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Can palm oil waste be a solution to fossil fuel scarcity and environmental sustainability? A Malaysian case study provides the answer

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Abstract

The main aim of this paper is to examine the potential of energy resources of non-fossil origin as a feasible alternative that will enhance energy security and environmental sustainability. This is examined quantitatively based on a case study in the state of Sarawak located in Malaysia. It is demonstrated that optimizing the use of palm oil waste from the palm oil industry in Sarawak for bioenergy production can be a crucial means of mitigating the pressing problems of hydrocarbon resource scarcity, waste disposal and the greenhouse effect. The conclusion is that biomass in general, and palm oil waste in particular can be a sustainable energy source to rely on in the near future especially for the emerging Asian economies.
Keywords: palm oil plantation, biomass, second law of thermodynamics, energy security, environmental sustainability.

1 Introduction

The Southeast Asian nations along with China and India are shifting the geopolitics of global energy due to their insatiable appetite for energy demand amidst robust economic growth. The quest for increasing energy resources in the region is straining traditional and depletable fossil fuel reserves such as coal, oil and natural gas. Conceivably, the finitude fossil fuels coupled with concerns over increasing carbon footprint and anthropogenic climate change have led to growing regional interest in exploring alternative energy sources.

One potential solution is to re-model the energy-mix away from fossil fuel resources to biomass energy. This is examined quantitatively based on a case study in the state of Sarawak in Malaysia. It will be demonstrated that optimizing the use of palm oil waste available in abundance in the state for bioenergy production can be a crucial means of mitigating the pressing problems of hydrocarbon resource scarcity, waste disposal and the greenhouse effect.

A theoretical scaffolding of natural resource scarcity in relation to fossil fuels is presented, with particular reference to oil. The discussion that follows highlights the fact that the search for alternative renewable energy sources in a finite natural world poses one of the biggest challenges humanity has ever faced. It concludes that biomass in general, and palm oil biomass in particular can be a sustainable energy source to rely on in the near future for the emerging Asian economies including China and Southeast Asia, and especially for Indonesia and Malaysia, as they are respectively the largest and second largest palm oil exporters in the world.

2 Fossil fuel resource scarcity: some basic concepts

Natural resource economics distinguishes between renewable and non-renewable resources. Renewable resources are resources that may be replenished indefinitely through natural biological regeneration processes and sustainable harvesting. These include for example, forest or fishery stocks. Non-renewable or exhaustible resources, however, have no natural biological regeneration abilities, at least not within a relevant human or economic time scale. Mineral deposits and fossil fuels are such examples. These resources are often found in fixed amounts, that is, they are finite and are consumed more quickly than nature can regenerate them. Since the stocks of these non-renewable resources are depletable, when they become depleted, it is an irrecoverable loss, and will be unavailable to future generations.

Non-renewable resources may be further divided into two categories: recyclable and on-recyclable. Mineral deposits, such as iron ore, can be recycled, but fossil fuels such as coal, oil and natural gas are physically non-recyclable. Once these hydrocarbon resources enter into a production chain, they will be irrevocably transformed into energy and waste. That is to say, once used, they will be gone forever. Another distinctive feature of these resources are that they are without a backstop technology. A backstop technology is a substitute technology that is not constrained by exhaustibility (Nordhaus [1]).

The irreversible nature of these fossil fuels may be explained with specific reference to oil using the second law of thermodynamics or the entropy law. Entropy is a measure of the quantity of energy not capable of conversion into work. That is to say, in any transformation of useful form of energy, for instance, usable oil to another form in a production process, it undergoes a process of entropic decay or dissipation whereby it will be destroyed and lost irreversibly (Georgescu-Roegen [2]). In other words, once used, it is gone forever. Furthermore, the entropy law imposes an absolute resource scarcity which cannot be overcome by the deployment of advance technology, exploration, or substitution (Daly [3], Georgescu-Roegen [4]). Technically speaking, fossil fuel resources are absolutely scarce thanks to the entropy law. Consequently, for a given reserve level, the amount that may be extracted will be permanently decreased as the exploitation process progresses over time.

Moreover, the amount of oil that can be extracted is also limited by geological constraints governing its formation. It may well be that the hydrocarbon resource, which is generated from the remains of prehistoric planktonic algae and bacteria (biotic material) takes millions of years to form under a precise combination of pressure, temperature and time. Consequently, the natural supply of oil cannot be physically increased over an economically relevant time horizon by resource-augmenting technological progress or industrial process. Thus, production level will begin to decline gradually and irreversibly once it reaches its peak level due to geological constraints. The peak oil production level coincides with the point at which the oil reserve has been depleted by 50 percent. Peak oil decline does not mean running out of oil, but running out of cheap pumpable oil. The period after the peak is known as depletion. Viewed from this perspective, oil is absolutely scarce because of the geological time necessary for regeneration.

This above exposition raises concerns about the continued availability of fossil fuel energy resources over space and time to support long-term growth and human socio-economic wellbeing. It further cautions us to reduce our dependence on finite hydrocarbon resources by diversifying our energy-mix based on the optimization of renewable and non-fossil energy resources. Renewable energy is defined as energy generated from continually replenished sources such as solar photovoltaic, wind power and biomass. The following subsection provides an assessment of the extent that palm oil biomass can contribute to this. This is based on a case study in Malaysia with specific reference to the state of Sarawak.

3 Biomass: the potential green wealth and the key to energy security

The use of renewable energy sources continues to grow rapidly amidst growing concern about hydrocarbon resource depletion and growing energy consumption especially in the fast developing Asian economies including China and Southeast Asia. Indeed, renewables especially biomass are increasingly becoming a mainstream energy source. Biomass is any organic matter derived from plants or animals. However, in the context of energy sources it is commonly used to refer to decomposable solid material that can be collected from biological organisms, primarily plants, on a renewable basis (Davis *et al.* [5]).

Biomass, a stored solar energy, is the fourth largest energy source after coal, oil and natural gas. It is also considered to be the most important renewable energy option (Ladanai and Vinterbäck [6]). In 2013, biomass accounted for about 19% of global final energy consumption, and biomass for energy (bioenergy) remained the major contributor to renewable energy worldwide at nine percent of all renewables in the same year (REN21 [7], Teske *et al.* [8]). The optimal use of biomass is also expected to contribute to energy security, significant reduction in greenhouse gas and mitigation of waste accumulation problems (Cigolotti [9]).

Despite this, however, biomass waste, which is available in abundance in the Asian emerging economies, remain basically unused or underutilized. This not only poses major disposal problems but also raises grave environmental concerns. It is thus argued that optimizing the use of biomass waste for energy production serves as a crucial means of mitigating fossil fuel scarcity problem while also promoting environmentally sustainable development. This will be systematically demonstrated based on a case study in the state of Sarawak in Malaysia.

4 Palm oil waste: some basic facts

Palm oil is the most important commercial agricultural crop in Malaysia. Currently, Malaysia is the second largest palm oil producer and exporter in the world after Indonesia, accounting for about roughly 32% (19.8 million tons) of global production level in 2014, with exports of 17.2 million tons in the same year (Index Mundi [10, 11]). The palm oil planted area as of 2014 was 5.39 million hectares (MPOB [12]). It may be noted that Indonesia's production level in the same year was 33 million tons, or 53.5% of global production level. It exported 22.5 million tons of palm oil in the same year. The positive annual growth rate of palm oil production also resulted in substantial production of biomass waste and residue in the palm oil industrial sector.

For the purpose of analysis, palm oil biomass comprises the following: (i) empty fruit bunches (EFB), (ii) palm kernel shells, (iii) mesocarp fibres which are derived from the palm oil production process. The palm oil industry also generates substantial amounts of liquid waste in the form of palm oil mill effluent (POME). POME is a brownish, concentrated and acidic liquid discharge. It is also a potent source of methane emission when it undergoes an anaerobic process, contributing to regional warming. If it is put to sustainable use, its high organic content provides one of the most promising sources of renewable energy in the form of biogas (methane) for bioenergy generation (Chin *et al.* [13]).

It is thus clear from the above that optimizing the use of biomass from the palm oil industry in Malaysia has great potential to contributing towards greening its energy-mix system, which is heavily dependent on the use of fossil fuels, and towards increasing security in the power generation sector. It may be of passing interest to note that in 2012, natural gas and coal contributed 46% and 41% respectively to the electricity generation mix in the country (Energy Commission [14]). It would also result in the reduction of waste product disposal from the mill. This will be discussed based on a case study in the state of Sarawak.

5 Greening the palm oil industry in Sarawak: the bioenergy potential

Sarawak is the largest state in Malaysia with an area of 124,450 square kilometres. The palm oil industry is one of the most important sectors underpinning the Sarawak's robust economic growth. It has expanded rapidly from about 54,790 hectares (ha) to about 1.26 million ha in 2014, and is expected to cover two million ha by 2020 (MPOB [15]). The rapid expansion of the palm oil industry in the state offers a promising opportunity for greening its environment and reducing its dependence on fossil fuel for power generation.

The amount of solid waste generated from each tonne of fresh fruit bunch (FFB) processed as shown in Table 1 contains energy which can be recovered by combustion in a boiler while POME produced may be captured for its energy-containing biogas, methane, for bioenergy generation.

Table 1: Solid and liquid waste produced per tonne of fresh fruit bunch (FFB) processed.

Biomass waste	kg
Empty fruit bunches	220
Palm nut shell	55
Mesocarp fibre	130
Palm oil mill effluent (POME)	650

Source: Sarawak Energy [16].

Based on the above, it is possible to compute the energy potential for palm oil waste in Sarawak (Table 2).

Table 2: Energy potential analysis of major palm oil solid waste in Sarawak.

Column		1	2	3	4	5	6	
	Moisture content (MC) (%)	Fraction of FBB (%)	Net calorific value (MJ/tonne)	Steam energy (MJ/tonne of FFB)	Mill steam use (MJ/tonne FFB)	Turbine efficiency (%)	MJ/tonne FFB	Electricity /tonne FFB (kWh)
Empty fruit bunches (EFB)	60	23	5,300	1036	324	30	214	59
Palm nut shell	37	13	11,100	1227	384	30	253	70
Mesocarp fibre	12	6	17,300	882	276	30	182	51
Solid waste total			33,700	3145	984		649	180

Note:

(a) All parameters in columns 1 and 2 are based on the information from UNFCCC (Kunak Bio-Energy Project 2921), p. 46. UNFCCC [17], EFB, palm nut shell and mesocarp fibre is around 23%, 13% and 8% by weight at its post-processing moisture content of 60%, 37% and 12% respectively. It should be noted that different moisture content results in different energy values. Prior to being used as boiler feed, EFB, for example, is typically air dried to reduce its moisture content or a screw press is used to remove oil and excess moisture to improve fuel property. The lost moisture weight means the usable fuel is only 23% of FFB by weight.

(b) Steam production in column 3 follows UNFCCC (Kunak Bio-Energy Project 2921) UNFCCC [17], at 85% boiler efficiency. To illustrate, steam energy is derived at column 1*column 2*85% (e.g. [EFB]: 23%*5,300 MJ/tone*85%=1036MJ/tonne FFB). Efficiency at 85% means the boiler is capable of converting 85% of the potential heat energy in biomass to hot steam, with 15% of the energy being lost.

(c) Steam diversion in column 4 is based on 25 out of 80 tonnes per hour of high pressure steam (31.3%) (e.g. 1036 MJ/tonne of FBB * 31.3% = 324 MJ/tonne of FBB) (McNish *et al*. [18]).
(d) Steam turbine efficiency in column 5 is assumed to be 30%, that is, it is capable of converting 30% of the heat energy in steam to electric energy (McNish *et al*. [18]).
(e) Energy output (MJ/tonne FFB) in column 5 is calculated based on steam energy (MJ/tonne of FFB) - Mill steam use (MJ/tonne FFB) X Turbine efficiency (30%) (e.g. 1036 MJ/tonne of FBB-324 MJ/tonne of FBB * 30% = 214MJ/tonne FFB while kWh is based on online conversion table.

Following the above, it is possible to estimate the energy potential of the palm oil industry in Sarawak (as shown in Table 3).

Table 3: Energy potential of the palm oil industry in Sarawak, Malaysia.

Basic information		Residual materials produced per tonne of fresh fruit bunch (FFB) processed		Total amount of residue materials produced in 2014	Electricity /tonne FFB (kWh)	Energy potential (kWh)	Fossil-fuel saving potential (tonne of oil equivalent
		Waste category	tonne				
Total planted area (2014)	1,263,391ha	Empty fruit bunches (EFB)	0.22	4,483,269	59	264,512,889	22,744
FFB yield per tonne per ha per year (2014)	16.13 per tonne/ha/yr	Palm nut shell	0.06	1,222,710	70	85,589,687	7,359
Total FFB yield (2014)	20,378,497 tonnes	Mesocarp fiber	0.13	2,649,205	51	135,109,434	11,617
		Palm oil mill effluent (POME)	0.65	13,246,023	26	344,396,596	29,613
Grand-total				21,601,207		829,608,606	71,333

Source of data: Leong [19], Malaysian Palm Oil Board [12].

It is increasingly clear from the above that the palm oil industry in Sarawak can be an important source of alternative energy that not only contributes to enhancing energy security by reducing its dependence on fossil fuel for electricity generation but also helps to promote environmentally sound waste and pollution control systems. It is also clear from Table 3 that optimizing the energetic use of palm oil waste allows Sarawak to generate more than 829,000 kWh (about 71,000 toe), and at the same time helps to mitigate its waste disposal problem. More importantly, given that every tonne of treated POME releases an average of 5.5 kilogram (kg) of methane (Yacob *et al*. [20], Madaki and Lau [21]), recapturing the biogas for energy generation serves as an important means of reducing greenhouse gas emission by 72,853 tonnes per year. Here, it is relevant to note that methane is 25 times more powerful than carbon dioxide as a global warming gas.

Extrapolating the Sarawak's case study to Malaysia as a whole, with a total palm oil cultivated area of more than 5 million ha with an average FB yield at 17.3 per tonne per year (MPOB [12], the amount of energy generated is about 3.7 million kWh or 323,000 toe and greenhouse aversion impact amounting to approximately 333,500 tonnes of methane or 8.3 million tonne of CO_2 equivalents (see Table 4).

Table 4: Energy potential analysis of major palm oil solid waste and POME in Malaysia.

Basic information		Residual materials produced per tonne of fresh fruit bunch (FFB)		Total amount of residue materials produced in 2014 (tonne)	Electricity /tonne FFB (kWh)	Energy potential (kWh)	Fossil-fuel saving potential (tonne of oil equivalent, toe)
		Waste category	tonne				
Total planted area (2014)	5,392,235 ha	Empty fruit bunches (EFB)	0.22	20,522,847	59	1,210,847,945	104,114
FFB yield per tonne per ha per year (2014)	17.3 per tonne/ha/yr	Palm nut shell	0.055	5,130,712	70	359,149,814	30,881
Total FFB yield (2014) (ton	93,285,666	Mesocarp fibre	0.13	12,127,137	51	618,483,966	53,180
		Palm oil mill effluent (POME)	0.65	60,635,683	26	1,576,527,755	135,556
Grand-total				98,416,378		3,765,009,480	323,731

Applying the Malaysian case study to the Indonesian palm oil industry, the environmental benefits accrued are even more impressive (Table 5).

Table 5: Energy potential analysis of major palm oil solid waste and POME in Indonesia.

Basic information		Residual materials		Total amount of residue materials produced in 2014 (tonne)	Electricity /tonne FFB (kWh)	Energy potential (kWh)	Fossil-fuel saving potential (tonne of oil equivalent, toe)
		Waste category	tonne				
Total planted area (2014)	8,000,000 ha	Empty fruit bunches (EFB)	0.22	39,600,000	59	2,336,400,000	200,894
FFB yield per tonne per ha per year	22.5 per tonne/ha/yr	Palm nut shell	0.055	9,900,000	70	693,000,000	59,587
Total FFB yield (2014) (tonnes)	180,000,000	Mesocarp fibre	0.13	23,400,000	51	1,193,400,000	102,613
		Palm oil mill effluent (POME)	0.65	117,000,000	26	3,042,000,000	261,564
Grand-total				189,900,000		7,264,800,000	624,658

Note: FFB yield per tonne per ha per year is based on the average of FFB yields of 23.5 $t\,ha^{-1}$ in Sumatra and FFB yields of 21.5 $t\,ha^{-1}$ year in Kalimantan (Harsono *et al.* [22]).

As demonstrated clearly in Table 5, the amount of energy Indonesia may recover from palm oil waste is approximately 7.3 million kWh or 624,000 toe, and the amount of greenhouse gas aversion is about 643,000 tonne of methane or 16 million tonnes of CO_2 equivalents. Assuming that Malaysia and Indonesia adopt zero-emission measures in the palm oil industries by optimizing the full use of palm oil waste, this can serve as a potential, albeit not exclusive, solution to fossil fuel scarcity and environmental sustainability as shown in Table 6.

Table 6: Environmental and energetic benefits of palm oil waste in Malaysia and Indonesia combined.

	Malaysia	Indonesia	Total	Remarks
Energy potential (kWh)	3,765,009,480	7,264,800,000	11,029,809,480	promoting energy security
Fossil-fuel saving potential (tonne of oil equivalent, toe)	323,731	624,658	948,389	mitigating fossil fuel depletion problem
Palm oil mill effluent (POME) (tonnes)	60,635,683	117,000,000	177,635,683	mitigating waste disposal problem
Major solid waste (tonnes)	37,780,695	72,900,000	110,680,695	mitigating waste disposal problem
Methane emission (tonnes)	333,496	643,500	976,996	mitigating greenhouse gas emission problem
Methane emission (CO2 equivalent) (tonnes)	8,337,406	16,087,500	24,424,906	mitigating greenhouse gas emission problem

6 Palm oil waste, resource scarcity and environmental sustainability: the implications

Undoubtedly, fossil fuel resources, especially oil, will continue to dominate the global energy mix. Oil is the major hydrocarbon resource that poses an ultimate constraint to sustaining long-term economic growth and human progress. This is because there is no immediate viable substitute for oil as a dominant energy source in terms of its intrinsic qualities of extractability, transportability, versatility and cost (Singhania *et al*. [23]). Close to 40 percent (or 152 quadrillion BTUs) of the global energy consumption is based on oil and no other fuel source holds as much energy as oil. For instance, it holds 1.3 to 2.45 times more economic value per kilocalorie than coal (Hanson [24]). It may be noted in passing that 1 quadrillion BTUs (British thermal units) is equivalent to about 180 million barrels of oil or 500,000 barrels per day for one year.

Oil is also useful in other ways. It is an essential input in many of the production chains or economic activities but its long-run supply capacity is fixed and finite. Thus continued exploitation necessarily leads to depletion once it reaches its peak production level. Examples of global oil fields which have reached their peak oil production levels include the Lower 48 States and East Texas oil fields in the United States, and the major North Sea oil fields in the United Kingdom and Norway (Zittel [25], Mearns [26], EIA [27], British Petroleum [28]).

To sum up, the long-term availability of oil is dictated by the entropic law of decay and dissipation, geological constraints, and the peak oil phenomenon as elucidated above. This will prove to be the ultimate resource constraint to long-term economic growth and human wellbeing amidst surging energy demand in the emerging Asian economies especially China, India and Southeast Asia (IEA [29]).

The above exposition is sufficiently indicative to fortify the search for alternative sources of energy, not as a substitute for oil but as a buffer against the continued and unabated stress of rapid and irreversible oil depletion caused by increased population and the fervent pursuit of economic growth and high consumerism especially in the Asian fast developing countries including China and India, and Southeast Asia.

The Malaysian case study highlights the fact that harnessing the energy potential of biomass waste offers a critical mitigating solution against ultimate fossil fuel resource constraint. It also serves as an environmentally benign energy option to reduce waste disposal problems which at the same time reduces greenhouse gas emission. Implicitly, viewed from the Asian perspective, it is without question that optimizing the use of the mostly unutilized biomass in the Asian emerging economies including China and Southeast Asia offers one of the most strategic means to address the fossil fuel-induced socio-economic quagmire.

Implicitly, given that globally about one billion tonnes of biomass from different sources is produced annually (Agamuthu [30]), optimizing the use of this huge amount of fossil fuel-saving waste is undoubtedly environmentally sustainable. Take the case of China which annually generates about 650 million tonnes of agricultural residue, straw and forest waste, 50 percent of which can be utilized for bio-energy production. However, a large portion of these resources is still largely unused or burned in the field, causing severe environmental problems (BE Sustainable [31]). A more serious observation is that only about five percent of the total biomass potential is being collected on a systematic basis despite the fact that if all the usable biomass waste was optimized for its energy potential, it would create 1.2 billion tonnes of coal equivalents (tce) or 0.84 billion tonnes of oil equivalent (toe) (Klimowicz [32]).

Similarly, Southeast Asia also has a huge biomass potential from various biological sources including rice husk, wood residue, bagasse and palm oil waste. For example, rice mills in the region generate about 38 million tonnes of rice husk and 30 million cubic meters of woody biomass annually. This mostly untapped biomass may be used for power and heat generation. Also, the sugar mills in Thailand, Indonesia, the Philippines and Vietnam generate roughly 34 million tonnes of bagasse every year which can also be utilized to generate electricity.

Conceivably, with the future of the global economy hinging on the continued availability of the finite and depletable fossil fuel resources, adopting the environmentally benign “waste to energy” strategy offers an inexorable solution to mitigate the entropic hydrocarbon resource depletion problem. Optimizing the sustainable use of biomass waste also serves to protect the sink capacity of our biosphere from the cumulative environmental impacts of the ever increasing volume of waste disposal.

7 Concluding remarks

The entropy law imposes a long-run absolute scarcity on the availability of the exhaustible fossil fuel resources, in particular oil and natural gas, which the deployment of advanced resource extraction technologies, the introduction of backstop technology, resource substitution, and exploration cannot reverse. Given the finiteness of these resources as well as the limited capacity of our terrestrial biosphere to absorb greenhouse gases, this paper demonstrates that harnessing the energy potential from biomass such as palm oil mill waste can play an important role in enhancing energy security, at the same time mitigating the imminent threat of hydrocarbon resource depletion, and waste disposal and management problems. Increasingly, the present case study has far reaching implications for the greening process of rising biomass waste streams across the globe especially in the fast developing Asian economies.

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