The Economics of the Malaysian Palm Oil Industry and Its Biodiesel Potential

Abstract

This article studies the Malaysian palm oil industry, tracing the industry from the oil palm plantations and ending to its finished products. Palm oil industry is a prominent industry in Malaysia, creating economic growth and development. For instance, the government helped roughly 90,000 low-income settlers with their families to become oil palm tree plantation owners. Furthermore, Malaysia has the industries to manufacture a variety of palm oil products that Malaysia exports. Palm oil exports comprised 13.7% of its gross domestic product. Subsequently, the exports cause a significant inflow of foreign-currency earnings. Moreover, Malaysia has the industries to produce biodiesel and fully offset its transportation diesel market with plenty of biodiesel and palm oil left over to export. Unfortunately, the Malaysian government had encountered two obstacles hindering the large-scale manufacture of palm biodiesel. First, the Malaysian government heavily subsidizes its transportation fuels, giving Malaysians the cheapest gasoline and diesel fuels in the world. Second, Malaysia has confronted import barriers from the European Union and the United States. U.S. Environmental Protection Agency ruled against the palm oil biodiesel, as a renewable fuel import because its lifecycle emissions are below the 20% threshold. Furthermore, the European Union imposed tariffs on Malaysian palm biodiesel, possibly protecting its rapeseed biodiesel industry from competition.

Keywords: Malaysia, palm oil, palm kernel oil, palm methyl ester, palm biodiesel

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1. Introduction

Oil palm tree originally grew in West Africa until the British brought the oil palm trees to Malaysia in the 1870s. People grew the oil palm trees in gardens and used them in landscaping. Then people discovered the trees produced a high-quality cooking oil. Subsequently, Malaysians began growing oil palms commercially since 1917 [1].

Malaysian government views the oil palm as an important source of economic growth and development. Government formed the Federal Land Development Authority (FELDA) to help low-income settlers and their families convert rainforests into rubber and palm tree plantations. FEDLA is a public agency with 25 subsidiaries and 20 joint-venture companies. Subsequently, FELDA had its initial public offering in 2012. Moreover, FELDA provides training, assistance, and home-construction loans to settlers and even buys the settlers' rubber and palm oil fruits to process in its facilities. FELDA [2] helped approximately 22,124 settlers acquire rubber plantations and 90,376 settlers develop oil palm plantations. Palm oil industry creates high-paying jobs in rural communities, eradicating poverty and improving the standard of living. Furthermore, Malaysia exported approximately $26.3 billion in U.S. dollars[1] of palm oil and its products in 2011, comprising roughly 13.7% of its gross domestic product (GDP). Consequently, the oil palm contributes significantly to the Malaysian economy.

Malaysian government is using the palm oil industry to reduce its greenhouse-gas emissions. Although, the Kyoto Protocol does not require Malaysia to reduce its greenhouse-gas emissions to its 1990 level, the government has taken a proactive approach to reducing global warming. Consequently, the oil palm industry could play a key role in recycling greenhouse-gas emissions and allowing Malaysia to reduce its carbon footprint on the world.

This research paper is divided into two sections. First section provides a background of the palm oil industry and analyzes some of the technical and economic issues of the palm oil industry and its diverse products. Then the second section examines the potential use and production of palm oil as a replacement for diesel fuel used in the transportation sector.

2. The Palm Oil Industry

This section examines the growing and industrial use of the oil palm tree, beginning with the oil palm plantations and finishing with its main products. Hence, it examines the potential land use and the principal products of the palm oil industry. Moreover, the palm oil plantation's wastes are analyzed and how the industry could mitigate these wastes.

[1] Used the exchange rate on November 4, 2011 that 1 Malaysian ringgit = U.S. $0.3276.

2.1 Palm Oil Trees

Palm plantation owners grow the *Elaeis gunineensis* for its palm products [3, 4, 5], and Malaysia became the world's largest growers of palm oil trees until Indonesia had surpassed it in 2007 [6]. Although the tree has a life span exceeding 200 years, the industry established the tree's economic life ranging from 20 to 25 years [4, 5, 7].

After the plantation owners had planted the oil palm trees, they can harvest their first crop between 43 and 53 months [4]. A fully mature palm tree produces 150 kilograms of fresh fruit bunches [5], where each bunch yields from 1,000 to 3,000 fruits [1]. Consequently, a plantation owner could harvest from 10 to 35 tonnes of fresh fruit bunches per year from one hectare of oil palm trees [4].

Oil palm differs from the other oil crops grown around the world, because it provides two sources of oil. Every fruit contains a kernel yielding between 45 and 50% of palm kernel oil. Subsequently, the mesocarp is the pulp surrounding the kernel and constitutes from 46 to 50% of palm oil [5]. For the rest of this paper, the palm kernel oil and palm oil refer to two separate types of oils. Composition of both palm kernel and palm oils are shown in Table 1. Fatty acid's name is shown in the table along with the fatty acid molecule's composition and its approximate percentage weight in the oil. Structure (x, y) refers to the number of carbon atoms, and the number of unsaturated bonds in the oil respectively. Consequently, palm oil comprises mainly palmitic and oleic acids while palm kernel oil consists mostly of lauric, oleic, and myristic acids, making palm kernel oil become a more saturated oil. Hence, the different compositions lead to distinctive products used by the food and chemical industries.

Table 1. Composition of palm and palm kernel oils [8-13]

Fatty acid	Formula	Structure (x, y)	Palm Oil (% by weight)	Palm Kernel Oil (% by weight)
Caprylic	$C_8H_{16}O_2$	(C8, 0)	0.0	2.0 to 4.7
Capric	$C_{10}H_{20}O_2$	(C10, 0)	0.0	2.8 to 7.0
Lauric	$C_{12}H_{24}O_2$	(C12, 0)	0.3 to 1.0	44.5 to 52.0
Myristic	$C_{14}H_{28}O_2$	(C14, 0)	0.8 to 6.0	13.7 to 19
Palmitic	$C_{16}H_{32}O_2$	(C16, 0)	32 to 47	6.0 to 10.1
Stearic	$C_{18}H_{36}O_2$	(C18, 0)	1 to 6	1.0 to 3.0
Oleic	$C_{18}H_{34}O_2$	(C18, 1)	39.1 to 52	10.0 to 18.1
Linoleic	$C_{18}H_{32}O_2$	(C18, 2)	2 to 11	1.0 to 2.9

Oil palm is a popular crop grown in tropical countries because it bears the greatest oil crop yield in the world as shown in Table 2. Table 2 contains the world's total production of oil in tonnes for 2010 along with the entire area harvested, and the yield, defined as the production divided by the area harvested. Consequently, the producers and mills extracted 0.3691 tonnes per hectare of palm kernel oil and 2.8276 of palm oil. Together, the producers obtain 3.1967 tonnes of oil per hectare. Of course, this is the world's average because Malaysia achieved yields between 3.88 and 5.69 tonnes per hectare. Rapeseed becomes the next highest yielding oil crop with 0.7198 tonnes per hectare. Rapeseed oil contains high levels of erucic acid that is toxic to humans [15]. Nevertheless, many farmers grow a genetically modified cousin, Canola containing low levels of erucic acid that many people use as popular cooking oil. Moreover, producers grow coconut trees in Malaysia, but coconuts yield low levels of oil, approximately 0.3505 tonnes per hectare. Finally, maize yields the lowest oil, even though it is the most widely grown.

Table 2. World Oil Production in 2010 [14]

Crop	Production (tonnes / year)	Area Harvested (hectares / year)	Yield (tonnes / hectare / year)
Coconut (copra) oil	3,987,563	11,376,698	0.3505
Maize oil	2,321,544	161,765,388	0.0144
Palm kernel oil	5,688,559	15,410,262	0.3691
Palm oil	43,573,470	15,410,262	2.8276
Rapeseed oil	22,774,074	31,640,756	0.7198
Safflower oil	131,959	772,705	0.1708
Soybean oil	39,840,137	102,556,310	0.3885
Sunflower oil	12,698,807	23,113,785	0.5494

Table 1 does not depict the full story. All the oils produce meal or cake that is the leftover residue after the mills had extracted the oil from the seeds. Meal contains high levels of protein that producers can mix with animal feeds. Consequently, the meal is a valuable byproduct of oil production. Furthermore, maize contains high levels of starch that producers use in a variety of products, including the manufacturing of ethanol and high-fructose corn syrup. Food industry uses high-fructose corn syrup as a substitute for cane sugar in the United States.

2.2 Plantation Land Use

Plantation owners grow commercially a variety of trees in Malaysia with the key ones being cocoa, coconut, rubber, and oil palm trees. High oil yields from the oil palm trees encourage the producers and plantation owners to convert rubber, cocoa, and coconut plantations into oil palm plantations [4, 7, 16]. Between 1980 and 2010, plantation owners decreased cocoa plantations by 394,819 hectares, rubber plantations by 1,000,700 hectares, and coconut plantations by 253,100 hectares while the oil palm plantations gained 3,830,460 hectares. Figure 1 shows the dramatic rise in planted oil palms. Total hectares of established trees are on the y-axis while years are the x-axis. Plantation owners grew and maintained approximately 4,853,766 hectares of oil palms during 2010 while cocoa, coconut, and rubber are declining.

Dramatic rise of the palm oil plantations in Malaysia could lead to economic exposure. Unfortunately, commodity prices experience wide swings and fluctuations according to Figure 2. Monthly commodity prices are measured in U.S. dollars per tonne, and they fluctuated wildly between 1980 and 2012. If Malaysia wanted to hedge against these wide price swings, then it should diversify its industries and retain the cocoa, rubber, and coconut plantations. Furthermore, the decision to plant a specific tree involves a time commitment. For example, if a plantation owner believes rubber prices will remain high, subsequently, he or she plants new rubber trees. Unfortunately, the owner must wait from five to six years for a rubber tree to begin producing rubber. However, the international price of rubber soared dramatically in February 2011 to $6,190.36 per tonnes and then dropped.

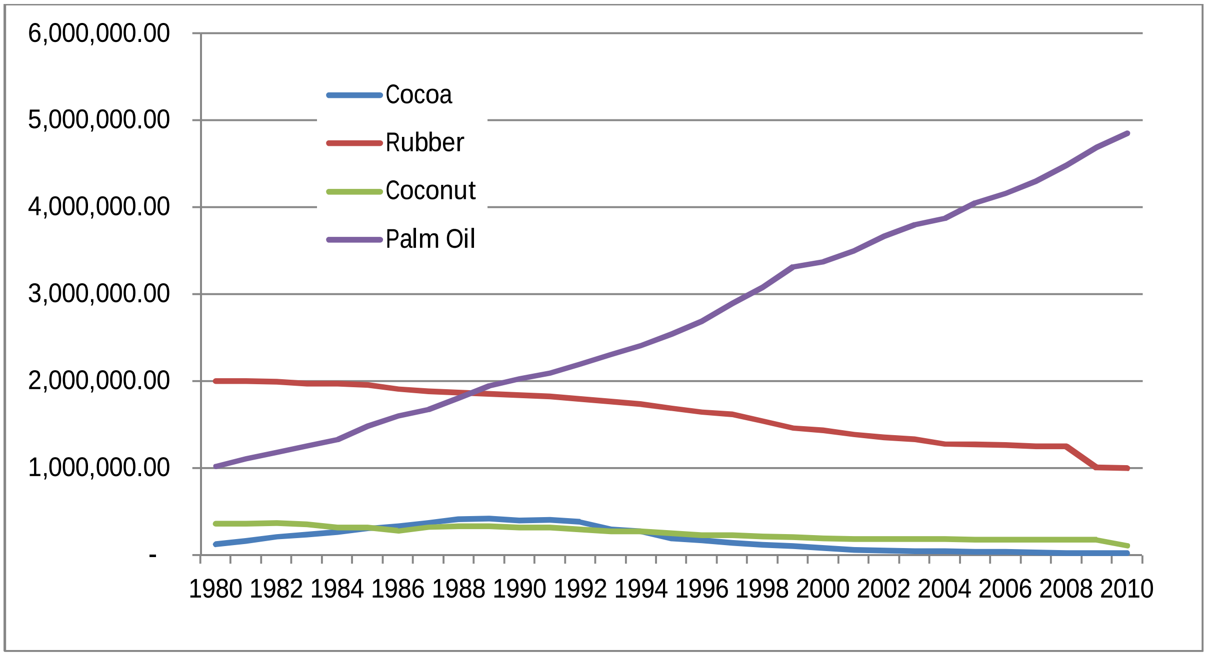

Figure 1. The total area of tree plantations in hectares for Malaysia between 1980 and 2010 [14, 17, 18]

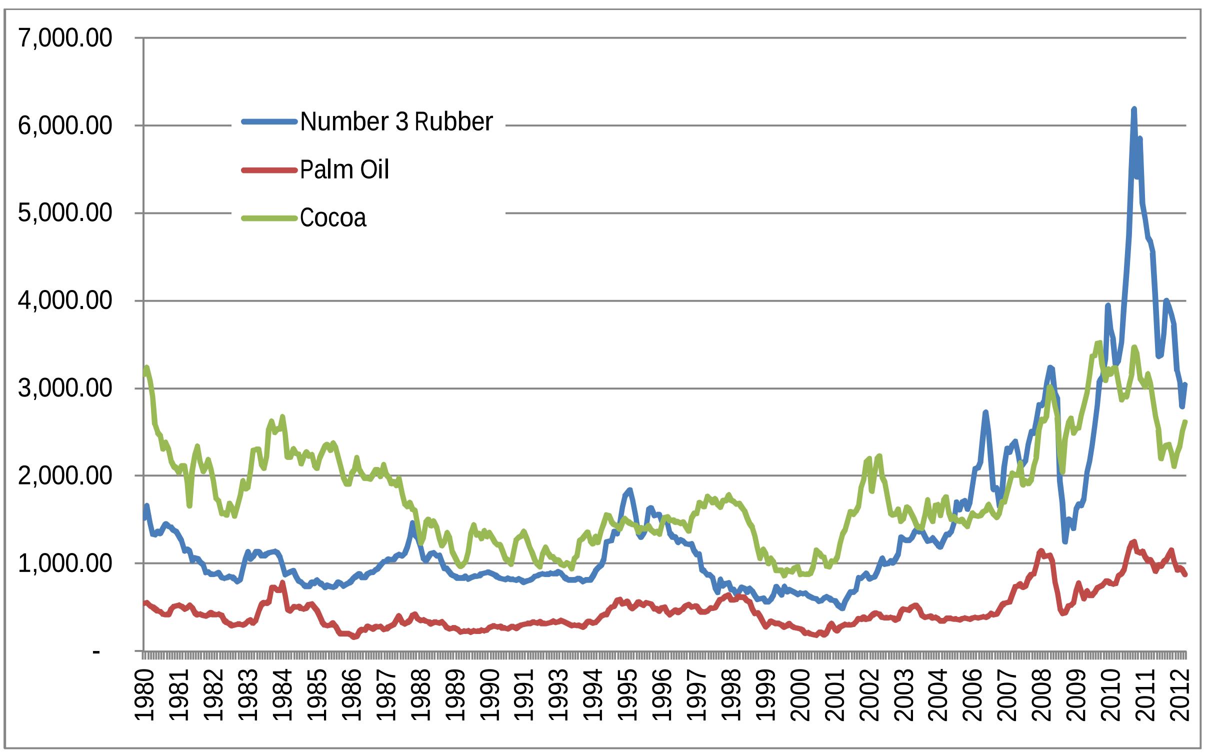

Figure 2. Monthly commodity prices in U.S. dollars per tonne between 1980 and 2010 [19]

Malaysian tree plantations themselves produce several byproducts. First, plantation owners could raise buffaloes, cattle, sheep, and goats on the plantations. Herbivores reduce weeding costs and reduce herbicide use [16]. Then the plantation owners can sell the animals to butchers for meat. Second, the large plantations and estates could have enough dairy cows to produce milk. Finally, everyone overlooks the bird's nest. The Chinese consumes birds' nests for medicinal teas and soups. Accordingly, some plantation owners constructed small shed-like structures on the plantations to attract the birds. Subsequently, the owners harvest and sell the birds' nests.

Environmentalists are concerned about converting pristine rain forests into palm oil plantations, especially in Borneo. Consequently, Malaysia loses biodiversity while some species become endangered such as the orangutans. Furthermore, the pristine rain forests accumulate and store large amounts of carbon in the soils as peat soils. When the landowners switch the land from undisturbed forests to oil palm tree plantations, the conversion releases some of this stored carbon into the atmosphere, leading to greater greenhouse-gas emissions [20]. When producers remove the natural forests, they compact the peat soil before planting the oil palm trees, preventing their heavy machines from sinking into the soil [20]. Carbon loss is greatest in the beginning and gradually declines over time [20].

Carbon in the peat soil is lost in three ways. First, as rainwater trickles through the soil, it dissolves and leeches the carbon from the soil [20]. Second, microorganisms break down the peat in the soil, forming carbon dioxide [20]. Finally, the tree roots penetrate into the peat, and they release carbon dioxide via root respiration as the plant consumes energy and builds structures [20].

Oil palm plantation contributes to the release of greenhouse gases: carbon dioxide, methane, and nitrous oxide. Carbon release and sink of greenhouse gases varies by soil type, drainage, age of the palm trees, and fertilizer application. Thus, greenhouse-gas emissions by converting land type from peat-forests to palm tree plantations are highly variable [20]. Subsequently, the ruminant herbivores create methane gases from enteric fermentation while their decomposing manure emits methane and nitrous oxide, even though plantation owners can use manure as a fertilizer, boosting palm tree yields [16].

2.3 Palm Oil Uses and Products

Malaysia possesses the manufacturing industries to process and refine the palm oil and palm kernel oil into a variety of products as shown in Table 3. Palm oil contains carotenes, tocopherols and tocotrienols. Carotenes are precursors to Vitamin A while tocopherols and tocotrienols are forms of Vitamin E [7, 12, 21, 22]. Carotenes give crude palm oil a reddish-orange hue. Moreover, the refining process removes the carotenes, creating palm fatty acid distillates as a byproduct. Palm industry can recover the carotenes from the acid distillates, and they could market and sell them as health-food supplements. Currently, the refiners sell the acid distillates for animal feeds and oleochemicals. Chemical industry uses oleochemicals in cosmetics, emulsifiers, fatty acids, lubricants, paints, pesticides, plastics, soap, and solvents [15].

Table 3. Palm Oil and Palm Kernel Oil Products [7, 21, 23-27]

Oil Product	Products
Palm oil	
Cooking oils	Margarine, reduced fat spread, shortening, and vanaspati
Fried foods	Doughnuts, French fries, potato chips, and nuts
Non-fried foods	Baked goods, nondairy creamers for coffee, tea, and cocoa mixes, condensed milk, dry and canned soup mixes, ice cream, instant noodles, mayonnaise, and salad dressings
Other	Soap noodles
Palm stearin	Shortening, margarines, vanaspati, and pastry and bakery products
Palm olein	Margarine and cooking oil
Palm Fatty Acid Distillate	Animal feed, soap, oleochemicals, and Vitamin E
Palm kernel oil	Cocoa butter substitute, confectionery products, detergents, ice cream, margarine, oleochemicals, and soap noodles
Palm kernel stearin	Cocoa butter substitute, confectionery products, nondairy coffee creamers, filled milk, and non-hydrogenated trans-fat free margarine
Palm kernel olein	Ice cream and soap noodles
Palm kernel cake	Cattle, catfish, poultry, and swine feeds

Food industry has three uses for refined palm oil. First, the industry uses the oil to fry doughnuts, French fries, nuts, potato chips, and instant noodles. Second, they use the palm oil as a fat substitute in nondairy creamers for coffee, tea, and cocoa mixes, condensed milk, dry and canned soup mixes, ice cream, instant noodles, mayonnaise, and salad dressings. Finally, Malaysia refines the palm oil into stearin and olein. Stearin is a saturated fat at room temperature while olein is 50/50 of unsaturated and saturated fat and is a liquid at room temperature.

Range of products is shown in Table 3, and the list is not exhaustive. Several products are listed multiple times in the table. For example, producers manufacture soap noodles comprising 80% palm oil and 20% palm kernel oil [25]. Soap noodles are a raw material for producing soap and are fatty acids that reacted chemically with sodium salts. For another example, the food industry uses combinations of the fats to produce margarine. Different combinations of palm oils give margarine distinctive characteristics.

Food industry almost exclusively uses palm olein to create margarine or fry foods. Palm olein comprises from 65 to 78% of palm oil [21]. Olein possesses a high thermal and oxidative stability, making palm olein a popular frying oil [7, 10, 28].

Food industry uses combinations of palm oil and palm oil stearin to make shortenings, margarine, and vanaspati. Vanaspati is a vegetable ghee that replaces clarified butter in fried foods in India and Pakistan. Furthermore, the producers use stearin to make bakery, pastry, and confectionery products because saturated fats have a long self-life [7, 27]. Finally, other uses include nondairy creamers for coffee, tea, and cocoa, ice cream, whipping cream, mayonnaise, and salad dressings [7, 27].

Palm kernel oil yields distinctive products as compared to palm oil. A crushing plant extracts the palm kernel oil from the palm kernel, creating palm kernel cake as a byproduct. Subsequently, the palm industry presses the cake into expeller pellets that contain high levels of protein. Then feed producers can mix the pellets into cattle, catfish, poultry, and swine feeds [26]. Furthermore, the crushing plant can refine the palm kernel oil into olein and stearin. Similar to the palm oil, the palm kernel oil has a variety of uses as shown in Table 3.

Palm kernel stearin has two applications. First, the stearin could replace the harmful trans fats used in margarine, shortenings, and vanaspati because palm kernel stearin is a natural, highly saturated fat that is not hydrogenated. Unfortunately, the food industry uses hydrogenated palm oil in a variety of products that it could switch safely to palm kernel stearin. Second, the chocolate industry could substitute palm kernel stearin for the expensive cocoa butter. Malaysia exports chocolate products, and palm kernel stearin would give the chocolate export industry a cost advantage. Palm kernel stearin gives the chocolate excellent melting properties and is oxidative stable [27].

Malaysia uses export-oriented growth to boost its economic growth rate, accumulate foreign currency earnings, and create jobs for its citizens, which is a similar strategy many Asian countries, such as China, Hong Kong, South Korea, Singapore, and Taiwan are using. Accordingly, Malaysia exports palm oil, palm kernel oil, palm kernel cake, palm olein, palm stearin, oleochemicals, and processed foods.

Monthly export commodity prices are shown in Figure 3 with units in U.S. dollars per tonne. Once the industry manufactures a product, individual demand and supply conditions determine the market's export price. For instance, the price of crude palm oil sometimes exceeds the export price of palm olein, even though olein entails more processing. Nevertheless, Figure 3 has four distinct patterns. First, palm stearin always has the lowest price against palm olein, crude palm oil, and palm kernel oil. Second, the export price for palm kernel oil usually exceeds the price of crude palm oil and palm olein. Although not shown, palm kernel stearin yields the highest price. Third, the palm kernel, expeller pellets earn the lowest price. Finally, some researchers claim the palm oil industry is recession proof. However, the commodity prices drop prominently in 2008 and 2009 after the 2007 Great Recession reverberated across the world.

2.4 Oil Palm Plantation Waste Products

Palm oil industry creates waste products that potentially harms the environment and emits greenhouse gases into the atmosphere. For instance, the mills accumulate empty fruit bunches, fiber, and shells. Mesocarp creates the fiber while the kernel remains produce the shells. Currently, the mills use the empty fruit bunches as mulch for the trees. Nevertheless, researchers believe the refiners could use palm oil wastes as a renewable fuel [7].

All the mills in Malaysia burn the fiber and shells to produce steam and bioelectricity that offset the mill’s demand for electricity and diesel fuel used as boiler fuel [3, 5, 7]. For instance, a mill needs approximately 15 to 20 kilowatt-hours of electricity to process one tonne of fresh fruit bunches [3, 5]. Furthermore, the Malaysian industries could burn palm oil wastes to generate electricity on a large scale. Mills could produce 7,483 kilowatt-hours of electricity per hectare, which is calculated in Table 4. If all mills burned their wastes, subsequently, they could generate 4.1 gigawatts of power with 4.9 million hectares of mature oil palm trees. The 4.1 gigawatts of power depend on an electricity-heat conversion efficiency of 35%, and the plant uses the residue heat to dry the wastes before they are burned. Although the wastes would be bulky to transport, especially compared to coal, one viable option is the local electric power plants co-fire the palm oil wastes with coal to reduce its greenhouse-gas emissions. Thus, the mills would transport their palm oil plantation wastes to their nearest electric power plant.

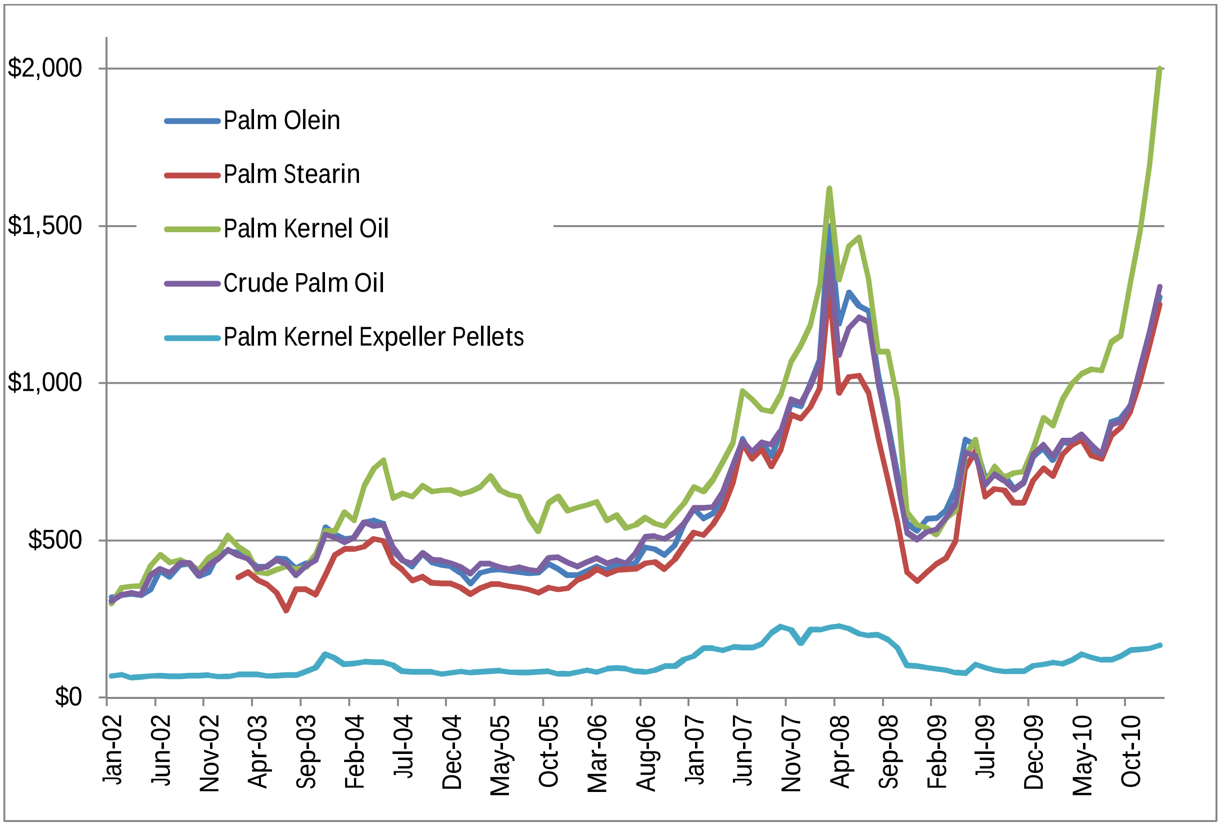

Figure 3. Monthly palm oil export prices in U.S. dollars per tonne between 2002 and 2011 [29]

Table 4. Potential Electricity Generation from Palm Oil Waste Products [5]

	Weight (dry) from Mature Trees (tonnes / hectare / year)	Moisture content (%)	Heat Value (dry) (kcal per tonne)	Potential Electricity (kwh / hectare)
Empty fruit bunch	1.55	65	3,700,000	2,334.43
Fiber	1.63	42	4,420,000	2,932.63
Shell	1.10	7	4,950,000	2,216.39
Total				7,483.45

Palm oil mills use water in processing and refining the palm oil products, which the mills discharge as an effluent – a viscous brownish sludge containing high levels of organic matter, oils, and grease. Palm oil mills discharged approximately 66.8 million tonnes of effluent in 2005 [4]. Furthermore, the sludge possesses high values for chemical oxygen demand (COD) and biochemical oxygen demand (BOD) [4].

If the mill discharged the effluent into lakes, streams, and rivers, then the microorganisms would break down the organic matter, consuming the oxygen in the water and killing the fish and water life [4].

Mills and producers could convert the palm oil mill effluent into fertilizer [4, 7]. They would collect the effluent and sludge into ponds and allow the water to evaporate. Then earthworms digest the organic solids, creating vermicompost. Next, the mills and producers could fertilize the palm oil trees or sell the vermicompost as a nutrient rich, natural fertilizer that people could add to soils [4].

Palm oil mill effluent is biologically hot. Some researchers recommend the mills collect the sludge into ponds with covered roofs. As anaerobic microorganisms break down the sludge, they create biogas. Subsequently, the mills could collect and burn the biogas as an energy source [4, 5, 7]. Unfortunately, biogas comprises mostly methane gas, a greenhouse gas. If the mills allow the methane gas to escape into the atmosphere, then they worsen the efficiency for the industry to recycle greenhouse gases. Nevertheless, the mills could flare the methane gas converting it to carbon dioxide. Consequently, one tonne of methane combusts into 2.7 tonnes of carbon dioxide. The 100-year global warming potential of methane is 16, which producers can reduce to one for carbon dioxide by flaring the methane.

Researchers proposed other uses for palm oil wastes. Dried sludge and palm oil kernel meal contain sugars, starch, and hemicellulose [30]. Then a mill could convert the starches and hemicellulose into sugars that microorganism can convert into fuel. Producers could use the *Clostridium acetobutylicum* bacteria to ferment the sugars into butanol [30], or use lignocellulosic fermentation to convert the sugars into ethanol. Some researchers prefer butanol to ethanol because butanol has a low vapor pressure and mixes with water [30]. Nevertheless, butanol production currently has low yields.

3. Palm Oil Biodiesel

The paper switches its focus to the issues and potential of substituting palm oil biodiesel for diesel fuel. Unfortunately, biodiesel does not substitute diesel fuel perfectly. Consequently, the biodiesel fuel properties are examined. Then Malaysia’s manufacturing, consumption, and export of biodiesel are studied, and problems Malaysia could experience in producing biodiesel on a large scale. Finally, Malaysia has access to two low-cost oil sources: tallow and yellow grease that could make biodiesel feasible in Malaysia.

3.1 Substituting Biodiesel for Diesel Fuel

Converting crude palm oil into biodiesel is a well-established process. Transesterification reaction breaks down the triglycerides in the oil into esters using an alcohol and a catalyst. Producers usually use methanol and an alkaline catalyst, such as sodium hydroxide, minimizing the processing costs. Consequently, one tonne of crude palm oil with a free fatty acid content of 3.2% yields 950 kilograms of palm methyl ester, otherwise known as biodiesel. Chemical reaction converts 95% of the oil by weight into biodiesel and produces roughly 130 kilograms of crude glycerol [11]. Chemical reaction in liters is 1,000 liters of palm oil yields approximately 967.4 liters of biodiesel. Furthermore, the refinery could purify and refine the glycerol into pharmaceutical grade that the chemical industry uses in a variety of products. Refined glycerol could play a critical role if a biodiesel refinery converts waste cooking oil into biodiesel, which is discussed in Section 3.2.

Pure vegetable oil cannot be combusted directly in diesel engines because the oil is denser and more viscous than diesel fuel. Vegetable oil does not entirely combust in the engine, fouling the fuel injectors, leading to a buildup of carbon along the piston’s walls, and causing the piston's rings to stick [8, 9, 13, 22]. Although engineers could redesign the diesel engine to run on pure vegetable oil, the biodiesel methyl esters can be blended with diesel fuel in any percentage up to 100% biodiesel. Hence, biodiesel does not require any modification to the diesel engine [11, 12]. Moreover, engines operating on biodiesel do not show any abnormal wear and tear on engine components [3, 11]. As shown in Table 5, the methyl esters from palm oil, palm kernel oil, and waste cooking oil have similar densities to diesel fuel.

Table 5. Fuel Characteristics of Biodiesel and Diesel Fuel [8, 9, 11, 13, 28, 31-35]

Fuel Type	Density (kg / l)	Kinematic Viscosity (nm^2 / s)	Gross Heating Value (MJ / kg)	Cetane Number	Cloud Point (^{0}C)
Diesel	0.82 to 0.86	2.0 to 4.5	44.8 to 45.8	40 to 52.0	-15.0 to 5.0
Biodiesel					
Palm Oil Methyl Ester	0.87 to 0.91	4.5 to 6.2	40.1	56.8 to 62.4	9.4 to 13.0
Palm Kernel Oil Methyl Ester	0.878 to 0.898	4.1 to 4.9	38.7	58.4	10.0
Waste-cooking palm oil methyl	0.875 to 0.886	4.40	37.4	60.4	13.0
Vegetable Oils					
Palm Oil	0.903 to 0.918	39.6	-	42.0	31.0
Palm Kernel Oil	0.897 to 0.908	28.7 to 35.5	44.4	-	24.0

Energy content becomes the most notable characteristic of fuel. Biodiesel contains less energy than diesel fuel. Gross heating value for palm oil biodiesel is 40.1 megajoules per kilogram while diesel fuel contains between 44.8 and 45.8 MJ/kg of energy according to Table 5. Unfortunately, palm biodiesel contains roughly up to 12% less energy than diesel. In testing biofuels in diesel engines, researchers observed a 5% drop in power, but a 10% increase in fuel consumption [35].

Kinematic viscosity becomes the second most valuable fuel property. Viscosity is the resistance to a liquid's flow. A highly viscous fuel fouls the fuel injectors and the fuel poorly vaporizes, leading to carbon and deposit build up within the engine [13, 34]. As Table 5 shows, the biodiesel made from palm oil, palm kernel oil, and yellow grease are slightly more viscous than diesel fuel. However, the greater viscosity may lubricate the engine better, and refineries could reduce the sulfur content in diesel fuels. Finally, pure palm oil and palm kernel oil are much more viscous, which would cause problems in modern diesel engines, unless engineers redesign them to handle more viscous fuels.

A fuel's cold properties are another salient characteristic of fuel. Cloud point reflects the minimum temperature when ice crystals form in the fuel filter, thus, hindering the flow of fuel into the engine while the pour point measures the temperature when fuel congeals inside the fuel tank [13]. Unfortunately, the cloud point is approximately 10 ^{0}C for palm and palm kernel biodiesel, which exceeds diesel fuel. Although the pour point is not listed in Table 5, the cloud point exceeds the pour point. Consequently, Malaysia would experience no problems using biodiesel in its tropical climate. However, Malaysia wants to sell its palm biodiesel to Europe and United States, where temperatures could drop below freezing during the winter.

Palm biodiesel has four advantages over diesel. First, biodiesel contains trace amounts of sulfur. Hence, tailpipe emissions would emit less sulfur dioxide [3, 11, 13, 28, 36]. Second, biodiesel contains from 10 to 12% oxygen by weight while diesel contains nil oxygen. Oxygen causes cleaner tailpipe emissions with reductions in black smoke, soot, particulate matter, and carbon monoxide [3, 8, 9, 11, 12, 13, 15, 22, 35, 36, 37]. Third, biodiesel made from saturated fats have a comparable Cetane number. Cetane number measures a piston's compression pressure that ignites the air-fuel mixture in the cylinder. Cetane number is necessary because a diesel engine has no spark plugs to ignite the fuel-air mixture. A fuel with a high Cetane number ensures a driver can easily start a diesel engine [12]. Finally, palm oil biodiesel has a much higher flash point than diesel fuel. Flash point is the lowest temperature when a fuel's vapors become flammable. Flash point for palm biodiesel ranges around 164-174 ^{0}C while diesel ranges between 60 and 98 ^{0}C, making biodiesel much safer than diesel for storage [9, 11, 13, 28, 34].

Palm biodiesel has one advantage over biodiesel fuels made from unsaturated vegetable oils, such as soybean, corn, and rapeseed oils. Palm oil, especially palm stearin is highly saturated and is chemically stable. Biodiesel made from saturated fats possess low iodine numbers, and are chemically stable [12]. For instance, diesel usually has an iodine number less than 10, while biodiesel made from waste-cooking palm oil equals 62 [35]. On the other hand, soybean biodiesel averaged 133 that exceeds the acceptable limit [9], while canola biodiesel is 107 [35]. Thus, palm biodiesel would not break down in storage tanks or form deposits, gums, and sediments in the fuel system.

Biodiesel has one potential disadvantage. Biodiesel could boost NOx tailpipe emissions. Nevertheless, NOx emissions vary greatly. Some researchers claimed reductions in NOx emissions [3, 11, 12, 36, 37] while others claim biodiesel made from saturated oil and fats have comparable levels of NOx emissions [3, 8]. Finally, other researchers reported higher NOx emissions [8, 9, 12, 13, 15, 35, 36, 37]. Nevertheless, technicians can adjust the ignition timing or add fuel additives to reduce NOx emissions [13, 36].

3.2 Palm Oil Biodiesel Production and Use

Malaysian palm oil industry produces a spectrum of products. Malaysian palm oil industry would probably never use palm kernel oil nor its olein and stearin for biodiesel because these commodities cost more than palm oil. Furthermore, palm stearin is the cheapest source for biodiesel, and Malaysians would not have to worry about its cold fuel properties in a tropical country. Nevertheless, Malaysia could have a problem selling palm biodiesel to Europe and the United States, where winter temperatures dip below freezing.

Malaysian government had passed the law, Malaysian Biofuel Industry Act, in 2007 to encourage the use of palm biodiesel [38]. Law requires all diesel fuel used in the transportation sector must contain at least 5% palm oil biodiesel per volume, or B5. Malaysia joined the ranks of the United States and Europe as it commits to reducing greenhouse-gas emissions and slowing down global warming.

Malaysian government founded its first 100,000 tonne biodiesel refinery in December 2007 that would produce 12,000 tonnes of pharmaceutical-grade glycerol [39]. By February 2011, Malaysia had 29 plants with a maximum production capacity of 3.37 million tonnes per year, but only 10 biodiesel plants produced biodiesel [40]. Industry hoped to export biodiesel to other countries, but crude palm oil prices remain high, making biodiesel uncompetitive [40].

Malaysia could use biodiesel to offset its petroleum production. For instance, it produced 11.0 billion liters of diesel fuel in 2009 while the public consumed 5.9 billion liters in the transportation sector and exported the rest [41]. If Malaysia diverted all its crude palm oil in 2009 into biodiesel, it could supply 19.8 billion liters, or 333.5% of its domestic market. Consequently, Malaysia could replace its diesel with palm oil biodiesel, and have plenty of palm oil remaining to export. Unfortunately, Malaysia would still extract petroleum, unless it found a substitute for its gasoline. Then the next question, would Malaysia give up its petroleum exports, which is a significant source of foreign-currency earnings?

Malaysia looked at the United States and Europe for a potential export market for palm oil biodiesel. However, the U.S. Environmental Protection Agency [42] had ruled palm oil biodiesel does not qualify for renewable fuel imports because one liter of biodiesel that replaces diesel fuel only would reduce lifecycle greenhouse-gas emissions by 17%. EPA requires at least a 20% reduction to qualify for renewable fuel. EPA cited the high methane emissions from uncovered effluent ponds and the carbon dioxide emissions from converting pristine rainforests into oil palm plantations. EPA's decision does not impose any trade barriers per se, but U.S. fuel distributors would not receive credit for using palm biodiesel under the national Renewable Fuel Standards. Consequently, U.S. refineries would never use palm biodiesel unless it became cheaper than diesel. Of course, this could be an elaborate form of trade protection and discrimination because the palm oil diesel would compete against the U.S. soybean industry. Moreover, the European Union imposed tariffs on palm oil biodiesel, although the EU wants its members to use more green energy. Critics claim the EU imposed a tariff because the EU leaders are protecting their rapeseed biodiesel industry. EU cited deforestation and changing land use in their decision.

Malaysia has another problem with using palm biodiesel on a large scale. Malaysian government subsidizes its petroleum fuels, giving Malaysians the cheapest transportation fuels in the world. Malaysia extracts and refines petroleum, and then exports half its petroleum products to other countries. Subsequently, the government pegs the fuel prices, setting the gasoline retail price to 2.70 ringgits per liter, or U.S. $0.885 per liter[2] and diesel fuel to 2.58 ringgits per liter, or U.S. $0.845 per liter [43]. If the world’s petroleum price rises, then the Malaysian government boosts its subsidies to maintain the fixed retail price. Unfortunately, the diesel fuel prices are cheap in Malaysia while palm oil biodiesel remains expensive. Subsidy would make it difficult for the palm oil biodiesel to compete with diesel fuel. For example, Malaysia sold palm biodiesel for $1.494 per liter in January 2011, nearly a two-fold increase in the retail price for diesel. Government would need to subsidize the palm oil biodiesel if it wanted Malaysians to use biodiesel on a large scale. Malaysian government could remove the fuel subsidies, but the subsidies are politically popular, and their removal could lead to riots and civil unrest.

[2] Used the exchange rate on November 4, 2011 that 1 Malaysian ringgit = U.S. $0.3276.

Malaysian palm oil industry would produce glycerol as a byproduct of biodiesel and could sell glycerol to help offset the biodiesel costs. Chemical companies use glycerol to make cosmetics, cough syrups, foods, haircare products, mouthwashes, paints, pharmaceutical products, shaving creams, skincare products, soap, toothpaste, and water-based lubricants [15, 44]. However, a large biodiesel industry would boost glycerol supplies, dropping the glycerol's market price.

3.3 Tallow and Yellow Grease as Low-Cost Oil Sources

An inexpensive source of oil for biodiesel is yellow grease, brown grease, and tallow. Restaurants and the food industries create both yellow and brown greases as part of their daily operations. Yellow grease is used cooking oil while brown grease is grease captured in wastewater traps, preventing the grease from flowing into the wastewater system. Free fatty acid content of brown grease exceeds 15% while yellow grease falls below [44, 45]. Finally, tallow is leftover fat from the cattle, sheep, and swine industries.

Food industries and restaurants use palm oil to deep fry food because the palm oil has no unpleasant orders and contains high nutritional content [28]. Furthermore, the oil experiences little oxidation, giving food longer shelf life [28]. Subsequently, the palm oil darkens over time, and they replace the oil at regular intervals. Used frying oil becomes oxidized and contains roughly 9.3% of free fatty acids [28].

Producers use an alkaline catalyst to convert the used oil into biodiesel because the chemical reaction is the quickest and cheapest [13, 36]. However, the producers must remove the free fatty acids because they react with the catalysts, creating soaps in the biodiesel [28, 36, 45]. Unfortunately, brown grease contains greater levels of fatty acids, water, and contaminants from cleaning agents that require more cleaning and processing [45].

Biodiesel producers can use other technologies to manufacture biodiesel. Producers can use an acid catalyst to convert the free fatty acids into biodiesel. However, the chemical reaction is slower, more expensive [13, 36], and any residual acid in the biodiesel could damage engine components [13]. Producers could use glycerolysis to convert the free fatty acids in glycerides by adding glycerol to the oil mixture. Glyerolysis converts the free fatty acids into monoglycerides. Then they use a standard alkaline catalyst to convert the monoglycerides and triglycerides into methyl esters [46]. Finally, producers could use a supercritical reactor to heat the mixture under high pressure and temperature to convert the free fatty acids into biodiesel [13, 36].

Food industry created approximately 50,000 tonnes of frying oil waste and animal fats in Malaysia [28] that could yield 45.4 million liters of biodiesel with an 80% chemical conversion. However, producers can improve the chemical yield to roughly 95% if they use glycerolysis [46].

Yellow grease and tallow are not free waste products. Chemical industries use yellow grease to make animal feeds, clothes, cosmetics, detergents, lubricants, paints, plastics, pet food, rubber, and soap [15, 47] while they use tallow for animal feeds and soap [8, 48]. Nevertheless, the prices for yellow grease and tallow would be cheaper than palm oil and palm kernel oil, even though yellow grease entails greater processing costs. For example, yellow grease sold for $590 per tonne in the United States in 2010. If the price of yellow grease were comparable in Malaysia, then the cost of yellow grease to produce biodiesel would be $0.67 per liter. Once the processing cost is added, biodiesel from yellow grease would be comparable to Malaysia's diesel retail price.

Malaysian government could encourage its industries to convert waste cooking oil and tallow into biodiesel, creating two impacts on society. First, the government raises public awareness about recycling and its commitment to reduce its carbon footprint in the world. Second, industries begin investing in infrastructure that recycles waste products. Subsequently, the industries would expand their infrastructure over time to accommodate more recycling as Malaysians demand the use of more green technologies.

4. Conclusion

Malaysia uses the palm oil industry for economic growth and development. Industry creates jobs in rural communities and reduces poverty, and the government helps settle low-income families onto oil palm plantations. Furthermore, Malaysia manufactures and processes the palm oil and palm kernel oil into a variety of products that it exports. Subsequently, the palm oil industry generates a valuable source of foreign currency earnings. Unfortunately, the price of the palm oil is relatively too high for Malaysia to use as a transportation fuel, unless the government heavily subsidizes it. Otherwise, Malaysia could use palm oil to offset its diesel fuel consumption entirely and still have palm oil leftover to export. Malaysia further complicates the matter by subsidizing its petroleum fuel. Finally, Malaysia wants to export palm biodiesel to the United States and the European Union, but they erected barriers to Malaysia's palm biodiesel.

This paper only opens the doors to research of the Malaysian palm industry. More study is needed to assess the complete lifecycle emissions of the palm oil industry, including the emissions from the palm oil mill's effluent ponds and the conversion of rainforests into oil palm plantations. Another avenue of study is to model the Malaysian forestry and agricultural industries. Model could yield more insights into the dynamics of the various industries and more importantly, could evaluate different government policies. For example, an agricultural model could answer the level of subsidies the Malaysian government would need for Malaysians to use palm oil biodiesel on a large scale in the transportation sector. Furthermore, an agricultural model could predict the impact of a carbon emissions permit system if the Malaysian government required its industries to buy permits to emit greenhouse gases.

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