. POPM-2 processed the EFB to fertilizer and sold it at RM400/tonne. POPM-5 also used the EFB for compost in plant or returns it to plantation estate for mulching. POPM- 2, 3, 4, 5, and 6 dispose POC as landfill material. However, POPM-1 sold POC for road paving in plantation estates or rural area at RM2/tonne. POPM-6 also sold its POC to other factories. POPM-2, 3, 4 and 7 disposed POFA like POC. Same goes to POPM-1 and 6 which also used the same method to dispose POFA. As for POPM-5, it disposes some of its POFA by sending them to composting plant and the remaining is disposed as landfill material. From the scenario above, most of the oil palm mills dispose the waste generated through the landfill system especially the POC and POFA. Most of the EFB are used in mulching process in the plantation estate and thus the wastes are put to good use. For example, EFB can be processed as fuel and fertilizer and are sold to interested parties like factories. POC and POFA can be also used in road paving and are hence sold for some cash returns to the palm oil mill. **Table 4** shows the cash returns that accrued from sold by-products by some of the operating palm oil mills. While some are able to partially practice sustainable management of their waste and have some cash return, it is imperative to mention that an overall practice is required by all the palm oil mills. This would ensure that all waste generated are handled in such a way that zero-waste is achieved to leave the environment green. This could be attained through committed efforts of the management and entire organization. Those palm oil mills not having any cash returns do not in practice sell any of their waste to other factories who may need them as raw material and it is an opportunity not being harnessed by these processing mills.

Table 3. Waste handling methods and related economic benefits from their disposal

Palm Oil Mill	Types of Wastes		
	EFB	POC	POFA
POPM-1	shredded and sold to other factories at RM22/tonnes as a fuel after dewatering	sold at RM2/tonnes, for road paving in plantation estates or rural areas	sold at RM2/tonnes, for road paving in plantation estates or rural areas
POPM-2	processed to fertilizer, sold at RM400/tonne	wastes are disposed as landfill material	wastes are disposed as landfill material
POPM-3	return to plantation estates for mulching	wastes are disposed as landfill material	wastes are disposed as landfill material
POPM-4	return to plantation estates for mulching	wastes are disposed as landfill material	wastes are disposed as landfill material
POPM-5	shredded and sent to composting plant (40%) or returned to plantation estates for mulching (60%)	wastes are disposed as landfill material	wastes are sent to composting plant (5%) and the remaining as wastes are disposed as landfill material (95%)
POPM-6	some are burnt in the incinerator and the remaining are returned to plantation estates for mulching	sold to other factories at RM2/tonnes	sold to other factories at RM2/tonnes
POPM-7	wastes are returned to plantation estates for mulching	wastes are disposed as landfill material	wastes are disposed as landfill material

Table 4. Cash benefit from sales of waste by palm oil mills

Palm oil mill	Quantity (tonne per year)	Selling price (RM per tonne)	Income per year (RM)	Income in 13 years (RM)
POPM-1				
EFB	18, 161	22	399,542	5,194,046
POC	4,520	2	9, 040	117, 520
POFA	1, 507	2	3, 014	39, 182
POPM-2				
EFB	31, 196	400	12,478,400	162, 219, 200
POC	-	-	-	-
POFA	-	-	-	-
POPM-3	-	-	-	-
POPM-4	-	-	-	-
POPM-5	-	-	-	-
POPM-6				
EFB	-	-	-	-
POC	3,912	2	7,824	101, 712
POFA	-	-	-	-
POPM-7	-	-	-	-

Empty fruit bunches (EFB)

The EFB is a by-product of the palm oil production which has many advantages. EFB can be upgraded to become value-added fuels and renewable chemicals through fast pyrolysis. This process enables the EFB to produce bio-oil which can be burned in diesel engines, turbines or boilers. Also, it is applied in the production of specialty chemicals like flavouring (Abdullah *et al*., 2011). The waste that is burned can be used as fertiliser (Asha *et al*., 2012). Chubu Electric Power has been generating power since 2009 using EFB in eastern Sabah, Malaysia. They have built two small-scale power generation facilities (www.chuden.co.jp). EFB is also a potential recyclable waste that can be used as fuel to generate steam in mills (Ma *et al*., 1993).

Oil palm shell (OPSh)

The palm oil mills have traditionally used press fibre and shells as fuel for steam boilers and the generated steam is used to run turbines for electrical production (Zafar, 2013). Oil palm shell has the potential to produce phenol which can be a substitute for a petroleum based phenol. Phenol is a very important chemical in vast areas such as to manufacture products for automotive parts, household appliances, electrical components, etc (Md Kawser & Farid, 2000). Palm kernel shell that is carbonized can be used as charcoal and could be sold as products to consumer (Adewumi & Ogedengbe, 2005). Not only that, oil palm shell can been enhanced via pyrolysis method for conversion into biofuel in the form of manufactured pellets and an added economic value to the OPSh waste (Abdullahi & Sulaiman, 2012).

Mesocarp fibres

The mesocarp fibre is traditionally mixed with kernel shell and thereafter used as solid fuel to produce electricity for the mill. The excess fiber and empty fruit bunch are sent to the plantation from mulching (Harrison *et al*., 2008). Fibers that are recovered from pressed palm fruits are normally burnt as fuel to generate energy for the palm oil mills. The fibers too have been found to have abundant carotenoids, vitamin E and sterols (Choo *et al*., 1996). By using a method such as supercritical carbon dioxide (SC-CO_2), fresh palm-presses mesocarp and it is able to produce two types of value-added oils which are enriched with vitamin E and squalene (Harrison *et al*.,2008). Oil palm fibers are suitable for non-edible applications due to the high amount of free fatty acid and peroxide values. Minor components like phospholipids, vitamin E and carotenes can be extracted for the production of nutraceutical products (Rusnani *et al*., 2012).

Palm oil mill effluent (POME)

The POME is wastewater effluent that is discharged from the palm oil processing mill which has soluble materials that are harmful to the environment if not well treated before disposal (Igwe & Onyegbado, 2007). On another hand, it is very difficult to decompose POME in natural conditions even though it is organic in nature. However using earthworms, POME can generate useful and valuable products such as vermicompost. Vermicompost can be utilized as fertilizer in oil palm plantation as it is rich in nutrients (Rupani *et al*., 2010). This high concentration may cause several pollution problems including oxygen depletion in the aquatic environment. The characteristics of the POME are shown in **Table 5**. The strength of the raw POME is comparable to domestic wastewater typical of a town having an absence of industrial effluent with an average BOD_5/COD ratio of 0.48 for the sampled palm oil processing mill POME and this indicates a biodegradable wastewater. However Department of Environment, Malaysia new regulations to meet BOD_5 of 20 mg/L in the states of Sabah and Sarawak whereas in the Peninsular, there is yet to be as low discharge limit as stated, but the enforcement is likely to occur in the near future. This new policy demands that new treatment methods or improvement on the existing ones to achieve the discharge standard before disposing treated effluent into rivers or inland waterways be obtained. Currently a number of research works is being funded and supervised by the Malaysian Palm Oil Board (MPOB) to meet this new regulation amongst other needs.

Table 5. Pollution load of the POME at various POPM

Palm oil production mill	Mill operation (days per annum)	Pollution Load*, kg/ton FFB					
		BOD_5	COD	TN	TP	TS	SS
POPM-1	342	1,080.7	2,273.1	24.8	14.1	1,809.3	879.7
POPM-2	312	2,034.8	4,280.1	46.8	26.6	3, 460.7	1,656.3
POPM-3	348	531.2	1,117.3	12.2	7.0	889.3	432.4
POPM-4	–	–	–	–	–	–	–
POPM-5	300	1, 228.4	2,583.7	28.2	16.1	2,056.5	999.9
POPM-6	348	919.2	1,933.5	21.1	12.0	1,539.0	748.2
POPM-7	–	–	–	–	–	–	–

*POPM – Palm Oil Processing Mill - Not sampled

Palm oil mill sludge (POMS)

The POMS is usually sent to the sand bed and dried and then used as fertilizer (Nutongkaew *et al*., 2011). POMS can also significantly lower the cost of biodiesel production, thereby making it a highly potential alternative feedstock for biodiesel production (Hayyan *et al*., 2010). Vermicomposting technology can be used in POMS management to mitigate the wastes (Rupani *et al*., 2010).

Palm oil fuel ash (POFA)

About 5% of POFA is produced after combustion and since its uses are limited it has to be disposed at the landfill else it could cause potential environmental issues. However, POFA has low pozzolanic reaction because of its large particle size and porous structure. Owing to its pozzolanic properties, it may be suitable in making high-strength concrete (Sata *et al*., 2004). Partial addition of POFA to cement is of advantage especially for mass concrete works where great concern is taken to avoid thermal cracking due to excessive heat (Abdul Awal & Hussin, 2011). Also, by adding POFA, the performance of modified asphaltic concrete can be enhanced. Creep resistance and fatigue properties of the asphalt concrete mixes are also improved when POFA is added (Borhan *et al*. 2010).

Palm oil clinker (POC)

The POC can be utilised as a replacement for sand in the production of foamed concrete. Thus it helps to sanitise the environment and creates cheaper cost and renewable aggregates for construction purposes (Chandran, 2010). POC that is infused in concrete is comparable to ordinary concrete. Previous study observed that (Bashar *et al*., 2011). POC concrete is suitable to be used as a durable structural lightweight concrete. Another study also found that POC can be used as lightweight aggregate for the production of structural concrete (Bashar *et al*., 2013).

Biogas generation

Biogas generation is usually present in the processing of palm oil. In treatment of the POME particularly, anaerobic digestion of the effluent is a major production stage for biogas production. It should be noted that the biogas contains methane which has 21 times the global warming potential of the carbon dioxide (Ng *et al*., 2012). Several anaerobic digestion methods are applied in the local palm oil mills. Most mills in Malaysia apply the open anaerobic digestion pond which allows the biogas to escape into the environment e.g. in POPM-1, POPM-2, POPM-3, POPM-4, and POPM-5. Some mills cover their anaerobic digestion pond with canvas for the purpose of biogas capture. The biogas collected is either delivered to existing engineering facilities for further conversion into electricity through engines or micro-turbines or they simply burn the gas in a flare process to convert the methane to carbon dioxide and hence reducing the greenhouse gas effects such as in the case of POPM-5 and POPM-7. In other cases, there are palm oil processing mills which employ the anaerobic tank digester technology to decompose the organic matter in

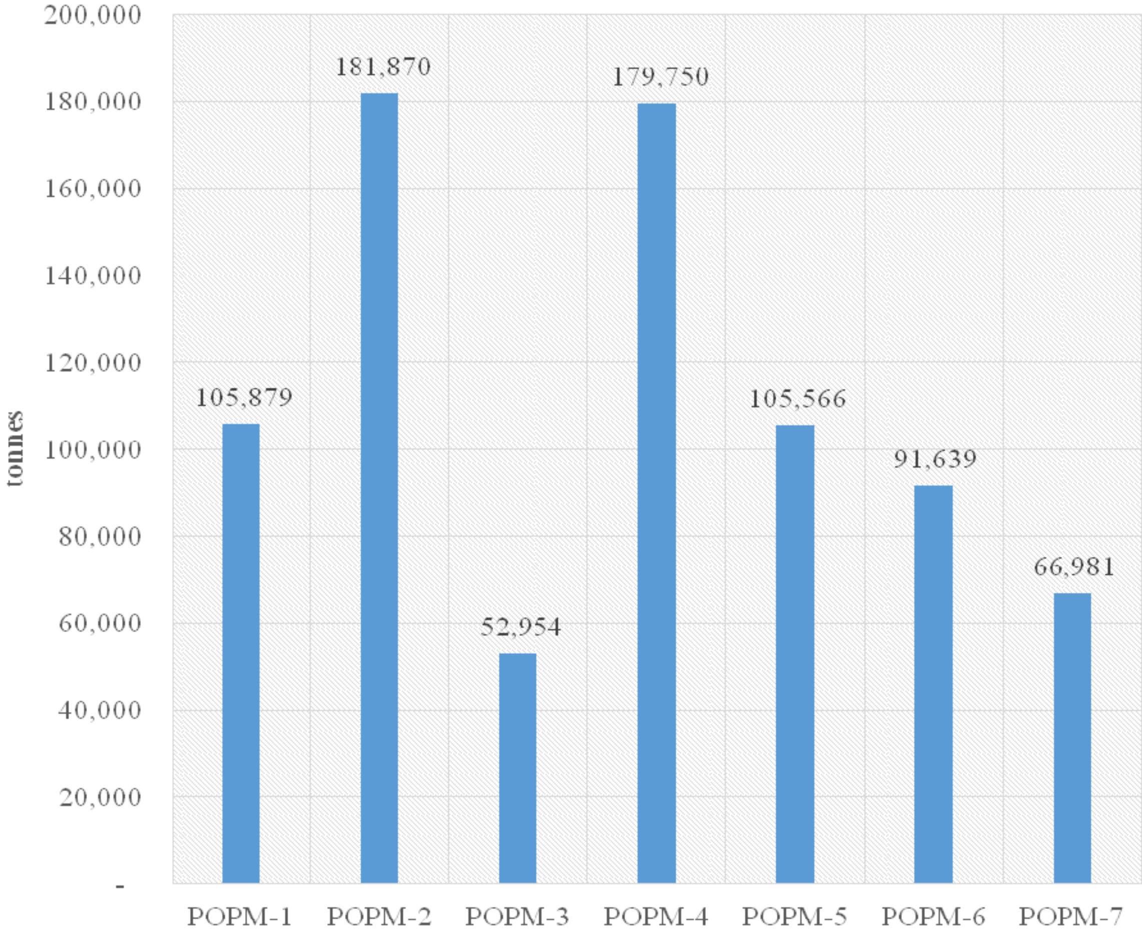


Fig. 2 Biogas generated annually in the seven palm oil processing mills.

POME. Similar to the ponding system, some of these digesters are open-top digester tanks while others are closed-top digester tanks. There are some mills which also apply more than one anaerobic digestion stage during the course of their POME treatment process. This may help them achieve improved treatment efficiency as against those using one anaerobic digestion stage.

Biogas production is highlighted in this paper because greenhouse gas emission issues have not been sufficiently given attention in the palm oil industry in order to enable them meet the requirements towards sustainable development (Ng *et al*., 2012). In this study, biogas generation in the palm oil processing mills was accessed and presented in **Fig. 2**. When one tonne of FFB is processed in the mill, 0.67 tonnes of POME is generated and biogas is produced at 28m^3 per cubic metre of the effluent (Chan, 1999; Ng *et al*., 2011; Ng *et al*., 2012). Since the palm oil industry is a major sector in the Malaysian economic development program and also highlighted in the National Key Economy Areas (NKEA) program, it is imperative to reduce the effect of green house gas and thus assist in environmental protection and preservation.

The purpose of the NKEA is to increase Malaysia's economic and income status by year 2020. One of the NKEA is actually focusing on oil palm sector which is a vital industry to the nation. As the fourth largest contributor to the national economy, the Palm Oil NKEA program has included eight core Entry Point Projects (EPPs) spanning the palm oil value chain. One of the EPPs is building biogas facilities at palm oil mills across Malaysia. Biogas production is a potential source for both economic and environmental preservation benefits. The benefits of biogas cannot be over emphasized. It includes reducing greenhouse gas (GHG) emissions thereby reducing global and local environment impact, reducing land use for POME treatment, generating additional revenue in the palm oil sector, encouraging technology innovation and R&D, decreasing the dependence on fossil fuel and increasing fuel diversity and security of energy supply. It can also be a source of energy to the individual palm oil mills as well. It would also enable the facilities to apply for Clean Development Mechanism (CDM). Through the sale of carbon credits, CDM projects would be able to also convert GHG emission reduction into cash (http://etp.pemandu.gov.my).

CONCLUSIONS

The Malaysian palm oil industry is a pillar to the national economic advancement. It is also an important sector aimed at achieving the environmental preservation programmes. Thus to gear towards sustainability and the development of green cities in the country, actions which will turn around the palm oil production industry must be significant enough. The industry in fact has no other option than promoting green development. With possible estimation of the major palm oil by-products for commercialization purpose, practicability of sustainable efforts in recovering and reuse of these by-products are suggested for full implementation. These could range from processing the palm oil mill waste as feedstock in animal husbandry and to provide energy as fuel for other factories. This can only be achieved with intensive research work to enable zero waste outcomes. With respect to biogas generation when applied in CDM projects, it would offer the palm oil industry a chance to compete with other industries even in her treatment of recalcitrant wastewater. The study has provided insights on the palm oil industry waste which could be harnessed to become a potential source for revenue generation at the same time achieving a sustainable and green environment. With more stringent policies, possible clean technologies will be obtained through research and development for the Malaysian palm oil industry.

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