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NO. 4, 2012

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Contemporary land-use transitions: The global oil palm expansion

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Cover photo: Deforestation of peat forest in Miri Division in Northern Sarawak, Malaysia (December 2009). See where this picture was taken: http://loc.alize.us/#/flickr:4171421914 Source:

Contemporary land-use transitions: The global oil palm expansion

Rico Kongsager & Anette Reenberg

GLP Report No. 4

Contents

1 Introduction

Land is a key parameter in Global Environmental Change. The land change science community has for decades focused on the accelerating pressure on the Earth's limited land resources (e.g. Lambin & Geist, 2006) resulting from contemporary trends in, e.g. globalization, economic wealth, climate change and population increase. Major research efforts have been invested in scrutinizing the proximate and underlying driving forces of land use and land cover changes at local to global scales. Tilman et al. (2001) reported that rapid and widespread agricultural expansion will pose a serious threat to natural ecosystems worldwide over the next 50 years. In addition, Turner et al. (2007) summarized the current state of insight by noting that virtually all land has been affected in some way by human action and that much of this change is a direct consequence of land use: 40% of the Earth's land surface is used for agriculture (including improved pasture and co-adapted grassland), which accounts for almost 85% of the annual fresh water withdrawal globally. The land use changes have, for example, a major impact on the global carbon budget as well as on biological diversity, and changes in land use strategies are increasingly presented as strategic instruments to counteract climatic changes (e.g. in connection with the Reducing Emissions from Deforestation and Forest Degradation (REDD) scheme or as an argument for promotion of biofuel to replace fossil fuel).

Human land use decisions play a crucial role in driving land use (GLP, 2005), but the complexity of the coupled human-environmental land system is widely acknowledged. During the last couple of decades, a general trend has been that local factors are no longer the most significant determinants of agricultural land use decisions. The geographic scales of interaction have changed significantly in recent years. This has major implications for the ways in which we conceptualize and explore the dynamics of global land use in order to enhance our basic understanding of people and the environment they inhabit. To understand these emerging complexities, the notion of land teleconnections has been used to describe the situation in which demands in distant places significantly influence local land uses at the place of production (Haberl et al., 2009; Seto et al., 2010).

Palm oil production is a prominent example of one of the few global land uses that have accelerated in importance as opposed to the majority of major agricultural crops, which have remained remarkably constant with regard to production acreage. It is also one of the land uses characterized by teleconnections. Widespread global demands impact on a limited number of local places. During the past few decades, the oil palm has become one of the most rapidly expanding equatorial crops in the world; oil palms are now grown in 43 countries and their total cultivated area accounts for nearly one-tenth of the world's permanent cropland (Koh & Wilcove, 2008). This impressive and rapid land use alteration caused by palm oil cultivation has been fuelled by the growing demand for vegetable oil on the global market, driven by population growth as well as the general improvement in economic wealth and consumption. The use of palm oil as a biofuel feedstock is still limited, but that may change in the future since palm oil has higher energy efficiency than the current major biofuel crops (soybean and sugarcane). Moreover, the liquid biofuel market is one of the fastest growing markets for agricultural products globally (Gibbs et al., 2008).

Oil palm expansion can, however, contribute to deforestation, peat degradation, biodiversity loss, and forest fires and have a range of social implications (Sheil et al., 2009). Hence, oil palm agriculture deserves special attention. Over the past few decades plantations have directly and indirectly caused deforestation (Geist & Lambin, 2001), and oil palm plantations have become a major driver of deforestation in the tropics (Butler et al., 2009; Fitzherbert et al., 2008; Koh & Wilcove, 2009; Koh & Wilcove, 2008). In Malaysia and Indonesia more than half of the oil palm expansion since 1990 has taken place at the expense of forests (Koh & Wilcove, 2008).

The present report aims at providing an overview of the magnitude and geographical distribution of oil palm cultivation. It also considers recent trends in the palm oil market and the future prospects for palm oil. By way of background, we briefly summarize the agroecological characteristics of oil palms. The main aim of the paper is, however, to present a quantitative overview of the extent of land transformations related to the global oil palm production.

2 Methods and data

The point of departure for our analysis is the FAO statistics database (FAOSTAT, 2011), including figures for production, acreage, yield, import, and export. Mainly figures on processed palm oil are used and other vegetable oils including palm kernel oil are used for comparison. A 49 year period from 1961 to 2009 is applied in almost all illustrations, as it is the data range FAOSTAT can provide. This timeframe also represents the acceleration period of the oil palm cultivation. The development is depicted on a global and a regional scale, as well as for key countries that dominate global production (mainly Malaysia and Indonesia). Production data are usually provided for harvest years, e.g. the year 2008/2009 refers to harvests collected in the northern hemisphere in 2008 and in the southern hemisphere in 2009. At the time of writing (November 2011), 2008/2009 is the latest year for which final figures are available. Predictions for the year 2009/2010 are also available but they are not as precise as those for 2008/2009, as the figures are subject to revision for some years after their first appearance (Gunstone, 2011).

It must be mentioned that FAO data have, in general, been criticized for inaccuracy (e.g. Casson, 2003; Ramankutty et al., 2008) and some of the data applied in the current context are labeled 'unofficial figure' or 'FAO estimate'. FAO forest area data, for example, are defective as no independent remote sensing survey was carried out to validate the data at the time they were compiled (FAO, 2006). Nevertheless, a study by Stibig et al. (2007) showed that FAO statistics for Malaysia and Indonesia correspond well to estimates of cropland and forest areas generated from a remote sensing analysis. FAO and Landsat-based estimates for Malaysia's total forest area in 2000 differed by only 46,000 ha (0.2%). Although FAO gathered these forest area data through fully referenced country reports, which underwent detailed reviews to ensure completeness and correct application of definitions and methods, the fact that these data were self-reported make them liable to potential biases (Koh & Wilcove, 2008). If countries under-report forest losses to FAO, the analysis may underestimate the extent to which forests are being cleared to grow oil palm. Another issue of importance is the fact that the total volume of palm oil production in some developing countries is unknown due to a significant amount of household-based production for self-consumption or petty trade: However, the majority of the global production is produced in large-scale plantations managed and controlled by large companies (Fold, 2008).

Given that FAOSTAT data constitute the only available source to illustrate the trends in palm oil production they are used as the main source in this report, but other data sources such as government statistics, government and NGO reports, and academic literature have been applied as frames of reference.

3 Background

The oil palm (Elaeis guineensis Jacq.) is the most important species in the genus Elaeis, which belongs to the palm family, Arecaceae (Syed et al., 1982). It originates from West Africa, where the main palm belt originally extended from Sierra Leone, Liberia, Ivory Coast, Ghana, and Cameroon to the equatorial Congo (former Zaire) (Hartley, 1988), but at present oil palm is cultivated in the majority of countries in the tropics (Figure 1). Traditionally, in West Africa, oil palm production was managed as part of a mixed farming practice but today, most production is being expanded as an industrial-scale monocrop with large uniform age structure, low canopy, sparse undergrowth, a low stability microclimate, and intensive use of fertilizers and pesticides (UNEP, 2011).

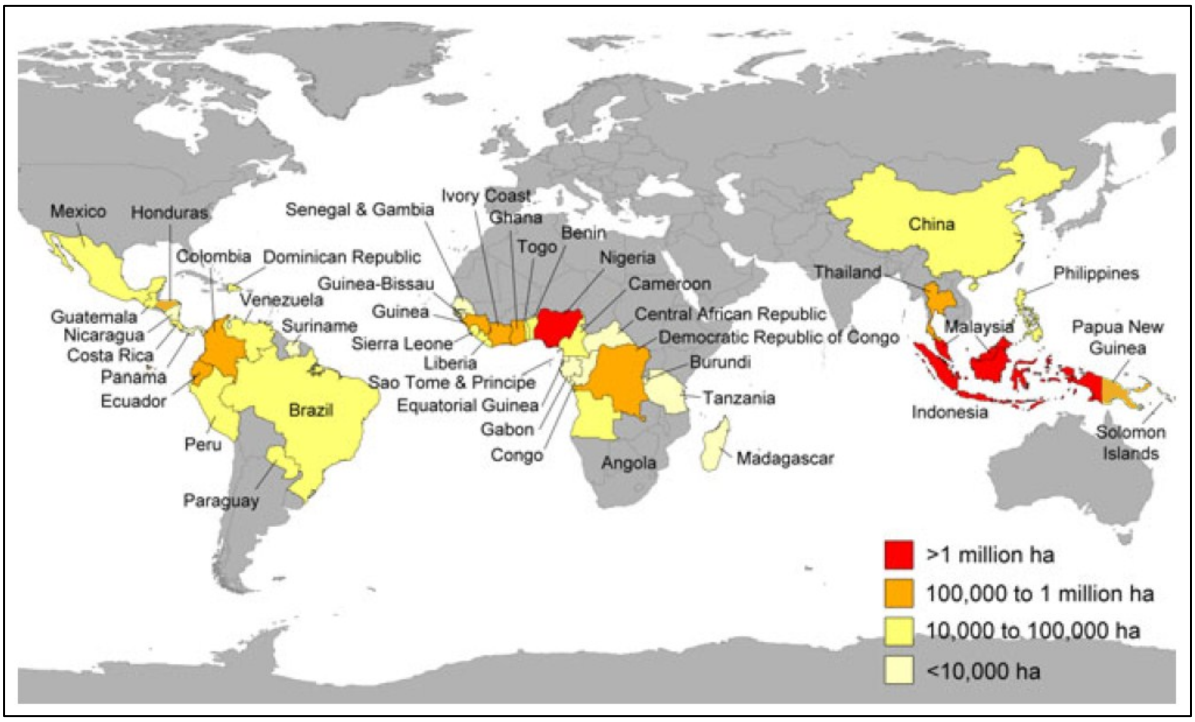

Figure 1: Map showing the extent of oil palm cultivation in the 43 oil palm-producing countries in 2009. The original map is taken from Koh & Wilcove (2008) and updated by the authors with 2009 values from FAOSTAT (2011).

Oil palm has long been used as food and medicine. The earliest archaeological evidence of this is an earthenware jar containing residues of palm oil in a 5,000-year-old Egyptian tomb (RSPO, 2011). The development of oil palm as a plantation crop began in Southeast Asia, and it has become the most important industrial crop in countries like Malaysia, Indonesia and Thailand (Shuit et al., 2009). The African oil palm was introduced to Asia in the form of four seedlings from Mauritius and Amsterdam, which were planted in the botanical gardens in Bogor (Indonesia) in 1848 (Tate, 1996).

Oil palms can grow in the tropical climate zone 16° north and south of the equator; the annual rainfall should preferably be around 2,000 mm evenly spread throughout the year. Consequently, tropical monsoon regions with distinct dry and rainy seasons are less suitable for the cultivation of oil palms. The humidity should preferably be around 80-90%, and temperatures, which affect flowering and the ripening of the fruit, must be around 30°C. Oil palms need approximately five hours of sun daily and do not grow well under closed canopies. The high leaf area ensures high primary production (Okamoto, 2000). All in all, oil palms can only be cultivated in a limited number of places such as humid tropical forest areas.

Irrigation is often too expensive, though the young trees in the nurseries are irrigated when planted. Nowadays, plantations have well-established drainage systems with small canals and streams running through the groves. If the plantation is located close to rivers the tide can be exploited by opening and closing the locks to the plantation (Bek-Nielsen, 2009, personal communication). Seasonal droughts found at higher tropical latitudes greatly reduce yields (Basiron, 2007), and irrigation is often needed in plantations more than 10° from the equator (Bek-Nielsen, 2009, personal communication).

The production process is divided into four stages. 1) In the nursery, the seedlings are raised for about 12 months prior to transplantation in the field. 2) After 24 to 30 months, the oil palm starts to yield fruit in compact fresh fruit bunches. Depending on the plant material and palm age, each palm can produce 8-15 fresh fruit bunches per year, each weighing 15-25 kg and consisting of 1,000-1,300 reddish fruits (Figure 2). The yield per tree gradually increases until peaking at approximately 20 years; hence oil palm plantations are typically destroyed and replanted at 25 to 30 year intervals, although an oil palm can produce for approximately 35 years. Harvesting involves cutting ripe bunches manually using a chisel or sickle. The collection of harvested fruits is either done manually, sometimes with a wheelbarrow, or mechanically, using a tractor-mounted grabber with trailer. Once a plantation is established there is only a minimum of work related to, except weeding. 3) To preserve the freshness and quality of the palm oil, the fresh fruit bunches are preferably sent to the mill for extraction within 24 hours of harvesting. The fresh fruit bunches are steamed under high pressure to sterilize, loosen, and soften the fruits before they are stripped from their stalks and mechanically pressed to extract the oil. No solvents are used to express the oil. 4) The extraction of oil. The fruit consists of a fibrous mesocarp layer and an endocarp with a kernel (Figure 2). Oil (triacylglycerols) can be extracted from both the fruit and the seed, crude palm oil (CPO) from the outer mesocarp, and palm-kernel oil from the endosperm. The CPO is sent to a refinery to remove impurities, colors (by bleaching), and odors (by deodorizing). The refinery also separates the solid (palm stearin) and liquid (palm olein) fractions of oil to cater to a wide range of uses (RSPO, 2011; Sheil et al., 2009; Tivy, 1990; UNEP, 2011).

Figure 2: Bunch of fresh fruit and a cut through fruit (Hai, 2002).

4 Global trends in palm oil

In the following an overview of the main statistics regarding oil palm and the other major vegetable oils is provided.

4.1 Production quantity and area harvested

Historic development

Global palm oil production has increased constantly over the last five decades, from 1.5 Mt in 1961 to 45 Mt in 2009 (Figure 3). This represents an average annual growth rate of 7.0%, which is slightly higher than other vegetable oils such as soybean oil (5.3%/year) and rapeseed oil (6.4%/year). The rapid increase in production has led to palm oil surpassing soybean oil as the world's primary vegetable oil. Figure 3 shows the relationship between global palm oil production and the other major vegetable oils over the past five decades. Palm oil now accounts for approximately 32% of the global vegetable oil production, soybean is second with 25%, and rapeseed oil third with 15%.

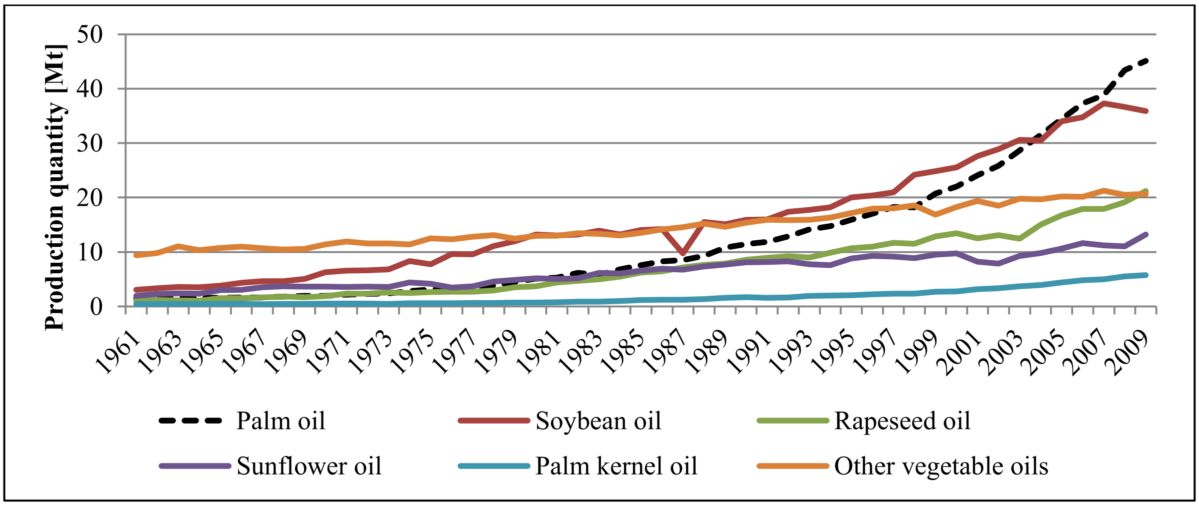

Figure 3: The production quantity [Mt] of palm oil in relation to other major oils. *Other vegetable oils* i.e. oil from groundnut, cottonseed, coconut, olive, maize, sesame, linseed, and safflower. Source: data from FAOSTAT (2011).

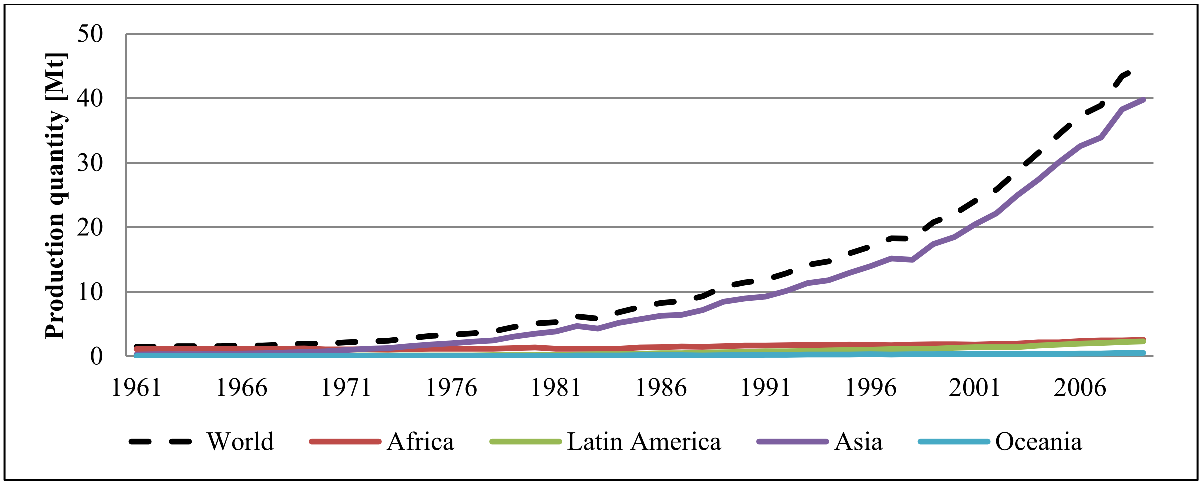

Figure 4: Production quantity [Mt] of palm oil from 1961 to 2009 for the world and the four regions producing palm oil. Source: data from FAOSTAT (2011).

In terms of geography, Asia has been the predominant region since the 1980s, and in 2009 Asia processed 88% of the world's palm oil (Figure 4). In 2007, Indonesia overhauled Malaysia and became the world's leading palm oil producer, and in 2009 these two countries produced 85% of the world's palm oil: Malaysia 39% and Indonesia 46%.

In the light of this, palm oil production in Africa, Latin America and Oceania at only 5.6%, 5.1% and 1.1% of the world's production, respectively, has no major impact on the world palm oil market at present. Nevertheless, there has been a huge increase in palm oil production in these three regions since the 1980s, with Africa and Latin America especially moving forward (Figure 5).

Most of the expansion of the world's palm oil production has been achieved by increasing the area planted with oil palm as opposed to yield improvements. The total global area planted with palm oil has expanded at an annual average growth rate of 3.0% over the last five decades and by 4.8% per year over the last two decades (Figure 6). Since 1970, global growth in oil palm production has mainly taken place in Asia (predominately in Malaysia and Indonesia). In 2005, Indonesia overtook Malaysia to become the world's leading country in terms of the area planted with oil palm, an advancement that was enabled by Indonesia's ample land and labor resources (Thoenes, 2007). In 2009 these two countries accounted for more than 60% of the area planted with oil palm globally. China, Thailand, and the Philippines are the other Asian countries that cultivate oil palms, but at a much smaller scale.

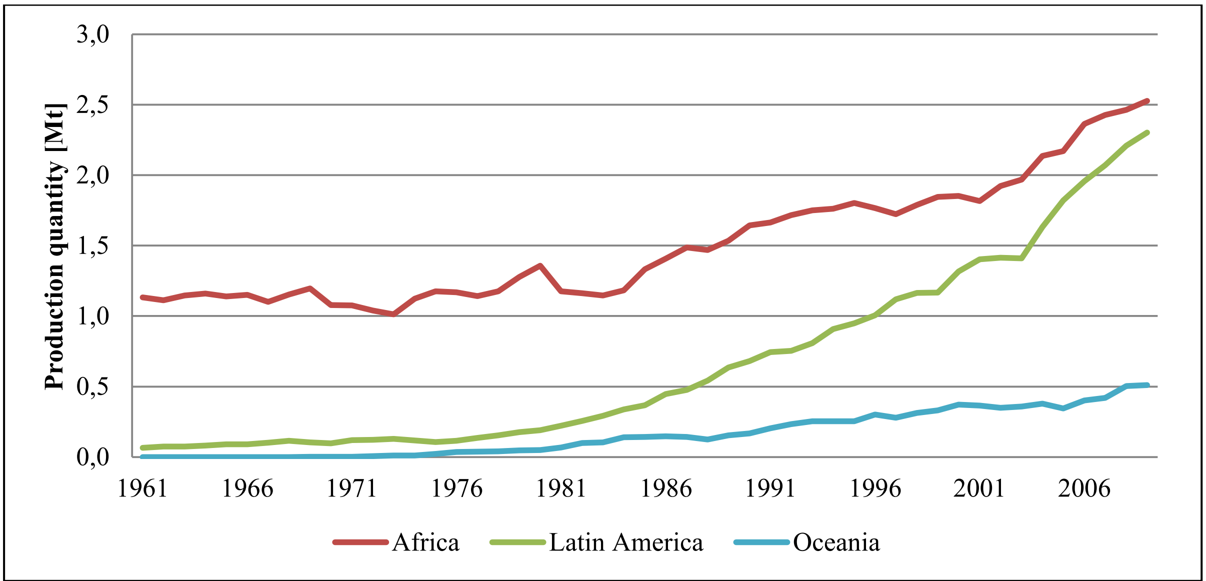

Figure 5: Production quantity [Mt] of palm oil from 1961 to 2009 specified for Africa, Latin America and Oceania. Source: data from FAOSTAT (2011).

Africa has only experienced a modest growth rate in the area harvested of 1.8% per year over the last two decades, compared to Latin America (5.5%), Oceania (5.4%), and Asia (7.2%). The main producer in Africa is Nigeria, which in 2009 accounted for 71% of the area planted with oil palms in Africa, which in turn accounted for 21% of the world area planted with oil palms. Up to the 1960s, Nigeria played the dominant role in global palm oil production. However, over time the low-yielding production was inadequate to satisfy even domestic demand, leaving nothing for export. Soon Nigeria was left in a distant third position in world palm oil production, and poor government policies and implementation strategies have resulted in a slow growth rate (Ugbah & Nwawe, 2008). Twenty-one other countries in

Africa grow oil palms, with Ghana, Guinea, the Ivory Coast, and DR Congo as the most important palm oil growers by area after Nigeria.

The area harvested in Latin America and Oceania is still very modest compared to Asia and Africa. In 2009, the fourteen countries that cultivated oil palms in Latin America represented only 4.7% of the total world area of oil palms. The largest cultivators were Colombia (24%), Ecuador (19%), Honduras (14%), Brazil (13%), and Costa Rica (8%). In Oceania only two countries cultivate oil palms: Papua New Guinea (91%) and Solomon Islands (9%). These two countries accounted for just 0.9% of the world total oil palm area in 2009.

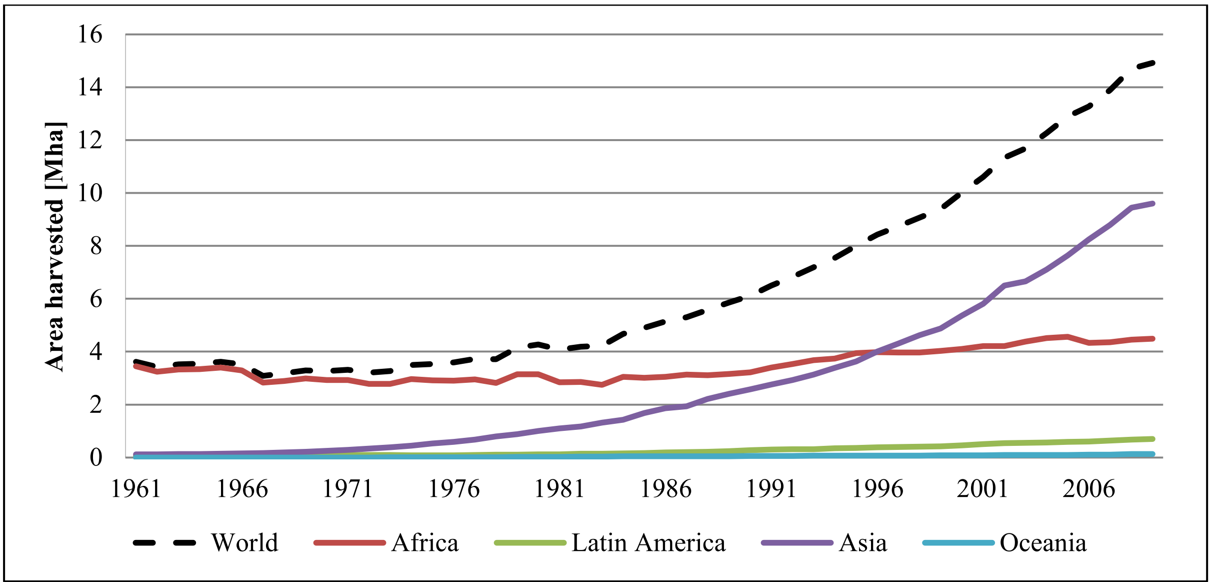

Figure 6: Area harvested [Mha] of oil palm fruit from 1961 to 2009. Source: data from FAOSTAT (2011).

Future development

The dominant position of palm oil in total vegetable oil output is expected to remain unchanged and may strengthen slightly in in future (Thoenes, 2007). At a global level, palm oil production is expected to total 47.8 Mt this year (down from 48 Mt in 2010/11). Although a significant rebound in yields as part of the biological yield cycle is expected in 2011/12, more modest growth in palm oil production is expected in future. The forecast for global palm oil production in 2011/12 stands at 52.3 Mt, rising to 55.2 Mt in 2012/13 (Global Forecasting Service, 2011). In addition, FAPRI (2011) forecasts that global palm oil production in 2025/26 will be around 70 Mt.

Concerning the future development of palm oil yields in Malaysia and Indonesia there are mixed signals, with disappointing export levels contradicting field reports of improved yields. Furthermore, it is questionable whether there is suitable space for more plantations in Malaysia and Indonesia. Lack of land has already resulted in conflicts (Fold & Hansen, 2004; Pye, 2010), and recent research from Malaysia suggests that available land for new plantings in Malaysia and Indonesia will run out more quickly than previously expected (Global Forecasting Service, 2011). The oil palm expansion in Malaysia is projected to be much smaller than in Indonesia, but at the same time, less land is available for expansion there (Wicke et al., 2011). By contrast, land and a less expensive labor force mean fewer constraints in Indonesia[1]: However, the costs of establishing new plantations are expected to rise with the gradual enforcement of legislation imposing environmentally sustainable expansion and cultivation methods (Thoenes, 2007). Nonetheless, increased environmental concerns, competition from other oils, and the difficulties leading palm oil producers face in reducing their production costs will challenge the established palm oil sector (Carter et al., 2007).

The lack of land in Asia offers the possibility of increased competition - in the long term - from emerging producers in West Africa, East Africa, and other parts of Asia, as well as South and Central America (Thoenes, 2007). Persson & Azar (2010) point out that the largest potential for oil palm expansion lies in the Amazon and Congo river basins. Consequently, a number of plantation companies have already acquired land in Africa for future development (Global Forecasting Service, 2011). In spite of this, FAPRI (2011) forecasts that 89% of the global palm oil production in 2025/26 will take place in Malaysia (37%) and Indonesia (52%).

The supplies of vegetable oils in general have grown at a rate of just over 5 Mt a year over the last 10 years. According to Gunstone (2011), demand is increasing for two major reasons: 1) demand for food to feed a global population that is increasing in numbers and wealth, and 2) demand for biodiesel as a partial replacement for fossil fuel. The population is increasing at around 80 million per year and it is estimated that a further 1.2 Mt of vegetable oils is required per year to supply these additional numbers. Furthermore, demand increases with the general increase in economic wealth, as reflected in oil consumption per capita (Figure 7). Between 2000 and 2010 total consumption per capita increased by 6.2 kg/yr (from 13.7 to 19.9); food use accounted for 3.4 kg, and non-food use for 2.8 kg. This demonstrates that although non-food use has increased considerably, food use per person has also risen at a greater rate than population (Gunstone, 2011). In 2010/11 the average person consumed 6.8 kg of palm oil per year and this figure is forecasted to rise to 8.65 kg/yr in 2025/26 (FAPRI, 2011).

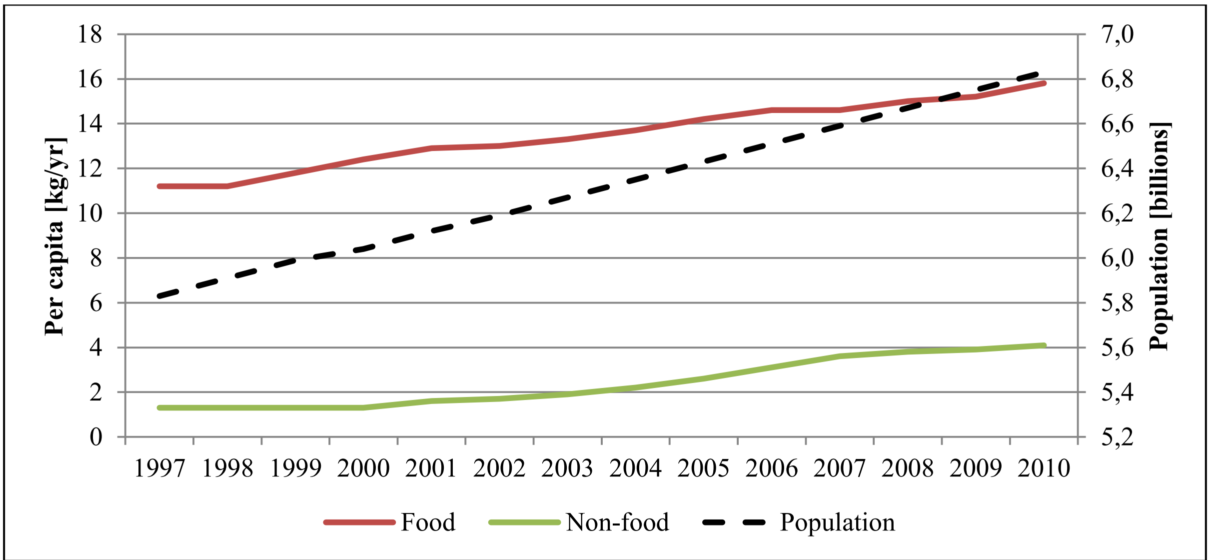

Figure 7: Population [billions] and food and non-food use of vegetable oils per person [kg/yr]. Source: data from Gunstone (2011).

[1] Most of the 500,000 plantation workers in Malaysia are now from Indonesia (Pye, 2010). In Indonesia, roughly 4.5 million people rely on palm oil estates: 900,000 people through direct employment and another 3.6 million through downstream processing, service industries, and remittances (Sandker et al., 2007).

Another estimate based on population projections and per capita consumption shows that the future demand for edible oil will be around 240 Mt in 2050 – nearly twice today's total. Most of the additional oil may be palm oil, since it has the lowest production cost of the major oils, but soybean oil production will probably also increase. The demand for palm oil in 2050 was estimated to be at least 93 Mt, and more likely between 120 and 156 Mt (Corley, 2009), compared to 45 Mt in 2009 (FAOSTAT, 2011). There are obviously significant uncertainties in these 2050 estimates, especially regarding population growth, per capita consumption, yield development for vegetable oil crops, and progress in the area of biofuels.

4.2 Trade

Exports of the nine main vegetable oils amounted to 60.45 Mt in 2010/11 and are highly dominated by palm oil at 36.41 Mt – equaling 60% of the world's export of vegetable oils (USDA, 2011a). Compared to its main competitor, soybean oil, which in 2010/11 constituted 16% of vegetable oil exports, production of global palm oil output has since 2005 matched that of soybean oil (Figure 3). Regarding trade, global shipments of palm oil surpassed those of soy oil in the mid-1970s, and palm oil exports exceeded soybean oil shipments by 3.7 times in 2010/11(USDA, 2011a). Yet, the soybean oil figure does not include export of unrefined soybeans, which in 2008/09 was equivalent to a further 13.8 Mt of soybean oil (Gunstone, 2011).

The increasing demand for vegetable oils, particularly in developing countries, is being supplied mainly by palm oil from Malaysia and Indonesia (Gunstone, 2011). In 2009, these two countries together provided 32.1 Mt, equaling 90% of exported palm oil in the world (Figure 8), and in 2010/11, they provided 91% (USDA, 2011a). The demand for palm oil is increasing and the share is anticipated to grow further, approaching 70% of world vegetable oils in the year 2015. It is forecasted that Malaysia and Indonesia will be the only countries of importance with a net export in 2025/26 (Thoenes, 2007).

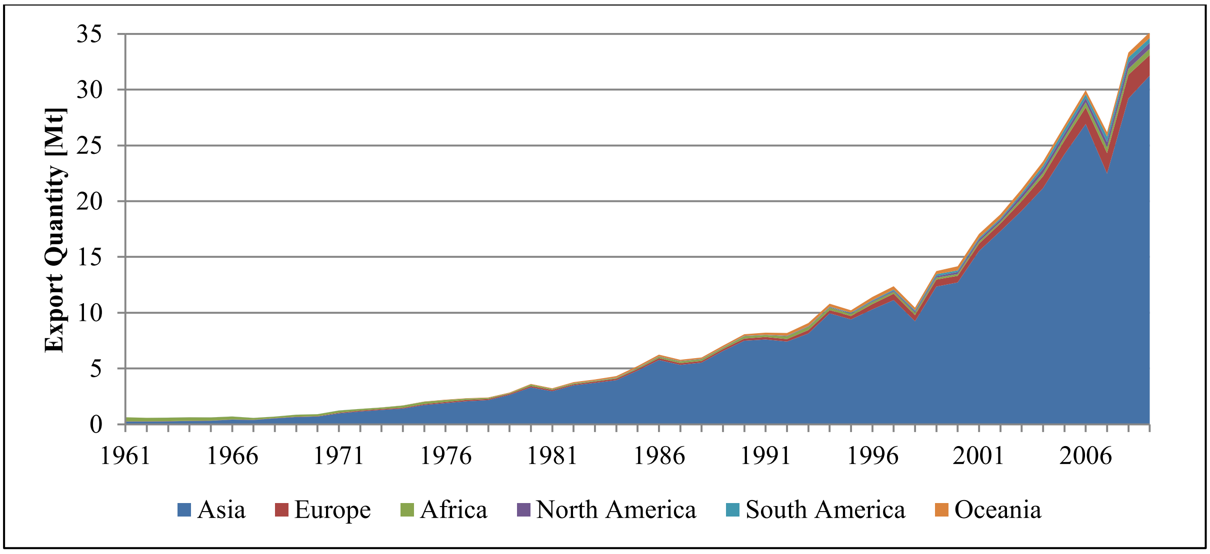

Figure 8: Export quantity [Mt] of palm oil from 1961 to 2009. Source: data from FAOSTAT (2011).

Europe was the main palm oil importer in the 1960s and until mid-1970s. Since then, the main importers have been Asian countries. However, in the last decade African countries have also started importing larger quantities (Figure 9). The drop in import/export in 2007 was mainly caused by the high price of palm oil that year (Figure 14). By 2008 it had already returned to the earlier growth rate.

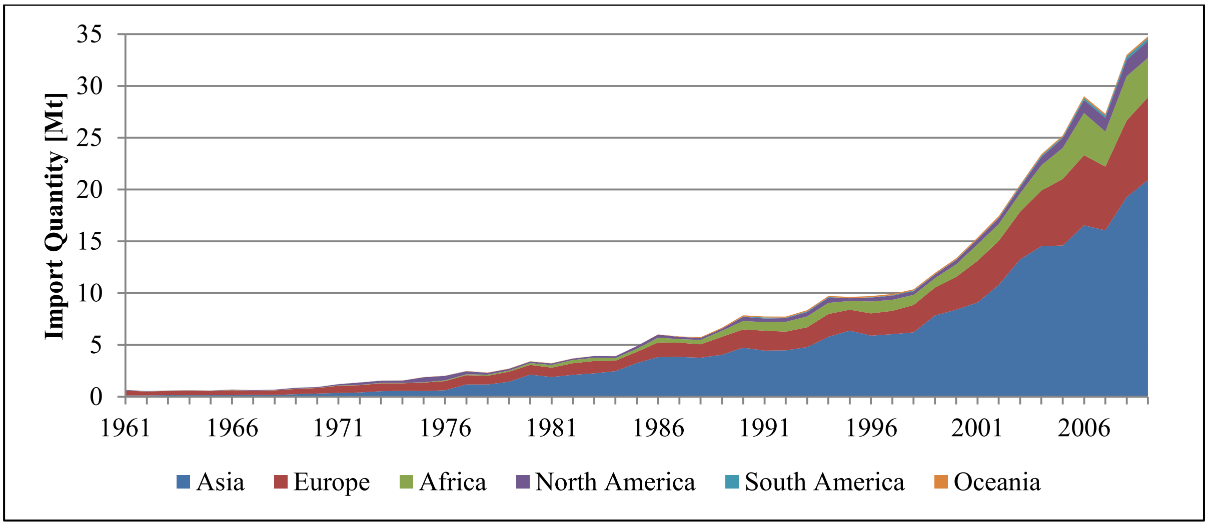

Figure 9: Import quantity [Mt] of palm oil from 1961 to 2009. Source: data from FAOSTAT (2011).

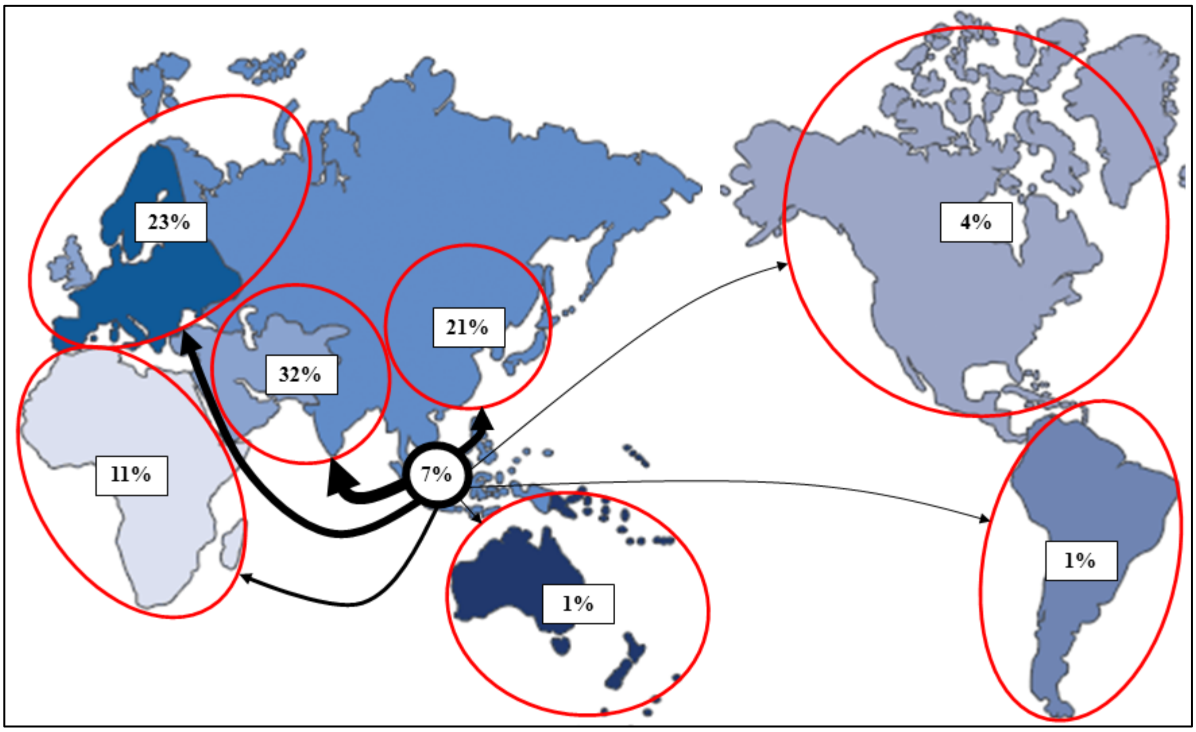

Figure 10: Export of palm oil from Malaysia and Indonesia in 2009. The thickness of the arrows indicates the size of export. The 7% in the black circle indicates internal trade between Malaysia and Indonesia. Source: data from FAOSTAT (2011).

The trade pattern from Malaysia and Indonesia in 2009 is shown in Figure 10. The global export of palm oil largely originated from these two countries. The oil was exported to virtually every country on the globe, but the main part remained in Asia, particularly China (19%), India (18%), Pakistan (5%), and Bangladesh (3%). Europe imported 23% of the export from Malaysia and Indonesia, of which Western Europe accounted for half. Africa imported 11%, which was not evenly distributed: Northern and Southern Africa imported 4% each, and Eastern, Middle, and Western Africa imported 1% each. North America imported 3% of palm oil exports and Central America 1%. Oceania and South America each imported only 1%. Internal trade between Indonesia and Malaysia amounted to 7%, which was largely exported from Indonesia to Malaysia. It is predicted that the pattern shown in Figure 10 will change only slightly in 2025/26, when China, India, and the rest of Asia are expected to increase their share of the global exports (FAPRI, 2011).

The trade figures do not reflect where the palm oil is actually consumed. Many of the palm oil products consumed in Europe and North America that contain palm oil are produced elsewhere. These very complex indirect import flows of palm oil and other vegetable oils cannot be assessed (directly) via trade statistics. In many cases, the final end use (energy, feedstock for the chemical industry, or food) is not known when the commodity is traded (Heinimo & Junginger, 2009).

4.3 Yield

The oil palm yield has increased from 1.87 to 2.97 tCPO/ha worldwide over the last five decades (Figure 11), equivalent to 1.0% per year, which must be characterized as a low growth rate. Nevertheless, oil palm yields far exceed those of other vegetable oils. Rapeseed and soybeans, which must be considered as the main competitors of palm oil, yield only around 1.5 and 0.5 t/ha, respectively (Thoenes, 2007).

Changes in yield differ between the regions (Figure 11) and countries (Figure 12 and Figure 13). Currently, Asia has the highest yields, and in 2009 the national averages in Malaysia and Indonesia reached 4.4 and 4.1 tCPO/ha (FAOSTAT, 2011), respectively. However, the yield has stagnated over the past 30 years, and Indonesia and Malaysia increased their yield by less than 1% per year in that period (FAOSTAT, 2011). The stagnated average yields in the early 2000s were possibly a result of expansion into less fertile areas, and the high proportion of immature plantations (Sheil et al., 2009).

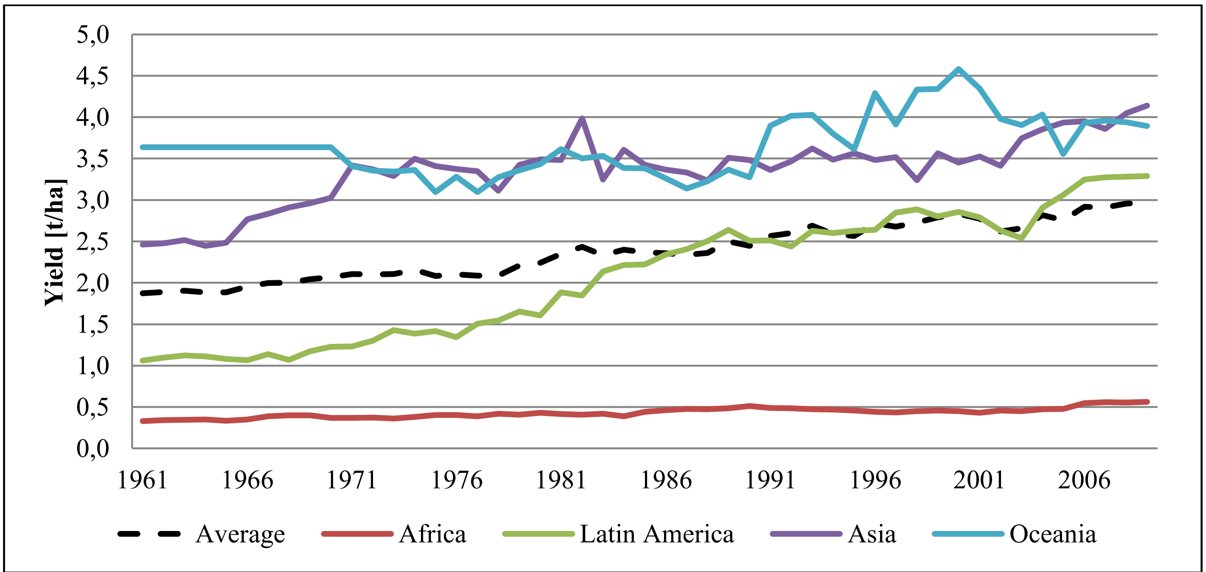

Figure 11: Yield [tCPO/ha] development for the regions from 1961 to 2009. Yield is calculated by dividing production quantity of palm oil by area harvested. Source: data from FAOSTAT (2011).

The national averages are also held back by smallholders with a low level of agricultural inputs (mainly Indonesia), a high proportion of over-mature plantations with low yields (mainly Malaysia), and inefficient management systems. However, improving the current average yield seems possible in both countries (Wicke et al., 2011); intensively managed commercial estates have achieved yields of 5-7 tCPO/ha, and even higher yields up to 10-15 tCPO/ha have been reported (Persson & Azar, 2010).

Oceania has obtained high yields over the last five decades but they have only increased their yield rate by 0.1% per year. Latin America experienced the largest increase (+2.4% per year) in the period, yet they are still almost 1 t/ha behind Asia. Africa had the same growth rate as Asia (1.1% per year) but the harvest is still approximately six times less per hectare compared to rest of the world. Gockowski & Sonwa (2011) even report a small decrease in palm oil yields from 1988 to 2007 in West Africa. This large difference between Africa and the other regions can be partially explained by the fact that statistics do not reveal the fact that there are considerable numbers of smallholder producers in Africa. These smallholders are often less well-linked to world markets and therefore their production is not registered. However, it is still beyond discussion that the developing countries have a huge yield gap compared to the more developed countries. Currently the poorest countries produce only one-sixth of what the richest countries produce per hectare, and this gap is expected to widen further in the future (Tilman, 2010).

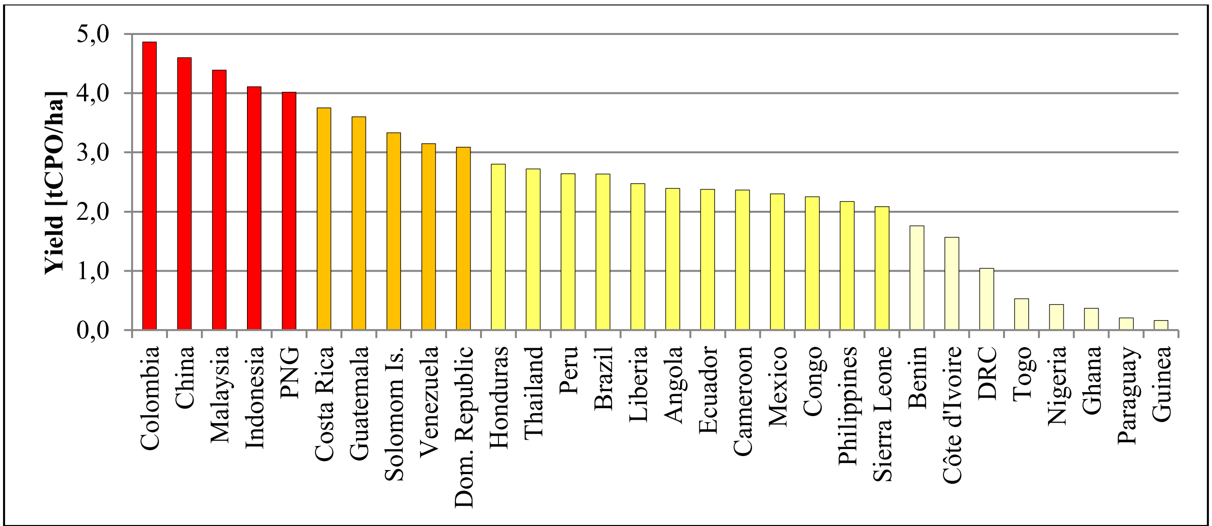

Figure 12: Yield [tCPO/ha] for the countries with more than 10,000 ha of oil palm in 2009. Yield is found by dividing production quantity of palm oil by area harvested. Source: data from FAOSTAT (2011).

According to Carter et al. (2007) the aim behind a well-managed plantation should be to produce an average yield of at least 20-25 t of fresh fruit bunches per hectare of mature oil palm and an oil extraction rate of 20-25%. This means that mature oil palms should yield between 4 and 6 tCPO/ha (plus a further 0.5 t or more of palm kernel oil when the by-product palm kernel is crushed). As Figure 11 makes clear, much of the world has not yet reached this level of efficiency in palm oil production. Improved yields for Indonesia and Malaysia are only slightly higher than the good commercial yields of 5.5 t/ha already obtained on some plantations in Malaysia (Jalani et al., 2002) and significantly lower than the best yields obtained from breeding trials of 10 t/ha and the theoretical yield of 18 t/ha (Corley & Tinker, 2003).

If yield improvements are to be realized, new strategies need to be determined and implemented. The most important strategies for increasing yields on existing plantations are to follow best management practices, including applying fertilizer and other agrochemical inputs more precisely; to practice good harvesting standards; and to transport the fruit quickly to the mill (Jalani et al., 2002). Earlier replanting with higher yielding palms is also effective. This is especially an issue in Malaysia, where the share of immature palms has decreased and the share of old palms (>25 years) has increased (Wicke et al., 2011). Planting higher yielding palms is the most important strategy for new plantations to achieve high oil yields per hectare, and therefore large companies naturally seek maximum yields by planting high-yielding varieties. But most smallholders do not have the cash to buy high-yielding seedlings or are unable to differentiate between good and bad seedlings sold by unscrupulous traders (Sheil et al., 2009). Furthermore, changing management practices could, in turn, negatively affect the environment, particularly through nitrous oxide emissions from fertilizer application (Wicke et al., 2011).

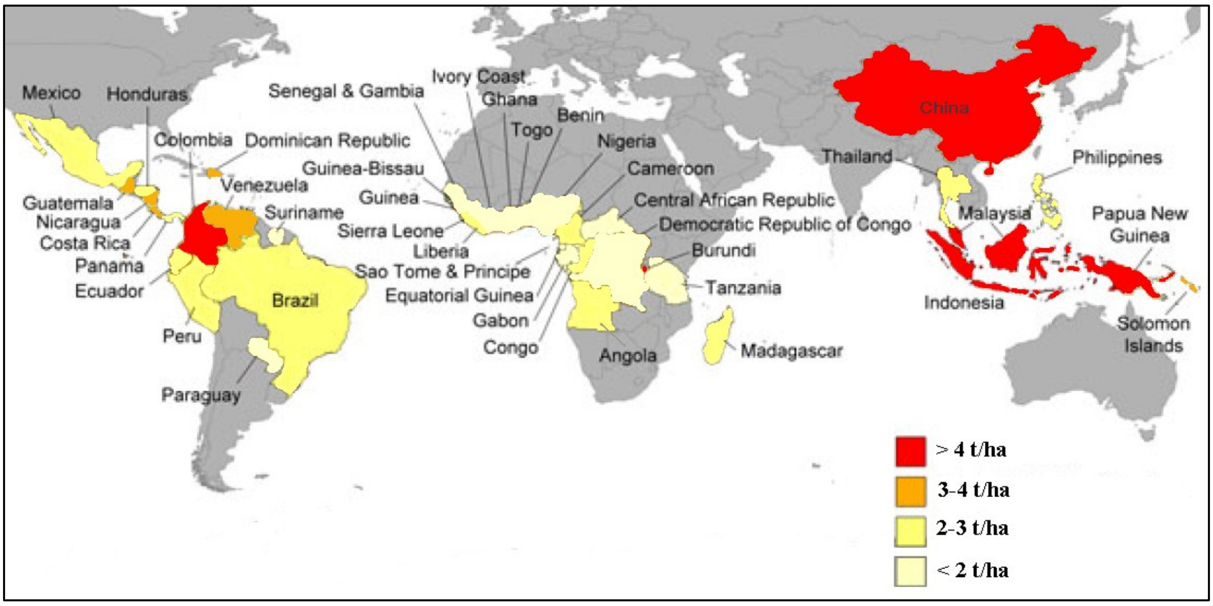

Figure 13: Yield [tCPO/ha] for all 43 oil palm growing countries in 2009. Yield is found by dividing production quantity of palm oil by area harvested. Source: data from FAOSTAT (2011).

Recently, the Malaysian oil palm industry has entered into a new dimension by the successful cloning of oil palm tree. The oil palm clones are reported to be able to produce up to 10.6 tCPO/ha. This value is at least 20-25% higher than the yield of conventional seedlings. Moreover, this new breed of oil palm clone has a shorter maturity period (two years compared to two and a half for the old breed). Apart from this, the new clone is also shorter, making the harvesting process easier. However, the price of clone oil palm seedlings is 15 times higher than the conventional price of hybrid oil palm seeds, and the Malaysia Palm Oil Board (MPOB) is therefore taking steps toward sponsoring the producers of clones and the planters of oil palm to allow them to replace old oil palm trees with high-yielding ones (Lam et al., 2009).

4.4 Price

The world market prices for the two major vegetable oils have fluctuated highly over the last five decades (Figure 14). Particularly speculations in food futures, natural disasters, and the introduction of biofuels have played significant roles. The exceptionally high prices of palm oil in 2008 were pushed by shortages of soybean oil and the demand from the world's largest palm oil importers, China and India, and they were in stark contrast to the very low values of 1998, when prices were very close to or below production costs. In 2009, the financial crisis caused prices to drop to levels around half of what they had been in 2008, but the price began to ascend again in 2010 and remains high compared to the early 2000s. In recent years, due to the demand for biodiesel, the prices of vegetable oils have become linked to those of mineral oil (Fry, 2009; Gunstone, 2011; Lam et al., 2009; MPOA, 2008; Sheil et al., 2009).

The price of palm oil and soybean oil has increased by 2.8 and 3.0% per year from 1960 to 2010, respectively. These two oils have shown almost identical trends during the period; however, over the last decade, the price of soybean oil has been slightly higher than that of palm oil (Figure 14). The trends for other vegetable oils like palm kernel, groundnut, and coconut oil are almost equal to the two shown in the figure, but their importance on the world food market is insignificant.

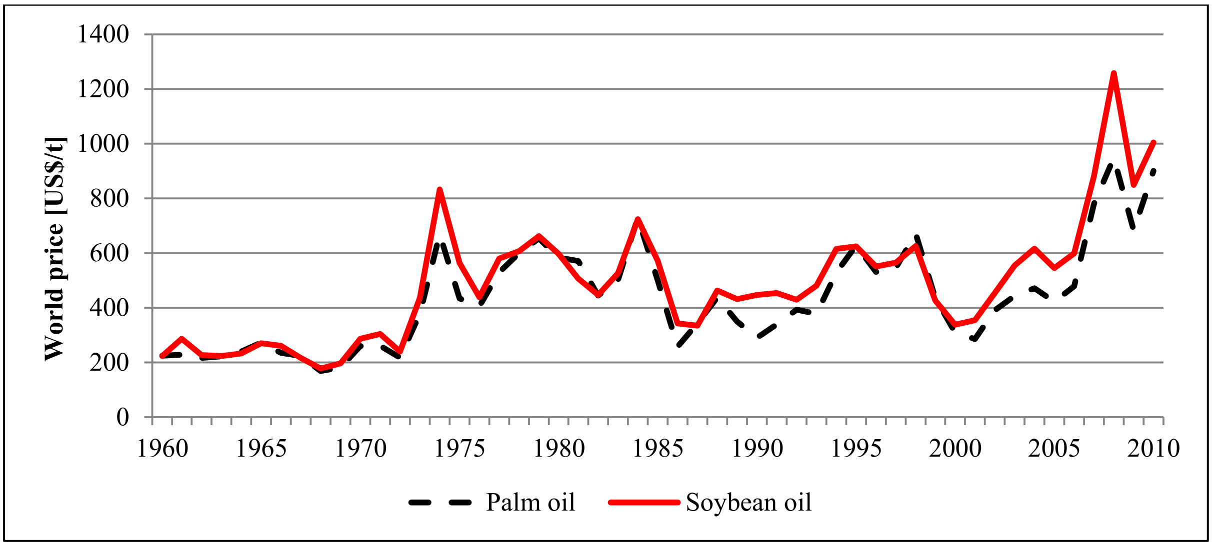

Figure 14: The development in palm oil and soybean oil prices [US$/t] over the last five decades. Source: data from World Bank (2011).

Over the last five years, energy markets have influenced agricultural commodity markets. Vegetable oil prices, notably rapeseed oil prices, are influenced by the value of energy and are currently growing exponentially. Although not achieving the value of rapeseed oil, palm oil prices are robust and many observers expect them to rise to heights not observed for many years (Carter et al., 2007). The palm oil sector can be considered a high performing industry that enjoys a strong market position, and it is the vegetable oil with the highest level of market penetration, with many nations (including large countries such as China and India) depending heavily on palm oil imports (Thoenes, 2007).

According to Carter et al. (2007), the main reason why palm oil has been so successful is the fact that prices for palm oil tend to be lower than prices for alternative vegetable oils as it is cheaper to produce. Since the early 2000s, palm oil has become the major discount oil in the EU market, despite the freight disadvantage in supplying this market. In much of Asia, palm oil is popular because of its low price compared to its main competitor, soybean oil. Two other factors that speak in favor of palm oil are the modest freight costs from South East Asian suppliers, and the fact that temperatures in the tropical/sub-tropical regions are warm enough to allow RBD palm olein to be used as household oil, without fear of clouding (Carter et al., 2007). RBD palm olein is a refined, bleached, and deodorized form of palm oil that is extracted after crushing the palm fruit, and it is used in many countries as an edible cooking oil (APOC, 2011).

A key influence on the palm oil price has been the use of vegetable oils in India, which can swing dramatically between palm and soybean oil due to the Indian import tariff policy (Carter et al., 2007; Thoenes, 2007). As one of the three largest vegetable oil importers, India's role in the oil markets is sufficient to make Indian consumption a major determinant of the relative prices of soybean oil and palm oil. However, as a consequence of the increasing import by EU and USA over the last five years, the influence of India has weakened (Carter et al., 2007).

The key reason for the success of palm oil is that it is cheap to produce, which provides a sustainable basis for its relatively low price. Figure 15 shows that palm oil was the most cost-competitive vegetable oil in 2009, with an average price around US$200 per ton lower than the other major oils. It is followed by soy oil, with a 24% higher price; the ranking continues with rapeseed oil and sunflower oil, for which prices are even higher. Despite the differences in production volume and price, palm oil and soybean oil had almost the same global economic value in 2009: 39.2 and 38.6 billion US$, respectively. Rapeseed oil and sunflower oil followed at 23.5 and 15.2 billion US$, respectively.

Labor costs weigh high on the overall production costs of palm oil; in fact, with regard to labor productivity, the performance of palm oil is relatively weak (Thoenes, 2007). There are some practical limitations on future cost reductions, and especially harvesting has proven difficult to mechanize. Furthermore, global average oil yields per hectare are also a major factor behind the production costs, as each harvested hectare of oil palm yields significantly more than land planted with soybeans, rape, or sunflower. The future price of palm oil will therefore depend on; 1) the ability to mechanize, 2) the potential for improving yields, and 3) the scope for expanding the oil palm areas in the two leading producer countries, Malaysia and Indonesia (Carter et al., 2007).

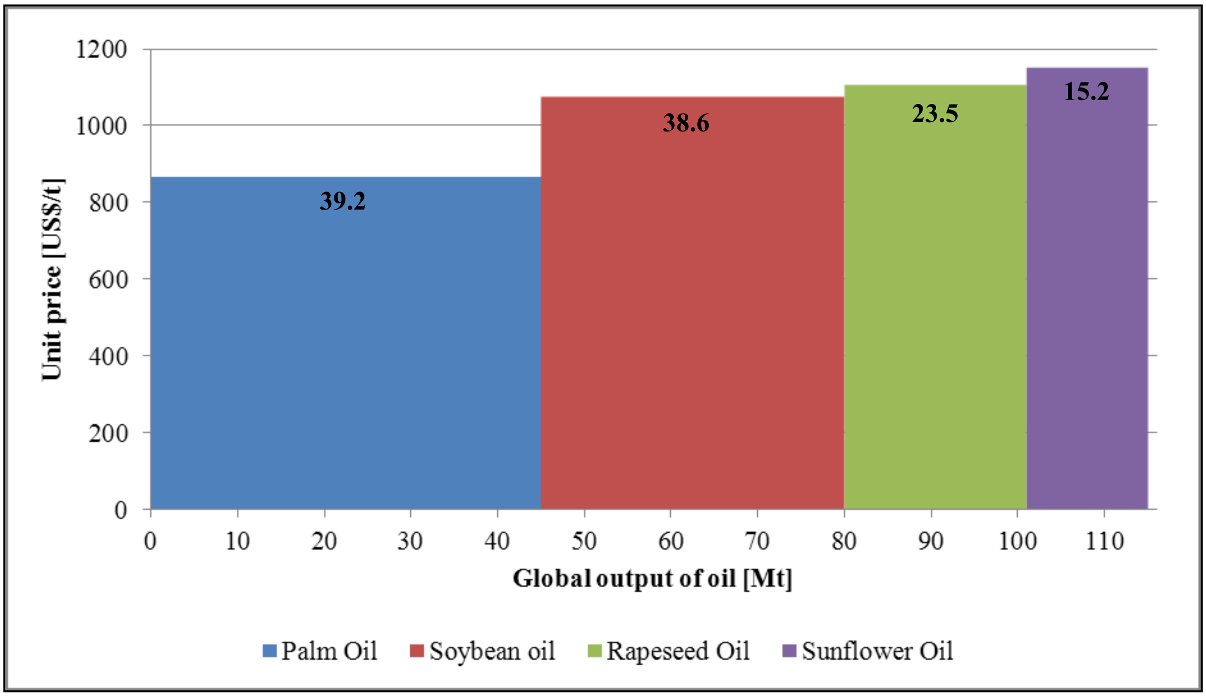

Figure 15: The figure shows the price level [US$/t] of the four major vegetable oil products (2009) as well as the relative importance of each oil in terms of the economic volume of the global production. The figures in bold are the economic value [billion US$] for each oil, which is calculated by multiplying global output and unit price. Sources: prices are from FAPRI (2011); Palm oil: Europe-Rotterdam-CIF Import Price; Rapeseed oil: Germany-Hamburg, FOB Export Price; Soybean oil and Sunflower oil: Europe-Rotterdam, FOB Export Price. To even out the large annual fluctuations, a five year average (2007-11) was applied. Production volume is data from FAOSTAT (2011).

The price of palm oil is expected to decline relative to other oils in 2011/12 and 2012/13, which should result in a higher global market share for palm oil, especially as the oil is well positioned in the major growth markets in India, China, and South-East Asia. Currently, global consumption growth rates of 7.2% in 2011/12 and 5.2% in 2012/13 are forecasted. The 2010/11 growth rate is estimated at a below-average 4.3%. By the end of the 2010/11 season, prices are expected to be around 1,175 US$/t, decreasing to 1,010 US$/t by the end of 2011/12. The rate of decline will be more marked if production increases more rapidly than currently expected. With the market surplus building in 2012/13, prices are forecasted to fall to 799 US$/t by the end of the year, the lowest level since early 2010 (Global Forecasting Service, 2011).

FAPRI (2011) predicts that palm oil consumption will increase over the next 14 years and forecasts that palm oil prices (the Rotterdam CIF import price) will progressively rise from around 900 US$/t at present (2009) to 1,162 US$/t by 2025, equaling an annual growth rate of 1.8%. The FAPRI projections only partly and tentatively take into account rising demand for biodiesel, as modeling domestic and global demand for biofuel is a very multifaceted task. Furthermore, possible future changes in national policies - e.g. in the area of biofuel production and consumption - have not been considered in these projections. The future UNFCCC/UN-REDD negotiations on biofuels and plantations will also have an influence on the palm oil price, since these negotiations can be favorable or adverse to oil palm expansion.

5 The uses of oil palm

The success of palm oil can partly be connected to its wide diversity of uses; it is practically omnipresent in our everyday lives. It can be found in numerous supermarket products; nevertheless, it is rarely specifically listed as an ingredient on product labels, as the term 'vegetable oil' is often used instead. Palm oil is mostly used as an ingredient in the manufacture and further processing of food products, but many other uses are becoming increasingly important. Moreover, there are multiple uses of oil palm byproducts, which can increase profits and reduce waste. Figure 16 provides an overview of uses of palm oil and oil palm byproducts.

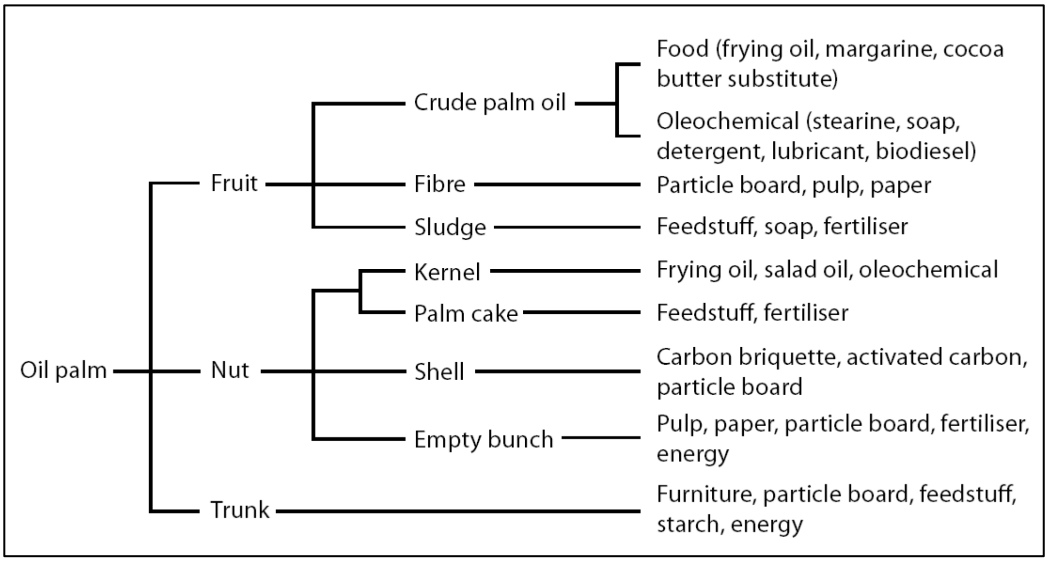

Figure 16: Uses of oil palm byproducts and biomass in food and manufacturing industries. Source: Fairhurst & Mutert (1999).

5.1 The use of palm oil – food vs. non-food purposes

No detailed list quantifying the end-uses of palm oil can be found in the literature despite the fact that a multitude of international authorities, agencies, institutions, and enterprises publish statistics on palm oil (Heinimo & Junginger, 2009). Furthermore, it is doubtful that such a list would be available, since the final use is not always clear when palm oil is traded (Butler et al., 2009). Therefore, the main focus here will be on shedding light on the quantities used in food and non-food production, and in the latter case, especially on the quantities used as biofuel. This division will help to elucidate the proportion of potential food that is used for other purposes.

Until recently the dominant use of palm oil has been food, yet with the emerging interest in bioenergy the use of palm oil for energy has increased and is expected to increase further (Corley, 2009). From 1998/99 to 2010/11 palm oil used for non-food[2] purposes increased from 17% to 27%, and in the same period, palm oil production increased by 250%, which means that palm oil used for non-food purposes rose by all of 450% in 12 years, or approximately 13% per year (data from USDA, 2011b). However, at present, palm oil is a minor player in the international trade in biofuels. Koh (2007), Thoenes (2007), Heinimo & Junginger (2009), and Rupilius & Ahmad (2007) estimated that palm oil represented 1%, 1%, 4%, and less than 5%, respectively, of the total biofuel market in 2006. Rapeseed and sunflower oil were estimated to hold 84% and 13% of the market in 2006, respectively (Koh, 2007; Thoenes, 2007). The reason for the dominant role of rapeseed oil is to be found in the high level of public support provided in EU countries, where rapeseed oil from domestic sources represents the main feedstock for biofuel production (Thoenes, 2007). However, in the future this may change since oil palm is one of the highest yielding tropical biofuel crops and consequently, provides the greatest carbon offsets (Gibbs et al., 2008). There is general consensus that, in the absence of subsidies, palm oil is by far the most competitive vegetable oil for the production of biodiesel (Thoenes, 2007).

In general, EU's biodiesel policy plays a central role (Carter et al., 2007) and considerable amounts of palm oil exported to the EU are used directly as biofuel since palm oil is more competitively priced than fossil fuel and domestic biofuel (i.e. rapeseed). EU palm oil imports have doubled to replace rapeseed oil in food production as more than half of the European rapeseed harvest today goes into biodiesel production. This change is likely contributing to indirect deforestation elsewhere (Persson & Azar, 2010).

For energy generation, palm oil can be burned directly as fuel, used as a raw material for biodiesel production, or employed in various intermediary forms (Thoenes, 2007). Furthermore, residue biomass from milling is utilized in palm oil producing countries to generate electricity (de Souza et al., 2010; UNDP, 2007). Palm oil based biofuel provides a high quality supplementary fuel for blending with fossil fuels such as petroleum to help meet the growing renewable energy demand emerging in developed countries (UNDP, 2007). The focus on palm oil for this purpose has been triggered by the sharp increase in industrialized countries' imports of biomass in the past decade. This is primarily due to policies stimulating renewable energy use and favorable prices of imported biomass compared to domestic biomass. This increasing global trade and consumption of bioenergy has been accompanied by growing concern about the environmental, ecological, and social impacts of bioenergy production. This concern has been spurred by reports about bioenergy crop production causing deforestation and the associated loss of biodiversity, greenhouse gas emissions, and displacement of forest people and related land conflicts (Wicke et al., 2008).

[2] Non-food is total consumption minus food use

Estimation of palm oil used as biofuel: To estimate the proportion of palm oil from the non-food category used as biofuel it is assumed that a) the EU27 is the only significant user of palm oil for energy among the countries with no palm oil production and b) the oleochemical industry in the EU27 used 0.3 Mt of palm oil per year and the rest was used for energy purposes. This method is similar to the one Heinimo & Junginger (2009) applied. This gave a volume of 1.9 Mt palm oil utilized for energy in 2010/11, equaling 33% of the domestic consumption in the EU27. Additionally, Thailand, Malaysia, and Indonesia used 500,000, 120,610, and 88,600 tons of palm oil for domestic biodiesel production in 2010, respectively. Thereby, the total amount of palm oil utilized as feedstock for biodiesel production was 2.6 Mt on a global scale in 2010/11 (Table 1), corresponding to 5.4% of the global production that year. With a conservative yield of around 3 t/ha (data from Figure 11) it can be estimated that biodiesel from palm oil takes up 867,000 ha of land in the tropics, corresponding to 1.2% of Borneo.

Table 1: Estimation of palm oil used as feedstock in biofuel production in 2010/11.

Region/country	Palm oil used as biofuel [t]	Source
EU27	1,900,000[3]	(USDA, 2011c)
Thailand	500,000	(Salvatore & Damen, 2011)
Malaysia	120,610	(FAPRI, 2011)
Indonesia	88,600	(FAPRI, 2011)
Total	**2,609,210**	

5.2 Future perspectives for palm oil used as biofuel

Thoenes (2007) commented that continuous technological progress and frequent changes in national policies make it difficult to determine the viability and prospects of biofuel production from different feedstocks. The many environmental and social impacts of biofuel production mean that buying palm oil biodiesel amounts to an act of ethical consumerism, and it would require persistent and collaborative efforts to restore the brand value of 'green' fuel (van der Horst & Vermeylen, 2011). The success of these efforts would depend on whether or not the next generation of biofuels entails competition for land or with crops that are traditionally used as food. In addition, non-tariff barriers can be obstacles to palm oil as the non palm oil producing regions want to protect domestic feeding stocks like rapeseed, soybean, and sunflowerseed oil. Furthermore, the outcome of the climate negotiations under the auspices of the UNFCCC is a great factor of uncertainty for the future development of all biofuels and other alternatives to fossil fuels.

Forecasts, opinions, and considerations for Asia, Brazil, and the EU are summarized below:

Asia: It is predicted that biodiesel production from palm oil in Thailand will double over the next 10 years (Salvatore & Damen, 2011), and it is forecasted that by 2025, Malaysia and Indonesia will have increased their biodiesel production from palm oil by 8 and 10 times, respectively (FAPRI, 2011). In Malaysia, blending of diesel fuel with 5% palm oil biofuel became mandatory in 2010, and once fully operational it is expected to utilize 500,000 tons of palm oil annually. In Indonesia, the government subsidizes the sale of biofuels by state-owned companies; the level of the subsidies depends on the price of fossil fuel and of biofuel

[3] Volume of palm oil for energy (1.9 Mt) = Industrial domestic consumption (2.2 Mt) - oleochemical industry (0.3 Mt)

feedstocks (notably palm oil). The intention in Indonesia is to produce about 600,000 tons of palm oil based biodiesel annually (FAO, 2009).

Brazil: Simulations show that the direct land use changes would have only a minor impact on carbon emissions since most biofuel plantations would replace rangeland areas. However, indirect land use changes, especially those pushing the rangeland frontier into Amazonian forests, could offset the carbon savings from biofuels. The simulations also tested different crops that could serve as feedstock to fulfill Brazil's biodiesel demand and found that oil palm would cause the least change in land use and associated carbon debt (Lapola et al., 2010). Besides, palm oil production on deforested Amazon land has both socio-economic and environmental benefits. Of the economic aspects, it is not only the amount of income generation that should be considered but also the fact that palm oil production relies on the available production factors such as labor and land (da Costa, 2004).

EU: European efforts are under way to account for and reduce greenhouse gas emissions and to increase the use of renewable energy: Several EU energy directives encourage a switch from fossil fuels to renewable energy derived from plant biomass. However, as a result of the public criticism of unintended and undesired effects of bioenergy production, various initiatives have attempted to develop sustainability criteria in order to ensure sustainable bioenergy trade. Such efforts began in Belgium, where an energy company developed its own certification system, which is now widely accepted by Belgian authorities; in the UK, where, as part of the renewable transport fuel obligation, reporting guidelines on carbon and sustainability are being developed; and in the Netherlands, where the so-called Cramer Commission on sustainable production of biomass has developed guidelines (Wicke et al., 2008). These initiatives contributed to the inclusion of a sustainability criteria in the EU Renewable Energy Directive (EU, 2008, Article 17) to 'verify' that biofuel sources do not derive from crops established on primary forests or wetlands. Moreover, the Renewable Energy Directive now specifies that an increasing percentage of biofuel requirements must be met by 'non-food' fuels such as second-generation biofuels (Pye, 2010). In other words, it is important to notice where and how the biomass is produced and harvested to determine whether bioenergy reduces carbon in the atmosphere compared to fossil fuels (EEA, 2011).

5.3 The effect of biodiesel from palm oil on the greenhouse gas balance

Producing energy from biomass is meant to reduce greenhouse gas emissions; Zah et al. (2007) evaluated the greenhouse gas emissions from biofuels, including palm biodiesel, and compared them with those from petrol, diesel and natural gas. Greenhouse gas emissions from 21 out of 26 biofuels were found to be 30% or even less of those from petrol. However, it is a mistaken assumption that biofuels are carbon neutral, since burning biomass increases the amount of carbon in the air (as does burning coal, oil and gas) if harvesting the biomass decreases the amount of carbon stored in plants and soils or reduces ongoing carbon sequestration. Hence, to prevent a serious accounting error with this mistaken assumption a number of life cycle assessments have been conducted to estimate the ecosystem carbon payback time (ECTP) for biomass used as feedstock for biofuel. The ECTP corresponds to the years required to compensate for the carbon stock of the displaced ecosystem plus the annual emissions avoided due to the fossil fuel being displaced by the biodiesel (de Souza et al., 2010).

Although the approaches used in different life cycle assessments of palm oil biodiesel production vary, de Souza et al. (2010) tried to compare the results of the studies on ECTP. Souza et al. (2010) own study found the carbon debt associated with the forest displacement equals 126 tC/ha and this deficit will be compensated after 39 years by means of the annual displacement of diesel. Consequently, up to the 39th year the biodiesel plantation will be a net greenhouse gas source. In Wood & Corley (1991), Yusoff & Hansen (2007), Pleanjai & Gheewala (2009), and Yee et al. (2009) the average ECTP was estimated to be 43 years on average for conversion of natural forest to oil palm plantations. Persson & Azar (2010) found similar figures: 27 years in an *optimized scenario* and 45 years in a *good practice scenario*. Fargione et al. (2008), Gibbs et al. (2008), and Wicke et al. (2008) moved a step further by demonstrating that land use change is the most decisive factor in overall greenhouse gas emissions and thus must not be neglected in greenhouse gas emission calculations of palm oil based energy or any other type of bioenergy. Therefore, they calculate the ECTP for various scenarios and compare it with the ECTP of the former ecosystem.

According to Gibbs et al. (2008) the ECTP is one year for degraded land, cropland, or grassland, 10 years for woody savannah, 25 years for degraded forest, 75 years for natural forest, and 918 years for peat forest. However, they estimated that carbon payback times would be substantially reduced if median yields approached the top yields currently achieved around the world and that the ECPT would be reduced by a third for highly productive tropical crops, such as oil palm. Fargione et al. (2008) assessed the land use change of an oil palm plantation directly displacing a tropical forest and a peatland ecosystem and calculated an ECTP of 86 and 423 years, respectively. In addition, Wicke et al. (2008) estimated the ECTP to be 169 and 30 years for plantations established on former peat forest or natural rainforest, respectively. In contrast, Wicke et al. (2008) found a positive greenhouse gas sequestration already in the first year for plantations established on former degraded land – and even better results if four management improvements were presumed: establishment on degraded land, methane collection for electricity production, improved yields, and increased organic fertilizer.

The very long ECTP for plantations established on peatland is a result of the fact that tropical peatlands are one of the world's largest near-surface reserves of terrestrial organic carbon (Page et al., 2002), and that drainage has a negative effect for over 100 years (Hooijer et al., 2010). Technically, there is no need to drain peat for oil palm production since the plant can cope with waterlogged soils, but it is necessary to create access (Sheil et al., 2009). However, as noted previously, the largest potential for oil palm expansion lies in the Amazon and Congo river basins, where peat soils are not prevalent (Persson & Azar, 2010).

6 Discussion: Perspectives of oil palm development

Palm oil is currently the world's leading vegetable oil in terms of production and trade volume and is also one of the most important oilseed oils in the global market. The growing demand for palm oil stems from the increasing biofuel consumption and the unique features of palm oil as a food oil; demand is likely to rise additionally as the economies in China and India continue to develop. Furthermore, palm oil has been successful because its price tends to be lower than those of the major alternative vegetable oils since it tends to be cheaper to produce.

However, future trends will, as for any new and profitable land use system, be determined by a variety of factors, including land availability; access to labor, capital and technology; regulation; investments; security; competing land-uses; and alternative sources of income − balanced by market trends, notably including demand and consumer perceptions.

Since it would be too comprehensive to discuss all issues regarding palm oil, we have chosen specific important issues for further elaboration: land use changes, trade, food provision, environmental sustainability, and potential tools for climate mitigation.

6.1 Land-use changes

Between 1998 and 2008, the area covered with oil palm plantations has increased in all the major oil palm cultivating countries except for DR Congo (small decrease) and Guinea (unchanged) (Figure 17). In the same period the total agricultural land area did not change significantly (increase of 1.1%); however, in Indonesia, Nigeria, and Ghana it increased by 5.0, 6.3, and 6.5%, respectively. The Latin American countries even witnessed a decrease of around 2% in their agricultural area, except Brazil, which had an increase of 0.5% (FAOSTAT, 2011). Still, oil palm amounted to only a small portion of the total agricultural land area in most of these countries, except Malaysia, Solomon Islands, PN Guinea and Indonesia, where 50, 13, 10, and 10%, respectively, of the agricultural land in 2008 was cultivated with oil palm (FAOSTAT, 2011).

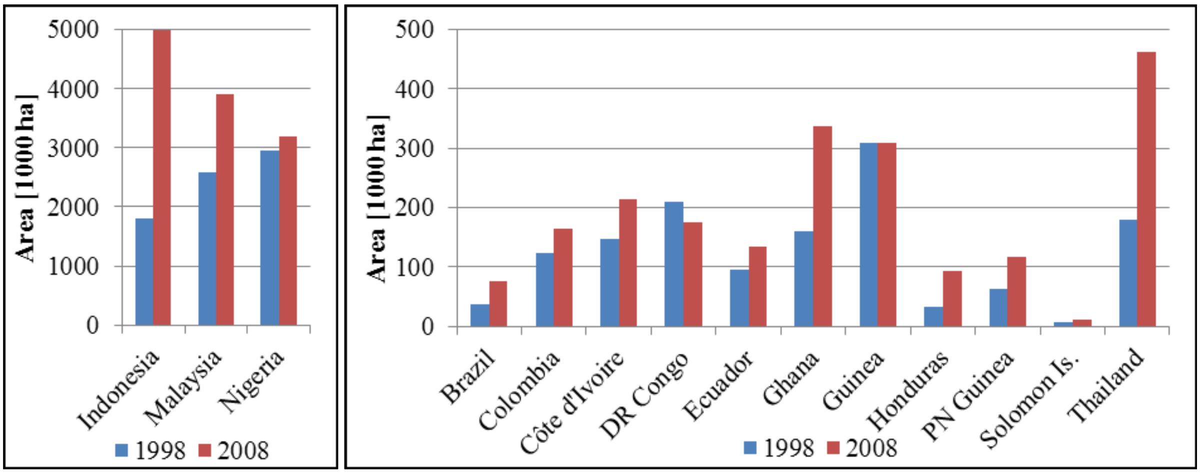

Figure 17: Area [1000 ha] cultivated with oil palm in 14 countries in 1998 and 2008. Source: data from FAOSTAT (2011).

In the same period the forest cover decreased in all regions and in almost all of the countries of interest, except in PN Guinea (unchanged) and Côte d´Ivoire (very small increase) (Figure 18). It would be an over-interpretation of the data to state that this forest loss has been driven by oil palm expansion; nevertheless, oil palm plantations increase the pressure on land as do all other crops, and most forest loss is associated with agricultural expansion (Abdullah & Hezri, 2008). Oil palm producers have asserted that forests are not being cleared to grow oil palm (Koh & Wilcove, 2008), and Lam et al. (2009) claims that indications of deforestation for oil palm plantations in Malaysia are baseless. However, there is proof of direct conversion of tropical forest or forest peatland to oil palm plantations (Abdullah & Nakagoshi, 2007; Hansen, 2005; Koh & Wilcove, 2008; Yusoff & Hansen, 2007).

Case studies present detailed information on the link between oil palm expansion and land use change. For the Malaysian state of Selangor, Abdullah & Nakagoshi (2007) found that oil palm expansion was the major contributor to peat forest fragmentation between 1966 and 1995. In the state of Sabah, Malaysia, McMorrow & Talip (2001) found that the major cause of forest disturbances had shifted from logging to palm oil production. For the Indonesian province of Riau, Uryu et al. (2008) determined that large-scale oil palm plantations were responsible for 29% and smallholder palm oil producers for an additional 7% of the total forest cover loss between 1982 and 2007. This translates into 85% of all oil palm plantations in the province being created on former natural forest land. In the Bungo District, Indonesia, Feintrenie et al. (2010) found that dense forest cover has decreased from 42% to 30% of the district area between 1993 and 2005, while oil palm plantations have increased from 4% to 19%.

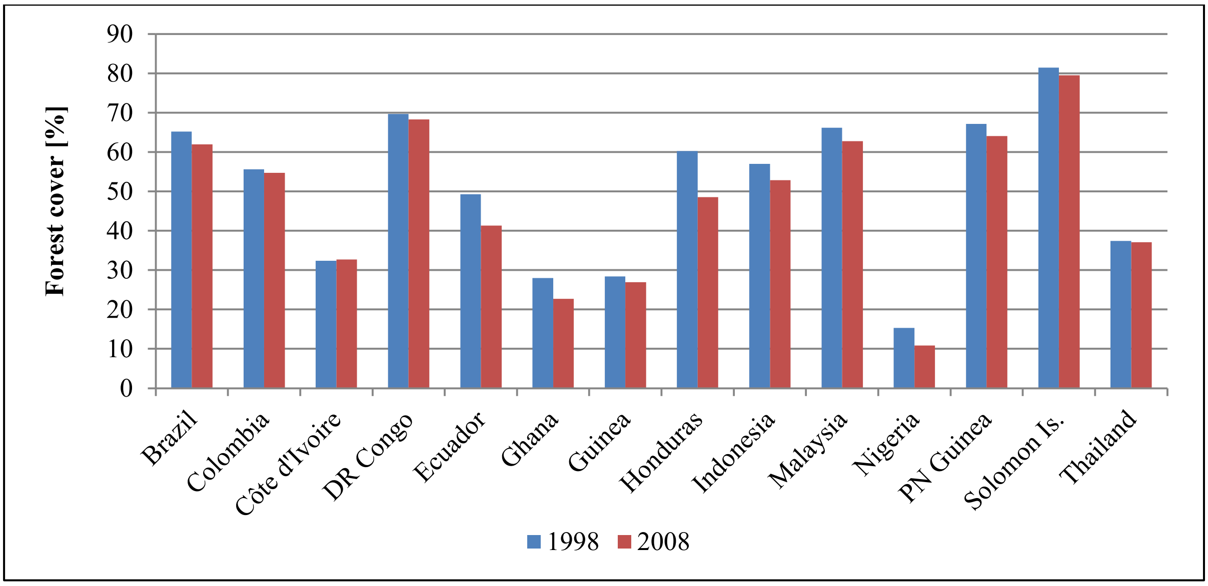

Figure 18: Forest cover [percentage of total land area] in 14 oil palm cultivating countries. Source: data from FAOSTAT (2011).

While detailed information regarding land use change as a result of palm oil production growth is available for specific locations/provinces as seen above, such information is sparse on a national scale (Wicke et al., 2011). In Malaysia, expansion of palm oil production is said to have occurred primarily on logged-over forest and on former rubber and coconut plantations, while in Indonesia, natural rainforest and peatland have often been converted to palm oil production. A recent estimate by Koh and Wilcove (2008) indicates that of all oil palm expansion between 1990 and 2005 in both countries, at least 50% has come at the expense of natural rainforest. Further, Koh et al. (2011) demonstrated that 6% (or ~880,000 ha) of tropical peatlands in Malaysia had been converted to oil-palm plantations by the early 2000s.

In regard to this, it is important to factor in the particular sequence and geography of palm oil expansion. At issue is not just a quantitative expansion, but also a qualitative shift. Historically, oil palm expansion has occurred in three sequences: 1) the 'national' phase; palm oil was established in the plantation heartlands on the western coast of Peninsular Malaysia and in northern Sumatra, which had been dominated by the rubber plantation economy since colonial times; 2) the 'transnational' phase; transnational corporations responded to increased demand for processed fats by expanding into Sabah and Sarawak in Malaysia and into Riau and Jambi on Sumatra, and 3) the current phase; biofuel-related expansion and planned expansion in Kalimantan, Sulawesi, and West Papua. The second and third phases from 1997 onwards haven taken or are taking place in 'frontier' regions, where the new plantations are established on logged or degraded forest areas and agricultural land (Pye, 2010).

Box 1: Historic land-use changes in Indonesia and Malaysia in detail

The land use changes in Indonesia and Malaysia are elaborated in detail here because these countries are the most important in terms of palm oil production. The largest change in Indonesia occurred in forest-covered land, which decreased from 130 Mha in 1975 to 88 Mha in 2009, while agricultural land increased from 38 Mha in 1975 to 54 Mha in 2009 (Figure 19). Approximately half of this agricultural expansion is due to an expansion in palm oil production, namely from 0.1 Mha in 1975 to 7.5 Mha in 2009. The other half of the expansion was caused by an increase in arable land, mostly to expand the cultivation of paddy rice (Wicke et al., 2011). On a national level, the large increase in palm oil production is small compared to the 39 Mha of forest cover loss since 1975, which indicates that there are other important causes of forest cover loss and land use change in general. As shown in the figure, palm oil production alone cannot explain the large loss in forest cover in Indonesia. Instead, a web of interrelated direct causes and underlying drivers appears responsible, especially logging, other forms of agricultural production, and forest fires (Wicke et al., 2011).

In Malaysia, land use change has also been considerable, but different from that in Indonesia (Figure 19). While deforestation was rapid until the beginning of the 1980s, it has slowed down since then, but the annual rate of forest cover loss has fluctuated. A rate of 1% or more was seen in the years 1994 and 2001, while rates as low as 0.01% were observed in some other years. Although forest cover is still greater than 50%, of the 18 Mha of forest-covered land in 2009, it is estimated that only 3.8 Mha was primary forest. The largest change in land use was the increase in oil palm cultivation from 0.6 Mha in 1975 to 4.7 Mha in 2009. At the same time, the area of other permanent crops, primarily the export crops natural rubber and coconut, decreased significantly (Wicke et al., 2011). The causes of forest cover loss in Malaysia vary per region. In Sabah and Sarawak, the most important causes have been timber extraction and shifting cultivation, while in Peninsular Malaysia, and in recent years increasingly in Sabah, forest cover has been affected mostly by conversion to agriculture and more specifically to oil palm plantations (McMorrow & Talip, 2001).

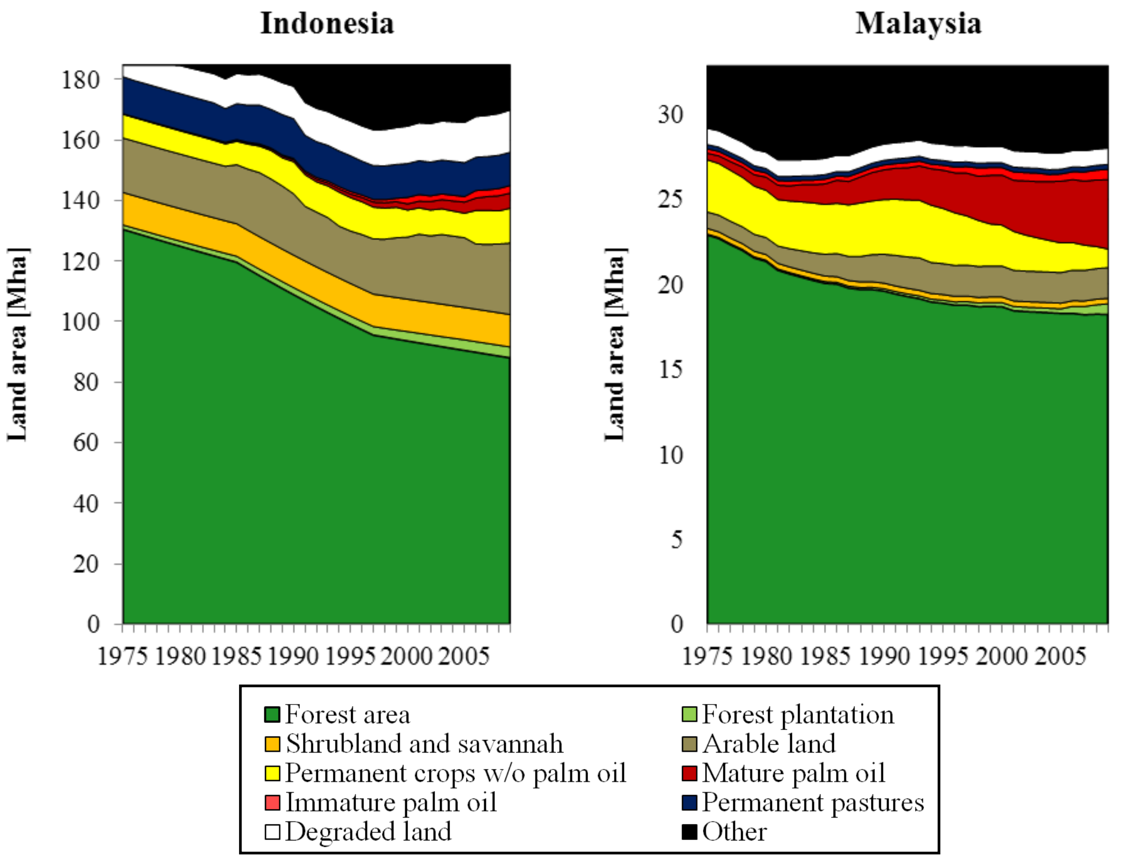

Figure 19: Land use change in Indonesia (left) and Malaysia (right) between 1975 and 2009. There are some uncertainties in the figures, as described in Wicke et al. (2011). Source: data for 1975-2005 are provided by Birka Wicke and can be found in Wicke et al. (2011). Data for 2006-2009 have been established by the authors using the method and sources described in Wicke et al. (2011) (see the Appendix for a further explanation).

In the third phase, most of the lowland forests located in Kalimantan and Sumatra have already been lost by legal and illegal logging (Venter et al., 2009), and clear-felling of forests by the timber and pulp industry is the first step in plantation development (Fitzherbert et al., 2008). Besides, oil palm is increasingly being planted on peatland because most mineral soil areas in the lowlands within Sumatra and Kalimantan have already been taken, peatland tends to have low population densities, and oil palm is the most financially attractive development option. This makes it easier to seek and gain ownership, and investors are less likely to become embroiled in social conflicts (Casson et al., 2007).

A study of the years 1998–2001 documented over 800 arrests, over 400 cases of torture, and 12 deaths in connection with land conflicts with plantations. Another study found that all of the 81 palm oil plantations in South Sumatra had some kind of conflict with local communities in the year 2000, and another study documented 200 palm oil-related conflicts in West Kalimantan (Pye, 2010). The new palm oil expansion is taking place in areas where peasant smallholder mixed farming systems still prevail and where between 12 and 60 million people are estimated to be living in and around forests (Li, 1999). These potential land tenure and human rights conflicts are one reason why companies prefer to develop on forested land and peatland rather than on cleared areas. Forest lands are often within the claim area of one or only a few villages. This makes negotiations relatively simple and, once key leaders in a village have been convinced to relinquish ownership of a forest area and accept the concomitant financial compensation, companies can lay strong claims to the land. In deforested areas, however, many individuals may move into an area and claim ownership. Companies in such areas need to negotiate with many more stakeholders than in forested ones, which increases costs and potentially delays plantation establishment (Sheil et al., 2009).

6.1.1 Anticipated land use implications

Koh et al. (2009) estimated that if all oil palm producers attain at least the 90th percentile of the global range in CPO yields (i.e. Malaysia's yield of 4.1 tCPO/ha/yr), global palm oil production would, without further expansion of cropland, rise to 57 MtCPO/yr (a 48% increase over current CPO production and more than double the amount of CPO traded internationally). This translates to 26 Mha of land spared from conversion to oil palm plantations, or over one-third of the tropical forest area in Indonesia suitable for, and thus under threat from, oil palm agriculture (62 Mha) (Stickler et al., 2007). Furthermore, Corley (2009) estimated that the additional area of oil palms required to meet the demand for edible purposes in 2050 is likely to be between 12 and 19 Mha. However, there are great uncertainties in these 2050 estimates concerning population growth, per capita consumption, yield development for vegetable oil crops, and progress in biofuels. With regard to biofuel, Koh (2007) estimated that 63 to 82 Mha of tropical land would be needed exclusively for oil palm to meet the demand for biodiesel in 2050; however, this is based on current trends, which most likely will change.

In addition, Wicke et al. (2011) indicate that the additional demand for palm oil in Indonesia and Malaysia until 2020 can be met without further forest cover loss by a combination of converting degraded land and improving yields. More specifically, the projections of total production in 2020 in Indonesia range from 31 to 63 MtCPO/yr. In the most optimal situation, which includes converting only degraded land and improving yields from 3.4 tCPO/ha/yr in 2005 to 5.9 tCPO/ha/yr in 2020, oil palm expansion would be limited to 1 Mha. However, if the key condition of yield improvements is not met, land expansion for palm oil production can increase to 28 Mha. Moreover, if large amounts of degraded land are already in use, an expansion of palm oil production on such a scale may not be considered sustainable as the conversion to oil palm plantations would cause the displacement of existing activities such as grazing or subsistence farming (Wicke et al., 2011).

Furthermore, the acreage of land spared could rise to over 160 Mha if breakthroughs in the production of F1-hybrid oil palm allow yields to reach their physiological potential of 18.5 tCPO/ha/yr (Sumatra Bioscience, 2008). However, the gap between average and maximum productivity is widening, not only among oil palm-producing countries but also among producers within countries such as Malaysia and Indonesia (Koh et al., 2009). This suggests that many oil palm producers, notably smallholders, are failing to take advantage of the full genetic potential of this crop, and that substantial scope for future productivity improvements exist (Corley, 2009).

Palm oil yield improvements are important since they can greatly reduce land requirements (Wicke et al., 2011). The hypothesis that productivity gains spare forests from land use conversion was originally posited by Norman Borlaug, who asserts that low land productivity is a fundamental driver of tropical deforestation and that therefore, efforts should be focused on increasing crop productivity in the tropical biome (Gockowski & Sonwa, 2011). Angelsen & Kaimowitz (2001) concluded, after testing Borlaug's hypothesis, that technological progress in the intensive sector is generally good for forest conservation, and labor-intensive technological progress will tend to reduce forest clearing. In a recent study, Burney et al. (2010) estimated in a counterfactual analysis that the current global atmospheric stock of CO_2e would have been 34% greater without the land savings accomplished by the yield increasing agricultural innovations of the last five decades.

Finally, the fact that oil palms have such high bioenergy yields per hectare, are so well adapted to tropical conditions, and already have been identified as a major culprit behind tropical deforestation in Southeast Asia, implies that oil palm plantations could become a key driver of deforestation in the future, when tightening climate policies are expected to increase the demand for bioenergy even further. Over a third of the land currently under forest in the countries harboring the world's tropical rainforests could be suitable to some degree for rain-fed oil palm cultivation (Persson & Azar, 2010), with major potential for expansion in the Congo and Amazon river basins (UNEP, 2011).

6.2 Trade

Pye (2010) examined how oil palm teleconnections contribute to agrarian transformation in Southeast Asia. He found that the palm oil biofuel development trajectory involves specific 'transnationalized circuits of accumulation and production'. He specifically noted the political links between Southeast Asia and Europe while he did not find the same pronounced links between Southeast Asia and the United States or China. He argued that a process of social differentiation and class formation is taking place, which is creating new social classes and a specific transnational social space of Indonesian migrants in the Malaysian oil palm plantations. This agrarian transformation is leading to a multitude of local land conflicts, negotiations between palm oil smallholders and plantation companies, and struggles by plantation workers over wages and working conditions.

Furthermore, Pye (2010) observes that it is important to note the different places and scales in which the process is unfolding. While each new palm oil plantation has a specific impact in a given locality and is shaped by national policies and local power relations, they are all related to transnational economic, social, and political spaces. The cause of the current agrarian differentiation and expansion can be located within a *corporate food regime*, in which a *palm oil industrial complex*, made up of transnational corporations (TNCs) and state capital and government agencies from Malaysia, Singapore, and Indonesia, controls the global commodity chains. The commodity chains and TNCs create a specific transnational economic space of production across Southeast Asia, with Malaysian TNCs driving plantation expansion, and another specific transnational economic space linking Southeast Asia to agribusiness and food TNCs in Europe. In the context of a neoliberal climate governance system, the *palm oil industrial complex* is hybridizing to form a *biofuel regime*, in which agribusiness allies itself to European oil and automotive corporations by adding biodiesel factories to existing structures of production. A new *transnational biofuels space* between Southeast Asia and Europe is thus emerging.

6.3 Food provision

Oils and fats are an essential component of a balanced human diet and the World Health Organization recommends that 30% of the energy requirements of an individual should be obtained from oils and fats. Therefore, the low cost alone is not sufficient to make palm oil an important source of edible oil in the world, unless it contains the nutrition required for humans' daily diet. At one time, palm oil was labeled unhealthy due to its high saturated acid content, which was found to increase the risk of cardiovascular diseases substantially. However, years of research resulted in new findings. Unlike other edible oils, palm oil is a balanced oil, which contains equal amounts of both unsaturated and saturated fatty acids, with the former constituted mostly by the preferred monounsaturates. Moreover, the palmitic and stearic in palm oil do not appear to elevate cholesterol levels beyond the normal ranges. Over the years, palm oil has indeed become an integral part of the human diet all over the world. For instance, in Malaysia, the average diet consists of about 27% fat, of which 80% comes from palm oil (Lam et al., 2009).

There is concern that the competing uses of vegetables oils for food and fuel could drive up agricultural commodity prices and encourage farmers to replace their lower earning food crops with biofuel crops, which could eventually lead to higher food prices. Higher prices on vegetable oils will put downward pressure on food demand, particularly for poorer members of the population (RSPO, 2011; Thoenes, 2007). Mendoza (2007) concluded that biofuels are the single greatest threat to food security especially for the low-income groups in view of their influence on the supply and prices of staple foods. Therefore, forthcoming land uses and land use changes need to relate to mitigation, adaptation, and food production to meet the challenges of climate change and food security, and thereby achieve win-win-win solutions. When climate change threatens food production and supply, adaption measures become essential. One of the most important areas in which trade-offs may occur over the coming decades in the field of agriculture is between mitigation and food security. Agricultural production will need to grow in order to meet an increased demand for food. This growth will almost inevitably lead to an increase in greenhouse gas emissions and in the sector's relative contribution to climate change. With food security at stake, many see this trade-off as necessary and one that should not be altered in favor of increased mitigation (Campbell et al., 2011). There are potential synergies between the objectives of mitigation, adaptation, and food security in the palm oil sector, as palm oil yields are higher than those of other oil crops, but this will largely depend on the location of the plantations. Hence, policy makers and farmers need to maximize synergies and minimize trade-offs in palm oil production to make it more sustainable.

6.4 Environmental sustainability

Numerous NGOs continuously alert the international community to the negative environmental impact of the development of palm oil. The debate has largely been spurred by land use change that occur by converting natural rainforest, peat swamp forest, cropland, or other land types to oil palm plantations. This land use change, in turn, has further environmental implications such as the loss of biodiversity, emission of greenhouse gasses from carbon stock changes in biomass and soil, forest fires, and related respiratory diseases. Furthermore, processing mills are a source of air and water pollution, and the impact of large estates on water regulation and quality is still under debate (Feintrenie et al., 2010; Sheil et al., 2009; Wicke et al., 2011).

In regard to the use of palm oil as feedstock for biofuel, the future extent of palm oil production will have to expand into non-peaty degraded lands since expansion in the past cannot be claimed to have been environmentally friendly or to have dramatically reduced greenhouse gas emissions. Expansion of oil palm into productive tropical ecosystems under current conditions will lead to net carbon emissions for decades to centuries, while expanding into degraded or already cultivated land will provide almost immediate carbon savings. Future crop yield improvements and technology advances, coupled with unconventional petroleum supplies, will increase biofuel carbon offsets, but clearing carbon-rich land still requires several decades or more before there is any carbon payback. No foreseeable changes in agricultural or energy technology will be able to achieve meaningful carbon benefits if crop-based biofuels are produced at the expense of tropical forests (Gibbs et al., 2008).

In a comparison of the resource use efficiency and environmental performance of nine major biofuel crops processed by first-generation conversion techniques, biofuel production from oil palm, sugarcane, and sweet sorghum appeared most sustainable with respect to nine production-ecological indicators. High net energy yields per hectare are obtained from these systems, which result in good nitrogen use efficiency, pesticide use efficiency and water productivity, and imply efficient use of land resources (de Vries et al., 2010). However, the set of indicators employed were not exhaustive and therefore, definite conclusions on the sustainability of the assessed biofuel production systems cannot be drawn. This is especially true since important issues related to social and economic sustainability, land use change, biodiversity and habitat destruction were not been taken into account. Zah et al. (2007) evaluated the environmental costs of 26 biofuels, including palm biodiesel (along with petrol, diesel and natural gas), and nearly half of the biofuels, including palm diesel, have markedly higher aggregate environmental costs than fossil fuels. Additionally, a recent life cycle assessment study by Schmidt (2010) showed that palm oil is environmentally preferable compared to rapeseed oil in regard to ozone depletion, acidification, eutrophication, photochemical smog, and land use, while the differences with regard to global warming and biodiversity are less clear.

6.4.1 The Roundtable on Sustainable Palm Oil

Growing demand for palm oil is expected to trigger further expansion in palm oil production, and concerns about the environmental and social sustainability of the sector's further expansion are growing among civil society groups, policy makers, and market players alike. Therefore, palm oil is increasingly facing image problems in general and especially for non-food uses. Consumer groups are voicing concerns about the sustainability of current palm oil production methods and the industry and policy makers are under pressure to respond to these consumer sentiments (Carter et al., 2007; Pye, 2010; Thoenes, 2007; Wicke et al., 2008).

In reaction to this negative campaign at the end of the commodity chain, key palm oil end buyers and retailers (Unilever, Migros, Sainsburys) teamed up with major producers (the Malaysian Palm Oil Association, Golden Hope) and the WWF to set up the Roundtable on Sustainable Palm Oil (RSPO) in 2004 (Pye, 2010). The goal is to promote the production and use of sustainable palm oil through certification and traceability, which is to be achieved through the development, implementation, and verification of credible global standards (Carter et al., 2007; Thoenes, 2007). The initiative is enjoying a growing membership that now includes major stakeholders from all parts of the commodity chain in both producing and consuming countries. Globally, RSPO accounts for approximately 35% of the production of palm oil, although less than 4% is certified as sustainable (Laurance et al., 2010).

RSPO has met external criticism, with some claiming that it is simply a cynical attempt at PR and *greenwashing*. In 2008, 250 organizations signed an 'International Declaration Against the *Greenwashing* of Palm Oil by the RSPO' (Pye, 2010). Laurance et al. (2010) list seven major challenges for the RSPO, and the main criticism is that the representation of conservation and social developmental organizations as ordinary members and on the board is too limited. Laurance et al. (2010) recommend among other issues that the RSPO push for serious reforms in order to be less industry biased. Nevertheless, there are large markets that have shown little interest in certification of sustainability and this may not be a requirement in the near future (Corley, 2009; Laurance et al., 2010). On the other hand, Bateman et al.'s (2010) study shows that western consumers are willing to pay a significant premium for palm oil grown in a manner that reduces impacts.

6.4.2 Sustainability and the future demand for palm oil

A climate and forest-friendly palm oil production expansion up to 2020 is possible in principle (Wicke et al, 2008). However, the demand for palm oil is expected to continue to grow after 2020, and it will become increasingly difficult to meet this demand sustainably. In addition, the right incentives must be given for the expansion to take place in a sustainable manner. Enhancing the sustainability of palm oil production expansion may be achieved by incorporating strategies for improving the impact of palm oil production growth on land use change as well as its greenhouse gas emissions, and most prominently, the use of degraded land and better management.

Measures that reduce land use change, especially deforestation and degradation of land resulting from other direct causes and underlying drivers, also need to be implemented. A key element for doing so is better planning and governance of land use, which entails, among other things, more appropriate demarcation of forest land and protection of land that still has forest cover, improved monitoring of land use, and more research to uncover the complexities and dynamics of the causes and drivers of land use change. Another measure would be to include the REDD mechanism in the post-2012 climate change regime (Wicke et al., 2011), since REDD may enable palm oil producing countries to receive funding and support for policies and measures that encourage companies to plant oil palm on degraded lands rather than on forested lands (Sheil et al., 2009).

Koh et al. (2009) evaluated the prospects of land sparing and wildlife-friendly farming – two contrasting approaches to reducing the impacts of oil palm agriculture – to promote sustainable production systems. They argued that landscapes under threat from oil palm expansion need to be designed in recognition of biodiversity, economic, and livelihood needs. Specifically, they advocated for agroforestry zones between high conservation value areas and intensive oil palm plantations to create a more heterogeneous landscape benefiting both biodiversity and rural communities. This proposal seeks to generate positive co-benefits for agricultural production, biodiversity and rural communities, and is consistent with the emerging paradigm of 'ecoagriculture' proposed by Scherr & McNeely (2008).

6.5 Potential tools for climate mitigation

There are strong linkages between agriculture and attempts to reduce emissions from deforestation, as agriculture is one of the principle drivers of deforestation. Intensification of agriculture, depending on the context and policies used, could reduce or increase pressure on forests. The increased interest in reduced deforestation as a tool for climate mitigation stems from the persuasion that it is a low cost carbon abatement option (Gullison et al., 2007). Both the IPCC (Barker, 2007) and the Stern Review (Stern, 2006) point to REDD as one of the least expensive abatement options available. However, the economic viability of the REDD schemes will depend on the profitability of alternative land uses, and since oil palm agriculture has become a major driver of tropical deforestation over the last few decades, it is obvious to compare the profitability of converting forest to oil palm versus conserving it for a REDD project.

Estimations show that converting a hectare of forest for palm oil production will be more profitable to land owners than preserving it for carbon credits, as long as credits are restricted to the voluntary carbon markets (Butler et al., 2009; Kongsager et al., 2011; Sandker et al., 2007; Venter et al., 2009). However, giving REDD credits price parity with carbon credits traded in compliance markets would boost the profitability of avoided deforestation in comparison with oil palm plantations. Hence, unless post-2012 global climate policies legitimize the trading of carbon credits from avoided deforestation, REDD will not be able to compete with oil palm agriculture or other similarly profitable human activities as an economically attractive land use option, in which case REDD will not be able to fulfill its primary function of avoiding deforestation. Additionally, palm oil prices are expected to remain high; consequently, investing in oil palm agriculture will remain an attractive alternative land use to REDD schemes, although in some forest areas REDD may be more profitable than oil palm developments because of poor infrastructure, unsuitable soils, inappropriate climate, and topography (Butler et al., 2009), or perhaps in the case of carbon-rich peat forests (Venter et al., 2009).

Results from Persson & Azar (2010) indicate that forests suitable for palm oil plantations may not be worth preserving solely on the basis of their carbon content; from a climate protection perspective, clearing forests for high-yielding bioenergy crops may indeed make economic sense as the greenhouse gas balance for bioenergy does turn positive within 27-45 years. However, an important limitation of the analyses is the exclusion of payments for environmental services (PES) beyond carbon, including forest derived goods and services that benefit local and regional economies (Butler et al., 2009). However, the success of PES remains equivocal and the uptake uncertain (Wunder, 2006). Moreover, the concept of PES presents some major challenges that need to be addressed (Kinzig et al., 2011). It must be noted that the estimates include considerable uncertainties, involving predicting the details of a future REDD scheme, oil palm operations costs, carbon and palm oil prices, the discount rate, future yield, carbon accumulation rates, inflation, and future technological achievements.

Furthermore, the REDD scheme faces several political and technical challenges, including concerns over national sovereignty and land rights of forest users, financial distribution, system leakage, and the establishment of appropriate deforestation baselines (Butler et al., 2009).

7 Appendix

This is a further description of the 2006-09 data used in Figure 19.

Data on the land use applied are based on data from literature (*italics*) and interpolated/extrapolated results (**bold**).

Indonesia

Year	**Forest area** 1)	**Forest plantation** 1)	**Shrubland and savannah** 2)	**Arable land** 3)	**Permanent crops w/o palm oil** 4)	**Mature palm oil** 5)	**Immature palm oil** 6)	**Permanent pastures** 3)	**Degraded land** 2)	**Other** 7)
2006	**90,0**	**3,4**	**10,7**	*21,5*	*11,1*	*4,1*	*2,5*	*11,0*	**13,4**	17,1
2007	**89,3**	**3,5**	**10,7**	*22,0*	*11,2*	*4,5*	*2,2*	*11,0*	**13,6**	16,7
2008	**88,7**	**3,5**	**10,7**	*22,7*	*10,9*	*5,0*	*2,4*	*11,0*	**13,8**	16,1
2009	**88,1**	**3,5**	**10,7**	*23,6*	*11,5*	*5,0*	*2,5*	*11,0*	**14,0**	14,9
2010	*87,5*	*3,5*								

Malaysia

Year	**Forest area** 8)	**Forest plantation** 9)	**Shrubland and savannah** 2)	**Arable land** 3)	**Permanent crops w/o palm oil** 4)	**Mature palm oil** 10)	**Immature palm oil** 10)	**Permanent pastures** 3)	**Degraded land** 2)	**Other** 7)
2006	*18,3*	*0,4*	**0,3**	*1,8*	*1,6*	*3,7*	*0,5*	*0,3*	**1,0**	5,0
2007	*18,2*	*0,5*	**0,3**	*1,8*	*1,5*	*3,8*	*0,5*	*0,3*	**1,0**	5,0
2008	*18,3*	**0,5**	**0,3**	*1,8*	*1,3*	*3,9*	*0,6*	*0,3*	**1,0**	4,9
2009	*18,2*	**0,6**	**0,3**	*1,8*	*1,1*	*4,1*	*0,6*	*0,3*	**1,0**	4,8

1) Interpolated with 2005 (Wicke et al., 2011) and 2010 (FAO, 2010a) figures
2) (Wicke et al., 2011)
3) (FAOSTAT, 2011) – resources, resourceSTAT, land
4) *Permanent crops without oil palm* are permanent crops from 3) minus mature and immature oil palm area.
5) (FAOSTAT, 2011) – production, crops, harvested area, oil palm fruit
6) *Immature oilpalm* is the total oil palm area (Indonesian Bureau of Statistics, 2012) minus mature oil palm area.
7) Calculated – *Total land area* from 3) minus all other land-cover types
8) (DSM, 2011)
9) (FAO, 2010b)
10) (MPOB, 2012)

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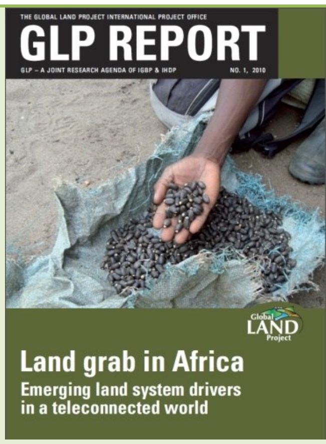

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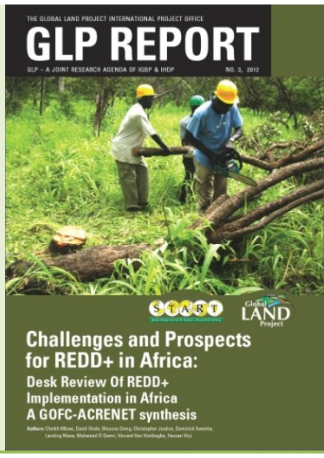

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