Chapter

Sustainability of the Oil Palm Industry

Dickson Osei Darkwah and Meilina Ong-Abdullah

Abstract

The oil palm (*Elaies guineensis* Jacq) is the largest produced and highly traded vegetable oil globally yet has the lowest cost of production and significantly higher productivity compared to other oil crops. The crop has the potential of alleviating poverty for smallholders and lifting the economies of countries with large scale production notably, Malaysia and Indonesia and currently on high demand for use as biofuel feedstock. Irrespective of these advantages of the oil palm, there is a global concern on the devastating impact of the crop on the environment and ecosystem during plantation developments and expansions. Deforestation, biodiversity loss, water and air pollution and toxic compounds from palm oil mill effluents (POME) are some of the negative impacts of the oil palm. For the industry to be more beneficial and impactful globally, sustainability strategies becomes urgent need. Sustainability strategies such as increasing the yield of oil palm, precision agriculture, sustainability certification, support for smallholders and circular economy have been put across to curtail the negative impacts of oil palm expansion.

Keywords: environmental issues, sustainability certification, circular economy, precision agriculture, increasing the yield of oil palm

1. Introduction

Oil palm (*Elaeis guineensis* Jacq), a palm of African origin produces palm oil accounting for 30.8% of today's global production of oils and fats [1]. The versatility of the oil palm in oleo-chemical applications, food and biodiesel production makes it a sought after commodity in food and non-food industry. Globally, it is by far the most productive oil-bearing crop per land use and is capable of fulfilling the large and growing demand of vegetable oil that is estimated to reach 240 million by 2050 [2, 3]. While 56.2 million tons of palm oil were extracted from 17.24 million hectare of land under oil palm cultivation, only 23.6 million tons were produced from rapeseed grown on 36.4 million ha and cost of production for these two commodities stood at US$ 700 and US$ 850 per metric tons respectively, indicating lower cost of production for oil palm [4].

The oil palm is significantly more productive, versatile and most economically viable among the leading vegetable and fat crops due to its cost-effective production, wide use, extreme yields and profitability. It is the ideal crop to address several of the United Nation's Sustainable Development Goals (SDGs). Economically, it has the capacity to eradicate extreme hunger and poverty, lifting millions of people out of poverty in Indonesia and other parts of the world where it is produced on a large scale. In Indonesia, the livelihood of 25 million people depend on oil palm cultivation while in Malaysia, the number of people employed increased from 92, 352 in 1980 to 570,000 in 2009.

The oil palm is a profitable crop and when coupled with good government policies have the capacity to transform the livelihood of millions of people and as well improve health care and education in rural areas [5–7]. In Brazil specifically, Paha, the average yearly investment return on oil palm cultivation is US$ 2,000 per hectares [8].

The production of palm oil is dominated by Indonesia and Malaysia which together accounts for 85–90% of total palm oil production. Indonesia, the top producer and exporter of palm oil has over 14 million hectares of oil palm plantations in 2018, out of which 55.09% are from the large private companies, 40.62% from small holder plantations and 4.39% from state large estates. Indonesia produced 48.3 million metric tons of palm oil in 2020 [9, 10]. Malaysia, the second producer of oil palm has over 5 million hectares of oil palm plantations and also produced 19.14 million tons of palm oil in 2020 [11].

Countries that have devoted large tracts of land for oil palm production have increased their economies greatly. Indonesia and Malaysia made over USD 18.7 billion and USD 9.8 billion from the export of palm oil in 2017 respectively.

Globally, the area planted with oil palm is 27 million ha with Africa accounting for 2 million ha and a recorded production of 0.27 gigatons of fruits and 71.4 megatons of palm oil produced globally [12–14]. The economic impact of the oil palm industry in general is not contributed solely by large plantation companies, it is estimated that smallholders cultivate about 50% of the oil palm area globally [15]. However, in Africa, the smallholders account for approximately 70% of the oil palm cultivated [16]. The cultivation of oil palm by small holders have resulted in increased farm and employment incomes, reduced poverty rates at local, regional and national levels [17].

Irrespective of the socioeconomic impact of the oil palm, great criticism has emanated from international groups such as Green peace, Rainforest Action Network and World Wildlife Fund (WWF) for unsustainable practices that have led to deforestation, increased greenhouse gas (GHG) emissions and the loss of biodiversity [18, 19]. Lim et al. [20] defined sustainable palm oil production as the production that protects the natural environment, promotes intra and inter-generational equity, while enhancing commercial operations and sharing economic growth with the local community through employment and fair trade. The negative impacts raised by these pressure groups may include forced labour, food safety and environmental issues etc. However, this chapter aims at bringing some of the negative impacts on the environment on oil palm cultivation and expansion to light and as well suggest some strategies that can be adopted to ensure the sustainability of the oil palm industry.

1.1 Environmental concerns

Globally, the area under oil palm has increased from 5 million ha in 1980 to more than 20 million ha in 2018 [21] with this expansion coming from Malaysia and Indonesia although 240 million ha of available land are suitable for oil palm cultivation, excluding intact forest landscapes, high carbon stock forest conservation hot spots and protected areas. Although the oil palm is the driver of the growth of most economies of countries producing on a large scale, the expansion has also led to tropical deforestation and associated biodiversity loss, greenhouse gas emissions, land degradation, forest and peat land fires as well as air and water pollution [18, 19]. Overall expansion of annual crops e.g. soybean, maize, paddy rice, and sorghum has been more rapid and more wide spread than expansion of perennial crops especially in South America, Africa and tropical Asia from 1999 to 2008 creating more biodiversity loss with oil palm noted to be the fifth on the list of biodiversity loss [22].

1.1.1 Biodiversity loss

Loss of biodiversity are directly linked to natural forest loss. Reduced habitat structures as a result of oil palm expansion provides fewer niches for flora and fauna. Endangered species such as tiger, elephants and orangutan are on the verge of extinction. As new lands are cleared from the forest, there is an increased access to lands which leads to increased hunting pressure as well as habitation by humans resulting in increased conflicts between human and these animals, example is the flood plains of the Kinabatangan River in Sabah, Malaysia and in Riau and Bengkulu provinces in Indonesia. The population and survival of these species are seriously endangered due to forest degradation and deforestation, illegal logging, illegal hunting and trade, forest fires, subsistence agriculture and development of agricultural plantations especially oil palm, rubber and acacia plantations. Species diversity, density and biomass of invertebrate communities is estimated to suffer at least 45% decrease from land use transformation of tropical forests to oil palm plantations [23].

1.1.2 Deforestation and green house gas emissions

An assessment of deforestation and forest degradation from 1982 to 2007 [24] showed a 65% loss of forest cover over the last 25 years period or a loss of about 4.2 m ha of forest. While the development of timber plantations contributed to 24%, oil palm cultivation contributed to about 29% forest loss following initial exploitation of the timber source. Deforestation has significant negative impact on loss of biodiversity, changes in climate and rainfall pattern and distribution due to alteration in precipitation retention and rainfall rates. Estimation of the proportion of deforestation to expansion of oil palm cultivation in Indonesia ranged from 11–16%. In Ghana, Forest Carbon Partnership Facility reported that agricultural expansions contribute to 50% overall deforestation however, it was later discovered that only 7% of deforestation is associated with citrus, oil palm and rubber expansion combined [25].

Aside from global warming which initially focused on combustion of fossil fuels for heat and transportation and the subsequent release of CO_2, other anthropogenic activities have also contributed significantly to the release of CO_2 and that conversion of Carbon dense tropical forests is likely to be an important part of these. Stern [26] reported that deforestation contributes to about 18% of the global greenhouse gas (GHG) emissions. Development of plantation on tropical peat lands which are drained leads to oxidation which results in significant CO_2 release over an extended period. Use of fires for land clearing and the emission of methane gas from the effluent treatment ponds of palm oil all contribute to GHG emissions.

1.1.3 Environmental and aquatic pollutions caused by palm oil mill effluent (POME)

POME is the wastewater produced by processing oil palm which has a higher biochemical oxygen demanded (BOD) and chemical oxygen demand (COD) and contains higher concentration of organic nitrogen, phosphorus and different supplement substance [27]. Oil palm trunks, oil palm fronds, empty fruit bunches, palm pressed fibers and palm kernel shells, less fibrous materials such as palm kernel cake and liquid discharge are waste products generated during oil processing [28]. The boom in the oil palm industry has resulted in the setting up of many oil mills for processing of the fleshy mesocarp and kernel. In Malaysia, mills increased from 10 in 1960 to 410 in 2008. For every ton of FFB produced, 600–700 kg of

POME is generated. POME has contributed to environmental pollution due to the production of large quantities of by-products during the process of oil extraction.

POME is generated mainly from oil extraction, washing and cleaning processes in the mill and these contain cellulosic material, oil and grease [29]. The oily waste which forms part of the POME are hazardous pollutants to aquatic environments because they are highly toxic to aquatic organisms when discharged in large quantities into watercourses e.g. river, streams. These goes a long way to contribute to human health hazards and environmental pollution. In Africa, many people depend on rivers as source of water. Sequestering POME into these watercourses creates a great danger for those that depend solely on these water bodies as a source of drinking water and other domestic and irrigation purposes. POME contains high amount of oil and grease (4000 mg/L), COD (5000 mg/L), BOD (25000 mg/L) and total solids (40, 500 mg/L) [29]. In Malaysia, about 44 million tons of POME are produced and are increasing every year [30].

Efficient POME treatment is very necessary to avoid continuous contribution to human health hazards and environmental pollution and also ensure the sustainability of the oil palm industry. Although treatment methods such as waste stabilization ponds, activated sludge systems, closed anaerobic digester and hand application harvester have been employed in the treatment of POME, the use of microalgae has received much attention in current times due to its ability to remove pollutants and also breakdown the organic compounds present in it [31, 32]. Micro algae has the potential of treating waste water such as removal of CO_2 and NOx and high capacity of nutrients absorption [33]. Undoubtedly, microalgae can use the nitrogen and phosphorus compounds in water waste to produce micro algae biomass for various kinds of lipid generation, which can serves as substrate for biofuel production [31].

2. Strategies for sustainability of the oil palm industry

2.1 Increasing the yield of oil palm

Considering the numerous negative impacts associated with oil palm expansion, priority should be given to increasing the yield of oil palm in a unit area rather than expansion of the unit area or if expansion should be perceived then should be done on marginal, degraded or abandoned land to safeguard the forest. There is a significant gap between actual yield and potential yield. Globally, potential oil yield with simulation models are 18.5 t/ha/yr. with commercial plantations actualizing 12 t/ha/yr. and average stagnated productivity of 3 t/ha/yr. by smallholders [34]. In Ghana, potential yield stands at 21 t/ha/yr. of FFB yet 11 t/ha/yr. and 6.0 t/ha/yr. are actualized in commercial plantations and smallholder farms respectively, a decline in yield of about 50% and 71% for commercial and smallholder farms respectively [35].

Increasing the yield of oil palm by 20% in Malaysia and Indonesia will add 7.7 million tonnes of palm oil and this is equivalent to the production from 1.9 million hectare of new plantings [36]. In Ghana, about 327,600 ha of oil palm is under cultivation with 16,600 ha by commercial plantations and 311, 000 ha by smallholder with actual yields of 11 t/ha/yr. and 6.0 t/ha/yr. respectively. Acquisition of quality planting materials coupled with best management practices may increase yields to 17.9 t/ha and 17.6 t/ha for commercial plantations and smallholders respectively and this will avoid the expansion area of 452,533 ha. Should the gap be completely closed i.e. obtaining 21 t/ha/yr. will spare an expansion area of 597, 636 ha [35].

Closing the gap between actual yield and potential yield will have positive impact on the environment since the increase in oil palm productivity will reduce pressure on new lands. There are numerous constraints leading to the suboptimal yields obtained in Ghana and other parts of the world. These includes planting of uncertified seeds (high *dura* and *pisifera* contaminations), unsuitable climatic conditions, poor soil fertility, non-performance of good agricultural practices or best management practices. IOI Corporation Berhad [37] were able to close the gap in excess of 6.0 tonnes oil per ha in 2008.

In other to bridge the gap, the following can be applied

1. Access to high quality (high yielding, early bearing, disease and drought resistant etc) oil palm planting materials

2. Strict adherence to best management practices

3. A switch from conventional agriculture to precision agriculture

4. Support to smallholder and commercial plantations.

2.1.1 Access to high quality planting materials

High quality oil palm planting materials coupled with best management application could significantly and immensely increase the yield and incomes of smallholder farmers and commercial plantations. The switch to *tenera* planting materials increased oil yield about 30% over the *dura* materials which were then planted due to the thicker mesocarp [38]. The advent of biotechnology tools such as the tissue culture have also led to the production of clonal palm. Planting clonal palm as against commercial D x P at the same time and under the same area has also increased yields by approximately 25% over the *tenera* materials [39]. However, clonal palms are limited to few industries and countries but commercial D x P are available in most oil palm growing countries. Unfortunately, many smallholder farmers especially do not plant *tenera* materials and thus have hampered productivity significantly. At plantations and institutional levels, admixture and other human errors such as unintentional use of pollen from a non *pisifera* palms, self-pollination of *dura* parental palms, open pollination of *dura* parental palms by surrounding *dura* palms and imprecise selection of seed or seedlings [40] have contributed to contaminations. Ooi et al. [41] reported an average non *tenera* contamination of 10.7% in independent planting sites surrounding the MPOB's 6 research stations located in Peninsular, Malaysia. While 9.2% were contaminations from *dura*, 1.5% was from *pisifera* contamination. The unintentional planting of *dura* or *pisifera* oil palm seedlings reduces the overall yield and impacts land utilization that would otherwise devoted to more productive *tenera* palms.

In Ghana, [42] reported about 70% *dura* and *pisifera* contamination, comprising of 69.54% *dura* and 0.69% *pisifera* after surveying 97 smallholder farms which were planted on mined lands in three Districts of Central region with the seedlings supplied to the smallholder farmers by a Contracted nursery operator. It is believed that the seedlings supplied to the farmers were uncertified.

The advent of molecular markers have enabled marker assisted selection (MAS). Deployment of these tools could be used as a certification procedure with proper enforcement in place such that germinated seed nuts (at the seed production unit) as well as seedlings (at the nursery stage) to be planted are checked and those that are *tenera* planted. This will assist in bridging the gap between potential and actual yield.

2.1.2 Strict adherence to best management practices

Best management practices (BMP) are cost effective and practical agronomic techniques that focus on reducing yield gaps in oil palm by using production inputs and resources efficiently [43]. The aim of BMP's in oil palm is to increase the productivity of oil palm through improvements in agronomic practices and increased crop recovery. The application of BMP's are site specific because they are structured to address a specific production constraints and biophysiological conditions of individual locations [44]. BMP's can be 'yield taking' and 'yield making' practices [45]. The 'yield taking' increases yield in the short term by improving crop recovery operations with activities including regular harvesting within an interval of 7–10 days, bunches harvested should have a maximum of 5 'loose fruits' on the ground, access roads should be created within the plantations (harvesting paths, foot bridges to help cross drains, ring weeding (about 5 feet) around the palms to allow unhindered access to harvesting and collection of loose fruits and fruit bunches, pruning of dead, diseased and unproductive fronds for air circulation and quick identification of ripe fruits, quick transportation of harvested fruits to the mill within 24 hours after harvesting to help reduce fatty acids in the crude palm oil produced.

The 'yield making' practices also include but not limited to replanting of dead palms as well as removal of non-*tenera* palms to ensure there is optimum planting density (148 palms/ha) with the hope of minimizing excessive inter-palm competition for sunlight and nutrients, construction of drains especially in lowland areas to aid drainage during the wet season and ensure the availability of water during the dry season.

In addition, intercropped plants that are closer to the palm should also be exterminated to avoid intense competition for sunlight, nutrients and moisture. Ideally, plants used as intercrops should be planted about 3 m from the oil palm tree. Regular integrated weed control measures (3 times in a year), planting of cover crops such as *Peuraria phaseoloides* to reduce soil erosion, improve soil tilth, increase soil biological activity and fix nitrogen into the soils. Finally, BMP's should include fertilizer application using crop residues such as empty fruit bunch and pruned frond as well as inorganic fertilizers. Although fertilizer application in oil palm contributes about 30% of the cost of production in oil palm [46] its dividend is great. However, fertilizer application should be preceded by soil nutrient analysis to help decipher the sufficiencies and deficiencies to know the sources of nutrients to be used, the right amount to be applied, the right time and right place to be applied. Globally, the recommended fertilizer application is 260 kg N, 50 kg Phosphorus and 220 kg Potassium ha/yr. although reduced fertilizers at a rate of 136 kg N, 17 kg Phosphorus and 187 kg Potassium ha/yr. may be used [47] for adult palms. In Africa specifically Ghana, a general recommendation of fertilizer for application in matured palm (beyond 5 years) is 6 kg/palm of NKP 10:10:30 in addition to magnesium and boron. Notwithstanding, there is the need to establish multifactorial, multi locational nutrient response trials across different agro-ecological zones in areas where fertilizer will be applied to guide future recommendations for current materials and new materials been bred for optimum yield and productivity.

2.1.3 A switch from conventional agriculture to precision agriculture

Fertilizer application, harvesting, transportation of gathered fresh fruits bunches and loose fruits, weed control, and sanitary control are all potential sources of high production costs. Within the framework of ecologically sustainable development, these processes can be optimized and competitiveness increased.

Precision agriculture is a modern production management system in which new technologies are used to collect, analyze, and manage data in a sustainable manner [48]. Agriculture field machinery such as automated steering systems, data-driven targeted application of fertilizers and pesticides, field robots and drones, soil analysis sensors, and autonomous driving are all part of precision agriculture.

Precision agriculture is based on climatic, edaphic, and agronomic factors that influence yield, and its implementation can improve product quality, yield per unit area, production cost, and environmental impact. Precision agriculture works under three perspectives: agronomic (fertilization and irrigation, ensuring that optimum levels of rainfall and plant nutrients are applied to the palms), environmental (precise fertilization applied such that lower quantities are emitted into the atmosphere, fertilization above the economically optimum levels may lead to detrimental environmental effects such as GHG emissions, nutrient leaching losses, soil acidification, ground water pollutions [49, 50] and finally under economic perspective (increase in the production per unit area, the reduction of inputs or increase in efficiency).

On the basis of spatial and temporal variability, information about different types of soil properties, rainfall patterns, and availability of water courses such as dams, rivers, and streams, as well as the productivity of oil palm within a particular plot, can be electronically retrieved from field record files in real time. With this background knowledge, satellite-controlled precise agricultural machinery and intelligent sensors can be used for targeted seed planting, fertilizer and pesticide application, irrigation, and other agricultural tasks.

2.1.4 Support for smallholder farmers

The RSPO defines smallholders as farmers who grow oil palm with other subsistence crops, where the family contributes the majority of labor and the farm is the primary source of income, and where the planted area of oil palm is less than 50 hectares. However, the Ghanaian interpretation of the RSPO's P & C uses a 40-hectare barrier to designate smallholders, whereas most smallholders produce on plots of less than 10 ha, sometimes in conjunction with other crops.

Smallholders are divided into two groups: those who are assisted and those who are self-sufficient. Supported smallholders have a contractual commitment to sell their FFB to a mill or corporation in exchange for help, but independent smallholders have no contractual duty to sell their FFB or CPO to a mill or buyer [51]. As a result, independent smallholders are responsible for the growth, management, harvesting, and transportation of their FFB to milling centers. Smallholder farmers face major challenges around the world, including access to funds, land tenure issues, agricultural input access, a lack of extension services and supervision support, market access, low bargaining power, opaque pricing mechanisms, and insufficient or lack of capacity to implement certification requirements [51].

Smallholder farmers' yields have been reduced as a result of the aforementioned restraints. Furthermore, many smallholders have been denied certification by the RSPO because they do not meet the RSPO Principles and Criteria. The empowerment of smallholders is required to remedy these deficiencies. These goals could be reached by bolstering current small-holder mechanisms to improve access to financing, productivity, milling efficiency, sustainability, and market access. It would also be ideal if independent smallholders were encouraged to enter into contractual agreements with companies to gain access to improved seedlings, agricultural inputs, and technical extension services who would oversee most farm activities such as fertilizer application, record keeping, lining and pegging, pruning, and other activities to help increase oil palm productivity and increase the income of the smallholder. This is recommended since, in some oil-producing areas, neither the government nor civil society organizations have a mechanism in place to assist small-scale farmers.

2.2 Sustainability certification

Sustainability certification is a market-based process in which consumers pay a higher price for products that meet particular environmental and social requirements during manufacturing and throughout the value chain. The Roundtable Sustainable Palm Oil (RSOP) is the most well-known international certification for palm oil, but national schemes such as the Malaysia Sustainable Palm oil (MSPO) and Indonesia Sustainable Palm Oil (ISPO) exist in Malaysia and Indonesia respectively [52]. Oil palm sustainability certification includes RSPO, MSPO, ISPO, International Sustainability and Carbon Certification (ISCC) and the Roundtable on Sustainable Biomaterials and Sustainable Agriculture Networks (RSBAN) (SPOTT, 2015). MSPO and ISPO are mandatory government-led certification schemes, whilst the RSPO and ISCC are implemented on a voluntary basis [53].

The RSPO, non-profit organization, which was formed in 2004 develops and implements global standards for sustainable palm oil by bringing together stakeholders from the seven sectors of the palm oil industry: oil palm producers, processors or traders, consumer goods manufacturers, retailers, banks/investors, and environmental and social non-governmental organizations (NGOs).

In order to produce Certified Sustainable Palm Oil (CSPO), enterprises must meet a set of environmental and social criteria specified by the RSPO. These criteria, when appropriately followed, can assist to reduce the detrimental effects of oil palm cultivation on the environment and communities in palm oil-producing areas. The RSPO is a global organization with over 4,000 members from 92 countries who represent all aspects of the palm oil supply chain. They have pledged to produce, source, and/or utilize sustainable palm oil certified by the RSPO.

MSPO as at 31st December, 2019 had certified 3.6 million hectares or about 62.26% of the total area under oil palm cultivation using the certification standards. The standards contains principles, criteria and indicators generally aimed at sustainable production with the intention of mitigating the negative social and environmental impacts and encompasses traceability system, good agricultural practices, improved natural resource management and environmental responsibility and compliance with existing regulations [54]. Before the certification of oil palm producers, these standards must have been complied and audited by the RSPO, MSPO and ISPO. The principles of RSPO, MSPO and ISPO are shown in **Table 1**. The principles for certification involves transparency, legal operation, efficient production systems, respect for community and human right, small holder inclusion, rights of workers should be respected and operation that conserve the environment. Within this framework, the MSPO and ISPO have these'd out their own principles to suit them as indicated in **Table 1**.

Carlson et al. [55] reported that certification reduced deforestation by 33%. Saswattecha et al. [56] also reported that RSPO certified producers at the Tapi Basin in Thailand caused lowering of environmental impact (23–34%) compared to non-certified producers (58–75%). Studies in Indonesia indicated that smallholders who adopted the RSPO certification improved their livelihoods and increased their economic returns; they were also better trained in fertilizer, herbicide and pesticide application and handling than non-certified independent smallholders [54].

Although the certification of smallholders are increasingly challenging due to increased oil palm plantation management cost and fees resulting in less adoption of the RSPO certification, the need to put efficient and viable system such

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Principles	RSPO	MSPO	ISPO
Principle 1	Behave ethically and transparently	Management commitment and responsibility	Legality of plantation businesses
Principle 2	Operate legally and respect rights	Transparency	Plantation management
Principle 3	Optimize productivity, efficiency, positive impacts and resilience	Compliance with legal requirements	Protection of the utilization of primary forest and peatlands
Principle 4	Respect community and human rights and deliver benefits	Social responsibility, safety and employment conditions	Environmental management
Principle 5	Support smallholder inclusion	Environment, natural resources, biodiversity and ecosystems services	Responsibility for workers
Principle 6	Respect workers' rights and conditions	Best practice	Responsibility for social and economic empowerment
Principle 7	Protect, conserve and enhance ecosystems and the environment	Development of new plantings	Continuous business improvement

Source: https://rspo.org/about (Accessed: 8 May 2021).

Table 1.
Principles of RSPO, MSPO and ISPO.

as support system for small holders may help the oil palm production to be more sustainable and also go a long way to achieving the UN's Sustainable Development Goals (SDG).

2.3 Circular economy

Oil palm fronds (OPF) and trunks (OPT) from oil palm plantations, as well as EFB, MF, PKS, and POME from palm oil mills, are all biomass waste produced by the oil palm. For every ton of crude palm oil produced, 9 tons of biomass are created [57]. Conversion technologies, on the other hand, have been created and commercialized in order to better convert waste into a more usable product. While biorefineries may be able to convert these wastes into biofuel and other biochemicals, the oil palm industry may require fertilizer, steam, fuel, and electricity for their plantation and manufacturing facilities [58].

The linear economy, in which solid wastes such as OPF and OPT are disposed of to plantations for natural decomposition and liquid wastes such as POME are treated in open pond systems without biogas capture, fails to capitalize on the oil palm's potential economic profits [59]. Through the recycling of biomass waste, the oil palm industries and biorefineries, as consumers of oil palm products, can be targeted to achieve a sustainable circular economy. **Figure 1** depicts the difference between linear and circular economies. In this figure, the linear economy (from i to iv) encompasses harvesting and processing of FFB into CPO after which all the by-products are disposed of at dumping sites and landfills with the consequence of environmental pollution, health hazards and no economic return. However, in the circular economy, there is the treatment, further processing, recycling and re-use of

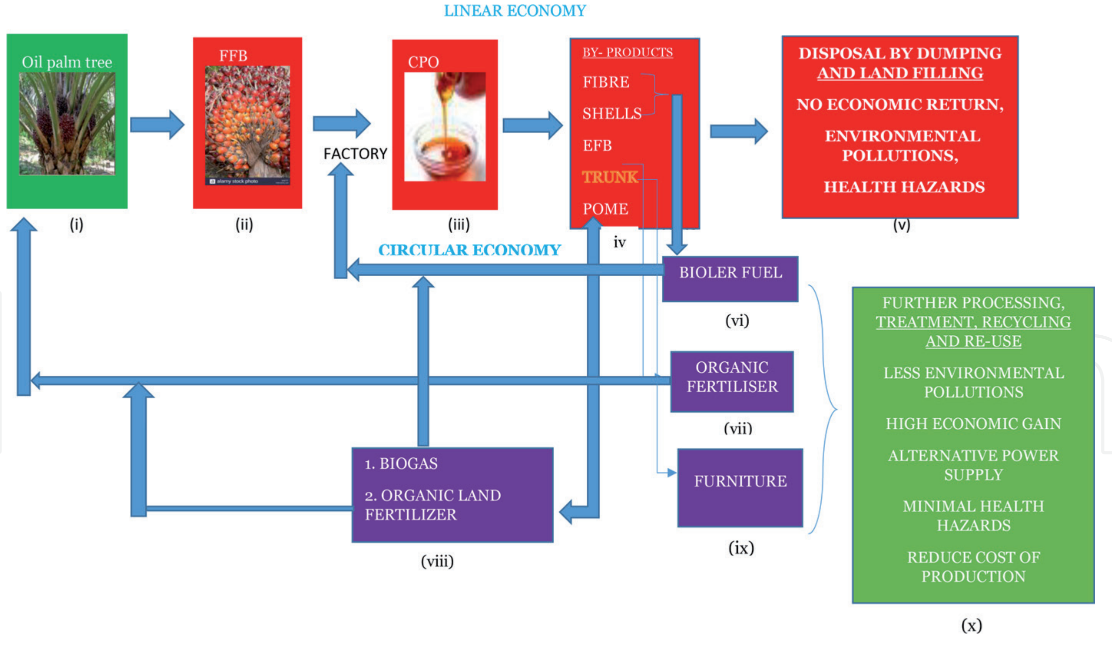

Figure 1.
Distinction between linear and circular economy. (i) Oil palm tree produces (ii) Fresh fruit bunch which is processed at the factory into (iii) CPO. By products (iv) such as fibre, shells, empty fruit bunch, shells, trunk, POME etc. are obtained. All these waste are disposed of by dumping and landfills with consequences of environmental pollution and health hazards. This whole process constitutes the linear economy. In the circular economy, fibre and shells as parts of the by-products (iv) are recycled as boiler fuel (iv) to produce power at the factory for continual processing. Similarly, the EFB from (iv) is processed into organic fertilizer (vii) which is used to fertilize the oil palm tree (i) to increase yield. In addition, POME from (iv) is treated to produce biogas and organic land fertilizer (viii) which goes back to the factory as energy and to the oil palm tree as fertilizer respectively. The trunk in (iv) is further processed into furniture (ix) for office and residential uses. This circular economy leads to less environmental pollution, minimal health hazards, reduce cost of production in (x).

the waste into boiler fuel, biogas, land organic fertilizers, furniture's etc. to produce power for the continuous running of the factory thereby reducing electricity bill, fertilization of oil palm plants to improve the yield and reduce cost of production and furniture for offices.

POME, EFB, decanter cake, and palm pressed fiber can be turned into new value-added goods (fertilizers) or used as an alternative energy source to power the manufacturing plant, thereby converting waste into wealth. Mattresses and cushions made from dried long fiber, renewable energy pellets and briquettes, and animal feed are examples of value-added products. Integrating the circular economy into palm oil production is an effective way to maximize the use of resources (raw materials) while reducing waste, pollution, and energy inefficiencies. This is accomplished by the reduction, reuse, and recycling of materials that are currently underutilized in the linear economy.

The circular economy is without a doubt one of the greatest sustainable development frameworks for the oil palm industry to effectively tackle biomass wastage issues while also avoiding high production costs, lowering negative environmental impact, and conserving resources for future generations. To maintain a competitive edge over the linear economy, better facilities, the incorporation of more advanced technology, and significant investment in the industry are required.

3. Conclusion

Globally, the economic impact of the oil palm cannot be underestimated. It is more productive and versatile among the leading vegetable and fat crops due to its cost effective production, wide use and extreme yield. Notwithstanding, there are environmental challenges that threatens the sustainability of the oil palm notably deforestation, biodiversity loss, increased greenhouse gas emissions and environmental and aquatic pollutions. In this chapter, strategies such as increasing the oil palm yield per unit area (intensification rather than extensification), precision agriculture adoption, support for smallholder farmers, sustainability certification, and circular economy are discussed. Adoption of these measures would greatly increase the oil palm's worldwide sustainability.

Author details

Dickson Osei Darkwah[1*] and Meilina Ong-Abdullah[2]

1 CSIR – Oil Palm Research Institute, Kade, Ghana

2 Malaysia Palm Oil Board, Selangor, Malaysia

*Address all correspondence to: oseidarkwah@yahoo.com

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