



British Journal of Applied Science & Technology
4(33): 4705-4720, 2014
ISSN: 2231-0843



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Possible Contributions of Palm Oil Mill Effluents to Greenhouse Gas Emissions in Nigeria

Elijah I. Ohimain^{1*} and Sylvester C. Izah¹

¹*Bioenergy and Environmental Biotechnology Research Unit, Biological Sciences Department, Faculty of Science, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria.*

Authors' contributions

This work was carried out in collaboration between all authors. Author SCI designed the study and wrote the first draft of the manuscript and managed literature searches. Author EIO reviewed and finalized the manuscript. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJAST/2014/10698

Editor(s):

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Complete Peer review History: <http://www.sciencedomain.org/review-history.php?iid=670&id=5&aid=6181>

Original Research Article

Received 5th April 2012
Accepted 28th April 2014
Published 23rd September 2014

ABSTRACT

Aims: Environmental degradation associated with greenhouse gases (GHG) including methane and carbon dioxide which causes global warming is one the challenges facing global environmental sustainability. This study was designed to assess the possible contribution of palm oil mill effluents (POME) to GHGs generation in Nigeria. The paper also discusses emissions from projection of three growth scenarios (current, low and high

*Corresponding author: E-mail: ehimain@yahoo.com;

growth rates).

Study Design: The study used historical oil palm production data for Nigeria and literature values on POME generation and conversion rate to methane and carbon dioxide.

Place and Duration of Study: Wilberforce Island Nigeria. 2013 – 2014.

Methodology: Literature review and projections

Results: Result show that in 2013, Nigeria produced 4.65 million tonnes of fresh fruit bunch and generated 18.75 million tonnes of POME, which resulted in the emission of 341,164,687.5 m³ of methane and 183,704,062.5 m³ of carbon dioxide under anaerobic conditions. Higher values could be generated for the low and high growth rate scenarios when compared to current growth rate. But under aerobic conditions, the values could be significantly lower. The emissions irrespective of the scenario could impact the air quality and still contribute to global warming.

Conclusion: The methane and carbon dioxide emissions from POME contributing to global climate change could be averted through conversion of POME to biogas, where it could be utilized as energy source for heating, cooking and electricity generation. In addition, palm oil mills can recycle POME to minimize the quantity being discharged into the environment.

Keywords: Anaerobic condition; energy conversion; environment; greenhouse gases; methanogenesis; methanogens; microbes; palm oil mill effluents.

1. INTRODUCTION

Environmental degradation is one of the major challenges confronting environmental sustainability in recent years. Major industrial activities that serve as source of livelihood often generates emission including air (oxides of carbon, nitrogen and sulphur, volatile organic compounds and suspended particulate matters), liquid and solid waste biomass. Several pollutant gases are associated with the emissions and have been variously reported to cause respiratory disease in humans [1]. Biomass undergo degradation and emits greenhouse gases (GHG) which are mainly methane and carbon dioxide (principal gases) and to a lesser extent nitrous oxide. Other less prevalent GHGs include hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride. Globally, efforts are being made to reduce sources of GHG through clean production technologies in the industrial sectors. However, developing countries like Nigeria, less attention is paid to climate change issues. In the recent years, oil and gas activities have been credited to be the major contributor of GHG due to gas flaring during crude oil production and emissions from internally combustion engine used for transportation. Ohimain et al. [2] estimated that about 50% of total energy used globally is provided by petroleum and natural gas. Atadashi et al. [3] stated that about 86% of total transportation fuel is provided by conventional resources such as petroleum. Nigeria is a major producer and exporter of fossil fuel (i.e. petroleum and natural gas). Yet, the country spends substantial part of her foreign exchange earnings for the importation of refined products [4–8]. Besides crude oil production in the Nigeria oil province, the country is also blessed with several mineral resources such as tin, iron ore, coal, lead, zinc limestone, niobium and arable land for agricultural purposes [9]. The Nigerian soil and climate is suitable for the cultivation of several agricultural products including both food and cash crops (including rubber, cocoa and oil palm). Oil palm cultivation and processing is a major sector in Nigeria and its economic importance are often underestimated [10,11].

Presently, Nigeria is the fifth largest producers of oil palm in the world behind Indonesia, Malaysia, Thailand and Columbia. Indonesia and Malaysia contributes about 86% of the total global oil palm output. Thailand and Columbia are two countries that have witnessed massive growth in the oil palm sector in recent years. Nigeria being the country that dominated oil palm production and export before 1972 have not witnessed any considerable growth compare to the four largest producing nations. The Nigeria oil palm growth pattern (Fig. 1), indicated that Nigeria oil palm growth rate is 10,000 metric tonnes per annum from 2004 to 2007 and from 2008 to 2011 the country's productivity was constant. Currently, the government and stakeholders are attempting to revitalize the sector which previous government had abandoned for crude oil [11,12,13]. Nigeria crude palm oil production rate stands at 930,000 metric tonnes in 2013 economic year.

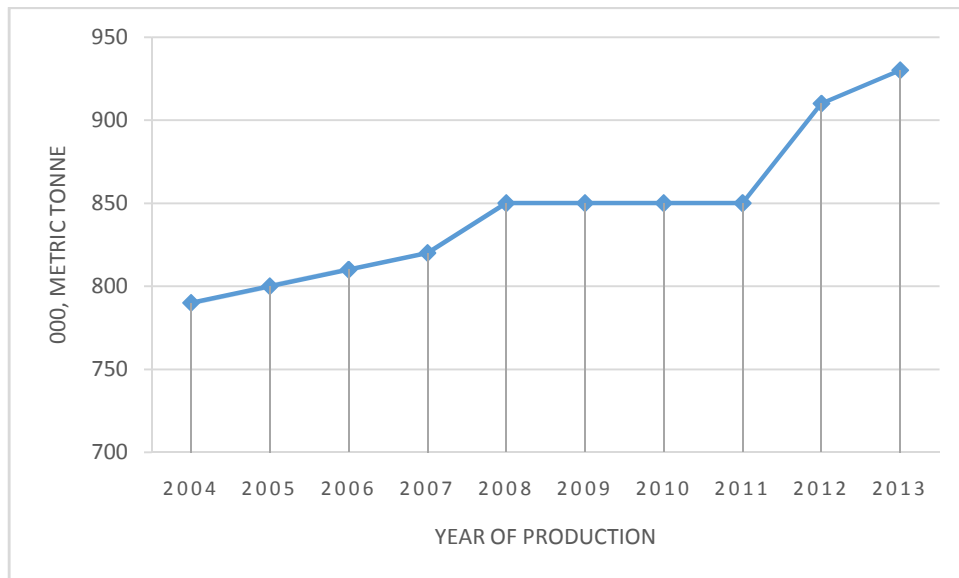


Fig. 1. Crude palm oil production in Nigeria for the period of 10 years (modified from [14])

Nigeria oil palm industry is characterized by three major scales of processors including smallholder/traditional, semi-mechanized and mechanized processors. According to Ohimain et al. [12,15], Ohimain and Izah [16], PIND [17], the smallholders' processors dominated the sector covering over 80% of total output using manual/rudimentary equipment for processing, which often lead to low quantity and quality of crude palm oil. Manual method of oil palm processing is arduous, time consuming and often result to about 25 - 75% loss of CPO [18–20]. Ohimain et al. [21] reported crude palm oil yield of 10 – 13% and 26 – 28% for Dura and Tenera varieties respectively. According to the authors, the Dura varieties are mostly processed by smallholders. The crude palm oil produced by the smallholders is of poor quality with high moisture, impurities and free fatty acid levels [10] and microbial counts and species [22]. Similarly, the semi-mechanized and mechanized palm oil mills account for about 16% and 4% of the sector respectively [23,24]. At least one semi-mechanized palm oil mills is located in all the oil palm producing states in southern Nigeria. The mechanized palm oil mills are few, with some state in the oil palm province not having any. Ohimain et al. [23] and Nwaugo et al. [25] reported that oil palms are mostly found in both wild and plantation in southern Nigeria.

The processing of fresh fruit of oil palm into crude palm oil generates three wastes streams including solid (empty fruit bunch, chaff, palm press fiber and palm kernel shell), liquid (palm oil mill effluents) and gaseous emissions (carbon monoxide, nitrogen dioxide, sulphur dioxide, volatile organic compounds and suspended particulate matters). The palm oil mill effluents (POME) generated in the mills are often discharged into the ecosystem without treatment. Environmental problems are associated with POME due to large volume of water involved [26,27]. Untreated POME, which contains complex vegetative matter, is thick, brownish in color with fibrous materials. POME is a mixture of colloidal suspension including 95-96% (water), 0.6-0.7% (oil) and 4-5% (total solids) [28–31]. POME discharged into aquatic ecosystem, releases foul odour and cause oxygen depletion due to the presence of oil, which could inhibit respiration among aquatic organisms and subsequently cause their death [32,33]. It could also lead to loss of soil flora and fauna [32]. POME poses a challenge to the health of inhabitants and deprive them access to source of drinking water. POME contain several macronutrients including nitrogen, potassium, magnesium, phosphorous, sodium and micronutrient (zinc, copper, cadmium, chromium, iron) [23,34,35]. In addition, it contains high pollution indicators including oil and grease, chemical oxygen demand (COD) and biological oxygen demand (BOD). (Table 1) presents the physicochemical properties of POME. POME contains microorganisms which can degrade the complex polymers of POME (i.e. carbohydrate, protein, oil) to emit methane and carbon dioxide which are GHGs. Oil palm being a major source of lipase producing microorganisms, several lipolytic bacteria, fungi and mold are capable of flourishing on it due to the abundance of nutrient [15,22,23], which aid in the degradation of POME to produce GHGs.

Table 1. Physico-chemical parameters of palm oil milling effluents in Nigeria

Parameters	Ohimain et al. [23]	Ohimain et al. [34]	Awotoye et al. [33]	IFC [35] (Guideline value for vegetable oil processing)
(Scale of production)	Semi-mechanized	Smallholder	-	-
pH	6.56	5.21 – 6.36	5.34	6 -9
DO, mg/l	4.69	2.57 – 4.13	1.25	-
COD, mg/l	1806.33	1231.00 – 2422.00	284.79	250
Total solid mg/l	-	-	517.11	-
Electrical conductivity, μ s/cm	-	-	2.51	-
BOD, mg/l	382.93	254.00 – 1541.00	123.68	50
SO ₄ , mg/l	-	-	65.75	-
NO ₃ , mg/l	-	-	262.26	-
K, mg/l	19.64	9.53 – 29.14	295.74	-
Mg, mg/l	-	-	283.46	-
Na, mg/l	-	-	332.26	-
Ca, mg/l	-	-	252.41	-
N, mg/l	12.87	7.55 – 20.65	-	10
P, mg/l	8.18	5.26 – 8.68	165.65	-
Cd, mg/l	0.03	0.01 – 0.02	-	-
Cu, mg/l	2.44	0.60 – 1.61	-	-
Fe, mg/l	5.62	1.81 – 13.81	183.49	-
Cr, mg/l	2.01	0.61 – 1.68	-	-
Zn, mg/l	-	-	120.95	-
Mn, mg/l	-	-	34.25	-

Major oil palm producing nations are aware of the pollution and GHG emission associated with the processing activities and effort are been made to mitigate the challenges, thereby striving towards quality, environmental conservation through sustainable development and cleaner technology [24,36,37]. Basically, GHGs are the gaseous constituents of the atmosphere that comes from natural and anthropogenic activities that engross and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the earth's surface, atmosphere and clouds covers [38]. In Nigeria, POME has been a major contributor of GHG and it has never been quantified. Therefore, this study is aimed at assessing the potential contribution of POME to GHG emissions in Nigeria. This study will be useful to environmentalists, government and policy makers to curb the effect of GHG and strategize for a more sustainable palm oil production.

2. METHODOLOGY

Baseline information used for this study was obtained from literatures. Data obtained were used to estimate the GHGs (i.e. methane and carbon dioxide) emissions from POME produced in Nigeria for the period of 10 years (2004 – 2013) and projection were made to 2029 on three categories i.e. high and low scenarios and current status.

2.1 Pome Estimation

One tonne of fresh fruit bunch (FFB) of oil palm produces 10 - 30% of oil [16,21,36,39-43], which translate to 0.1 – 0.3 tonnes of crude palm oil with an average value of 0.2 tonnes per one tonne of FFB. This value (0.2 tonnes) and Nigerian oil palm production statistics was used to compute the total FFB produced in Nigeria for the study period. During the processing of FFB voluminous quantity of water is required ranging from 5 – 7.5 tonnes per tonne of FFB [29,44]. Off these, about 50 – 79% ends up as POME [31,33,37,39,45] resulting in a mean value of 64.5% which translated to 4.03 tonnes of POME, that was used to estimate POME production in Nigeria for the period of study.

2.2 Estimation of Methane and Carbon Dioxide

Methane and carbon dioxide account for 65 % and 35% of biogas [32,46–50]. They are the principal gases emitted from POME. Yussof [36] and Ma [51] estimated that about 19.6m³ of biogas is generated from 1 tonne of FFB. Sridhar and Adeoluwa [32] reported that biogas yield from POME is approximately 20 to 28 (m³-CH₄/m³-biogas). Ng et al. [52] estimated that one tonne of POME could produce 28m³ of biogas. Other studies estimated that about 28 m³ of biogas is produced from 1 m³ of POME [38, 48-50,53,54]. Therefore 28m³ being largely reported was used for the computation.

2.3 Estimation of Future Scenario

The prediction of world palm oil was rated to be 21.12 million metric tonnes (MMT) in 2010 [55]. This projection led Ugbah and Nwawe [56] to state that Nigeria would produce 1.8MMT of crude palm oil by 2010. These rate was far from reality in 2010, the country produced 850, 000 metric tonnes of crude palm oil, being below 50% of the projection rate. Therefore, in this study, a three year interval and three projections were made including high, low and current status. A high projection was based on the growth rate of oil palm in the past three years (2011 – 2013), which is 8.60%. The low projection was based on average of the three years growth rate, which is 4.37%, while the current projection was based on the 2012/2013

growth rate (2.15%) of oil palm in Nigeria. The various projection category was used to compute the FFB, POME generation, Biogas potentials, Methane and carbon dioxide emission rate from 2017 – 2029.

3. RESULTS AND DISCUSSION

The production of crude palm oil involves several processing stages (Fig. 2). These processes are mainly carried by smallholders' processors, which accounts for over 80% of the oil palm processing industry. However, the semi-mechanized processors undergo all the processing steps carried out by smallholders except re-fermentation of palm press fiber to obtain second grade oil called palm press fiber oil. The mechanized processors are carried out using co-generation system and are devoid of fermentation and sieving processes. Irrespective of the method of processing, POME is generated in the sterilization, digestion and clarification phases in the palm oil mills. POME remained one of the largest liquid waste generated in industrial activities in Nigeria. (Table 2) presents the quantity of POME generated in Nigeria for the period of study. The result shows that Nigeria produces 3.950 to 4.650 million tonnes of FFB producing 790,000 to 930,000 metric tonnes of crude palm oil using 24.687 to 29.062 million tonnes of water for processing and generating 15.923 to 18.745 million tonnes POME for the past 10 year, with an increasing trend (Fig. 1). The FFB production reached 4,650,000 metric tonnes in 2013 which led to the production of 930,000 crude palm oil, while utilizing 29,062,500 tonnes of water and releasing 18,745,312.5 metric tonnes of POME.

Table 2. FFB to POME generation palm oil mills in Nigeria for the period of 10 years

Year	Total FFB produced, metric tonne	CPO production, metric tonne	Total water used in palmoil processing, metric tonne	POME, metric tonne
2013	4,650,000	930,000	29,062,500	18,745,312.5
2012	4,550,000	910,000	28,437,500	18,342,187.5
2011	4,250,000	850,000	26,562,500	17,132,812.5
2010	4,250,000	850,000	26,562,500	17,132,812.5
2009	4,250,000	850,000	26,562,500	17,132,812.5
2008	4,250,000	850,000	26,562,500	17,132,812.5
2007	4,100,000	820,000	25,625,000	16,528,125.0
2006	4,050,000	810,000	25,312,500	16,326,562.5
2005	4,000,000	800,000	25,000,000	16,125,000.0
2004	3,950,000	790,000	24,687,500	15,923,437.5

The prediction of oil palm production according to the projection category are presented in (Table 3). On a high scenario, Nigeria will produced 7,024,284.32 metric tonnes of FFB, releasing 28,316,646.17 metric tonnes of POME by 2029. In the low scenario, the country could produce 5,791,973.95 metric tonnes of FFB while generating 23,348,894.97 metric tonnes of POME before 2030. But for the 2013 oil palm growth rate (current status), the country will only produce 5,184,206.60 metric tonnes of FFB, while releasing 20,900,042.23 metric tonnes of POME by 2029. The various projections could be influenced by several factors such as prices, policy, and contributions from stakeholders and the government. Therefore, it is envisaged that the number of oil palm estates and hectares of oil palm estate could increase significantly from its current status. According to Ugbah and Nwawe [56], oil palm enterprise could increase due to increased demand, which has led private sector to invest in the establishment of new oil palm industries and the expansion of existing ones.

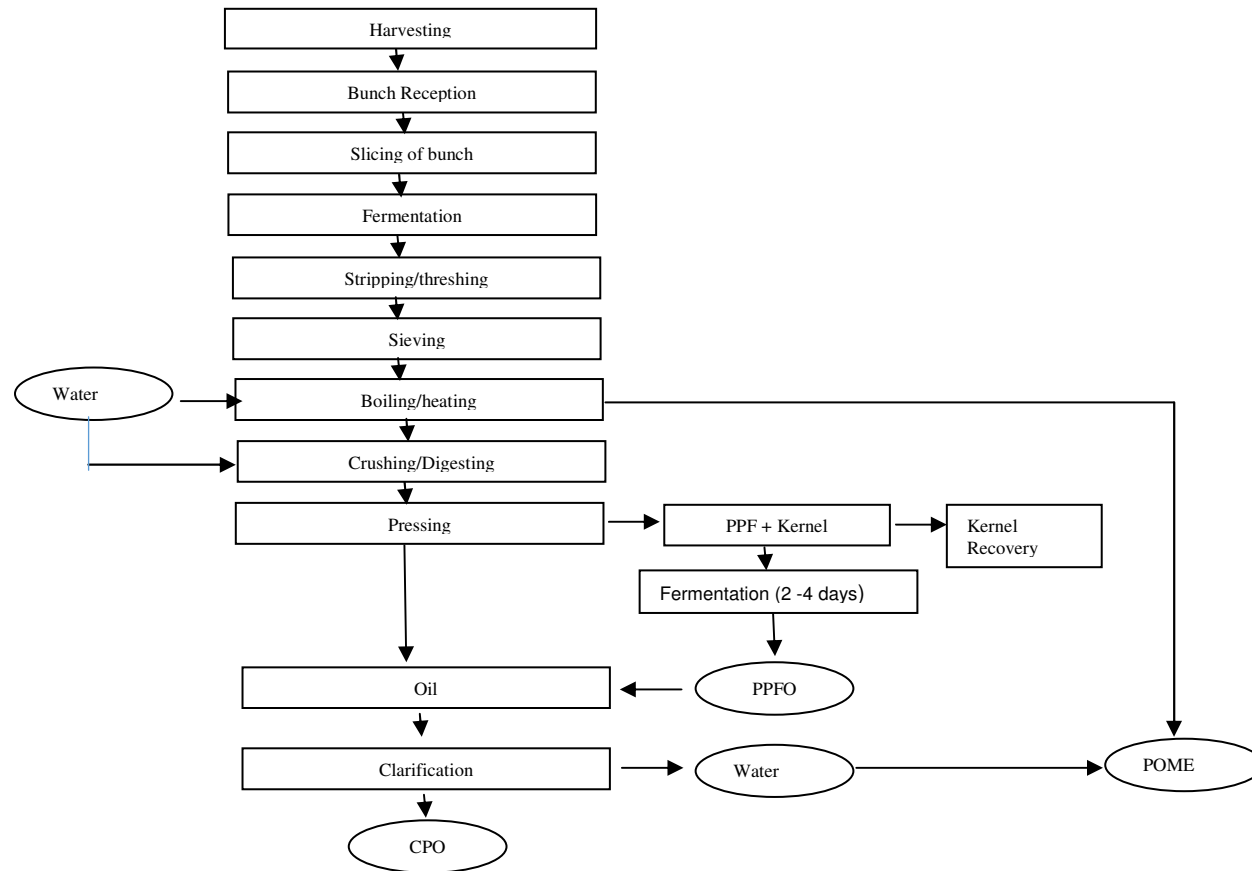


Fig. 2. The processes of POME generation from FFB in Nigeria [1,10,12,16,21,22,27,34,37]
 (POME = palm oil milling effluents; PPFO= palm press fiber oil; PPF = palm press fibre; CPO = crude palm oil)

Table 3. Predicted production of FFB and POME (2017–2029) on the various projection scenario

Projection category	Output, metric tonnes	2017	2020	2023	2026	2029
High	Total FFB	5,049,900.00	5,484,191.40	5,955,831.90	6,468,033.44	7,024,284.32
	Total POME	20,357,409.38	22,108,146.58	24,009,447.35	26,074,259.81	28,316,646.17
Low	Total FFB	4,858,785.00	5,076,944.45	5,304,899.26	5,543,089.24	5,791,973.95
	Total POME	19,586,977.63	20,466,432.30	21,388,375.12	22,345,578.49	23,348,894.97
Current status	Total FFB	4,752,300.00	4,856,850.60	4,963,701.31	5,072,902.74	5,184,206.60
	Total POME	19,157,709.38	19,579,178.98	20,009,920.92	20,450,139.17	20,900,042.23

POME, which is a mixture of oil, water and fibrous materials, contains nutrients and array of microorganisms. POME microorganisms are mainly acid formers, hydrocarbons degraders [23,27] and methanogen utilizers [57]. These microorganisms are able to utilize the minerals and polymers found in POME through degradation to form methane. Basically, POME contain complex polymers (protein, carbohydrate, lipids) which are acted upon by hydrolytic microorganisms such as *Clostridium* species, *Bacillus* species (converts Proteins to amino acid and peptides), *Clostridium* species, *Staphylococcus* species (degrade Carbohydrate to sugar) and *Clostridium* species, *Staphylococcus* species (converts lipids to fatty acid, alcohol). These processes is closely followed by acidogenic bacteria including *E. coli*, *Staphylococcus* species, *Pseudomonas* species, *Bacillus* species, *Desulfovibrio* species (which converts amino acids to fatty acids, acetate) and *Clostridium* species (conversion of Sugar to metabolic intermediary). Similarly, *Clostridium* species (acetogenic bacteria) is able convert fatty acid or alcohol to hydrogen or acetate. Another group of microorganism's are the methanogens such as *Methanobacterium* species which converts hydrogen and carbon dioxide to methane while aceticlastic methanogens like *Methanococcus* species converts acetate to methane and carbon dioxide.

(Fig. 3) present estimates of biogas produced from POME based on historical data and future projections. It is estimated that that Nigeria generated 445,856,250 m³ of biogas in 2004 which reached 524,868,750m³ in 2013. However, based on current oil palm growth rate, Nigeria could produce 585,201,182.50m³ by 2029. For the low and high scenario, 653,769,059.30m³ and 792,866,092.6m³ of biogas could be produced by 2029 respectively. Methane and carbon dioxide are the main principal gases emitted from POME.

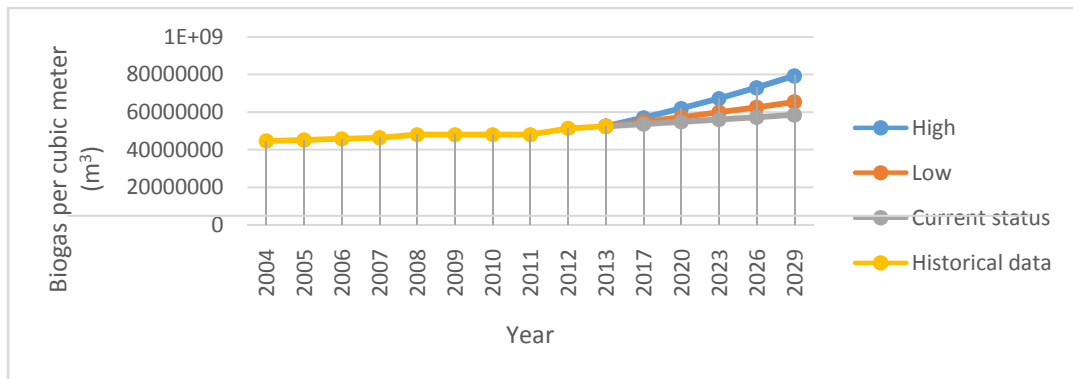


Fig. 3. Potential biogas production from POME in Nigeria and future projections

(Figs. 4 and 5) presents the possible methane and carbon dioxide generation from POME respectively. Methane being the highest GHGs generated from POME in the proportion of about 65% to 35% carbon dioxide. The amounts of these gases produced are depended on the quantity of POME generated in the year of study. However, for the past 10 years, the methane and carbon dioxide production from POME that have remained untapped ranged from 293 to 341 m³ and 158 to 183 million m³ respectively. Based on the projections made methane emissions could reach 515,362,960.20 m³ (high scenario) 424,949,888.50 m³ (low scenario) and 380,380,768.60 m³ (current status scenario) by 2029. Like methane, carbon dioxide emission of 277,503,132.40 m³, 228,819,170.80 m³ and 204,820,413.90 m³ for high, low and current status scenarios respectively before 2030.

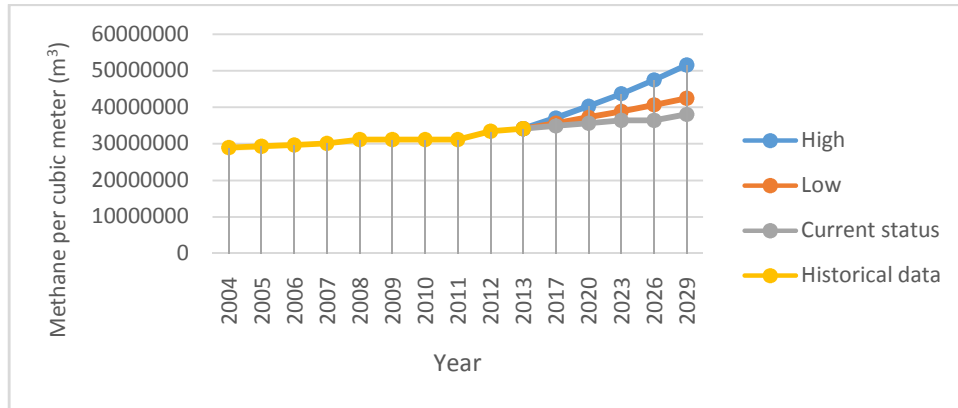


Fig. 4. Historical and projected value of methane production from POME in Nigeria (2004 – 2029)

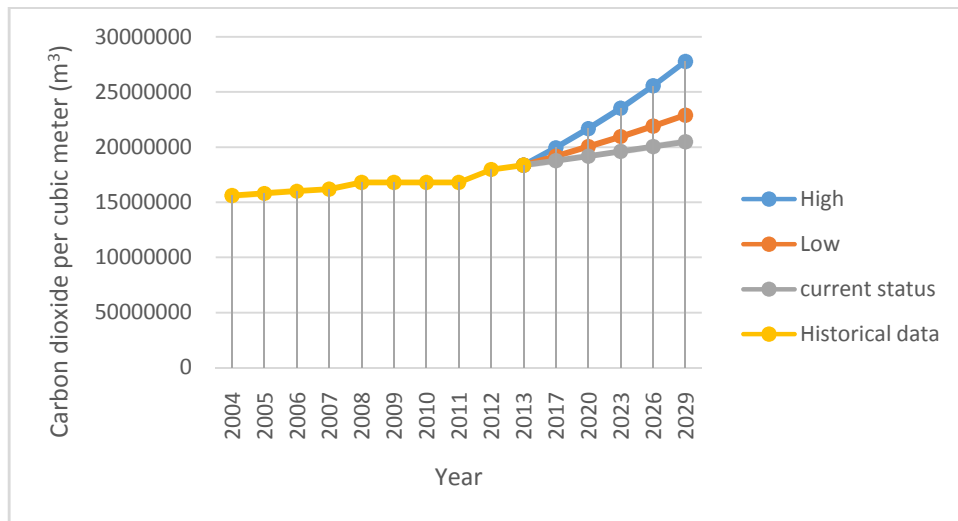


Fig. 5. Historical and projected value of carbon dioxide production from POME in Nigeria (2004 – 2029)

However, (Fig. 6) presents the growth rate of greenhouse gases contribution from POME in Nigeria based on the historical study period. In the year 2004, the growth rate was 1.27%. The emission rate followed the pattern of POME generation (Table 2). By 2008, the emission rate rose to 3.53% due to increased crude palm oil production, there after the industry remain stagnated leading to the same emission rate for 4 years (2008 – 2011). By 2012 the emission rate rose to 6.59% which decline to 2.15% in 2013 economic year. Generally, the emissions have been on the increase due to increase POME generation in the period of study. Although, anaerobic conditions are generally necessary for biogas formation, hence the methane and carbon dioxide actually reported during the study and projection period could be significantly less. Under aerobic conditions, POME could be degraded by hydrocarbon degrading microbes to carbon dioxide and water without methane production.

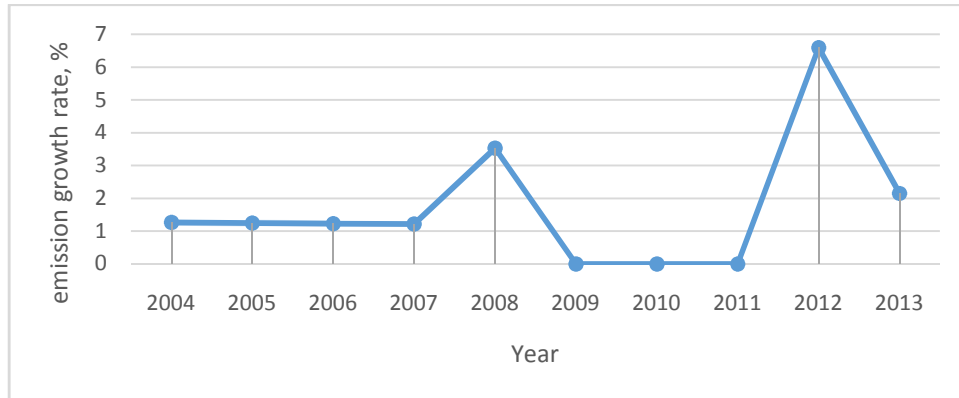


Fig. 6. Methane and carbon dioxide emission growth rate from POME in Nigeria

Biogas are basically a mixture of methane and carbon dioxide and of other gases. In Nigeria, POME have not been adequately utilized. The discharge of POME into the environment produces methane and carbon dioxide emissions. Methane is known to be 21 times more lethal on greenhouse gases effect compared to carbon dioxide [50,58]. The capture of energy from POME could prevent GHG such as methane and carbon dioxide emissions [54]. The increased population growth have led to enhanced emission of carbon dioxide into the environment. This have an effect on economic growth, energy prices, behavioral pattern of biological diversity and seasonal temperatures change [59]. Carbon dioxide is utilized by autotrophs including carbon dioxide utilizing microorganisms, plants and algae. Carbon dioxide emissions also promotes climate change, causing loss of biodiversity (flora and fauna), and ecosystem deterioration. The increase in atmospheric carbon dioxide has been credited to anthropogenic activities, which have led to increased global mean temperature. Yussof [36] reported 0.3 – 0.6°C increase in 19th century. Ali- Elredaisy [60] projected that the average global temperature could rise to 1.5 – 4.5°C by 2030. Wikipedia [61], Vijaya et al. [38] reported increased carbon dioxide emissions from 1.1% in 1990s to about 3% in 2000 in both developing and developed countries. Lam and Lee [50] reported that if carbon dioxide from POME is not captured, the contribution of palm press fiber and palm kernel shell for processing could increase the total carbon dioxide emission to 68.2 – 279.6 kg per tonne of crude palm oil. The authors also estimated that 1200 – 4900 million kg of carbon dioxide was emitted from Malaysia palm oil mills in 2009 excluding methane emission from POME and oil palm photosynthetic rate. Vijaya et al. [38] stated that when biogas is captured, the total GHG emissions drops to 137.63 kg carbon dioxide eq per tonne of crude palm oil, suggesting that there is a need to capture biogas from POME and use it as renewable energy.

Foo and Hameed [47] reported that methane from POME have a heating value of about 34.5 MJ/m³ with high reaction and performance process. Therefore, it is possible to tap energy like biogas from POME to prevent the attendant environmental impacts associated with the discharge of POME. Again, it may also impact positively through reduction in the dependency on fossil energy as kitchen fuel, transportation fuel and electricity supply. Hence, the production of biogas provides two benefits including environmental sustainability and energy production. The use of dwindling conventional fuel has been attributed to GHG emissions. King and Yu [62] reported that POME biogas could contain up to 97% methane which when adequately utilized could lead to nearly zero emission which is environmentally sustainable. In Malaysia for instance despite producing about 43% of the total oil palm

supply, only about 10% of the palm oil mills tap biogas from POME and utilize it as energy sources during oil palm processing [38]. The reasons for poor utilization of POME for energy generation in Malaysia are similar to Nigeria, including poor infrastructure and energy conversion facilities.

The conversion of POME to biogas involves the use of several aerobic and anaerobic bioreactors. Anaerobic reactor have proven to produce high methane concentration as compared to aerobic reactor. The different anaerobic bioreactors such as up-flow anaerobic sludge blanket, up-flow anaerobic sludge fixed-film, modified anaerobic baffled, continuous stirred tank reactor, anaerobic pond, anaerobic digester, expanded granular sludge bed, ultrasonic membrane anaerobic system, membrane anaerobic system etc can be technologically challenging especially in developing countries like Nigeria. Beside cost, operational condition such as pH, temperature, microbes, nutrients and organic loading rate could also be a major problem. Nigeria, being a major crude oil producing nation, may be reluctant to embrace biogas production from POME since its cost of production is higher than that of crude oil. Therefore, the economic feasibility of biogas production from POME may be uncertain.

4. CONCLUSION

Oil palm extraction requires voluminous quantity of water for processing, which a substantial amount end up as POME. In Nigeria, POME is discharged into the environment without treatment, where it causes detrimental effects due to its high pollution potential (BOD, COD, and oil and grease content). POME is biodegradable by lipolytic microorganisms that flourish in them leading to emission of GHGs such as methane and carbon dioxide, which are the principal causes of global warming. This study found out that emissions from POME could contribute significantly to global warming in Nigeria. We conclude that, beside the POME being utilized for biogas production, palm oil mills could recycle the waste water to reduce the quantity being discharged into the environment. This could lead to reduction of GHG emission being contributed by POME.

ACKNOWLEDGEMENTS

The authors which to thank the three anonymous reviewers of the manuscript for their contributions.

COMPETING INTERESTS

Authors declare that there are no competing interests.

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