International Journal of Sustainable Energy and Environmental Research
2024 Vol. 13, No. 2, pp. 52-61
ISSN(e): 2306-6253
ISSN(p): 2312-5764
DOI: 10.18488/13.v13i2.3772
© 2024 Conscientia Beam. All Rights Reserved.

Daily and spatial generation of palm oil mill effluent in determining volumetric capacity for bio-methane planning

E.B. Tambe[1+]
A.U. Okonkwo[2]
I.E. Mbuka-Nwosu[3]
S.E. Unuafe[4]
C.O. Cookey[5]
M.F. Umunna[6]

[1,4]*Department of Environmental Management & Toxicology, Delta State University of Science and Technology, Ozoro, Nigeria.*
[1]*Email: tambebe@dsust.edu.ng*
[4]*Email: unuafese@dsust.edu.ng*
[2]*Department of Environmental Management, Chukwuemeka Odumegwu Ojukwu University, Uli, Nigeria.*
[2]*Email: auokonkwo@yahoo.com*
[3]*Department of Environmental Management, Federal University of Technology, Owerri, Nigeria.*
[3]*Email: mbukai@yahoo.com*
[5]*Department of Crop Science and Technology, Federal University of Technology, Owerri, Nigeria.*
[5]*Email: China.mbuka@yahoo.com*
[6]*Department of Agricultural and Bioresources Engineering, Delta State University of Science and Technology, Ozoro, Nigeria.*
[6]*Email: umunnam@dsust.edu.ng*

(+ Corresponding author)

Article History
Received: 2 April 2024
Revised: 22 May 2024
Accepted: 31 May 2024
Published: 6 June 2024

Keywords
ADAPALM
Bio-methane
Communities
Daily generation
Planning
POME.

ABSTRACT

Cumulative determination of wastes generated per day and in different periods is a necessary prerequisite for planning waste recovery and averting environmental degradation. This study examined palm oil mills (small, medium and large-scaled mills) in the oil palm (Elaeis guineensis) industry at Ohaji/Egbema Local Government Area (LGA), Imo State, Nigeria for daily and periodic generation of palm oil mill effluent (POME). Survey research design was used. Eight catchment communities of the large-scaled mill, Agricultural Development Authority Palm (ADAPALM) were categorised into three strata in relation to the number of small-scaled mills in each community. In each stratum, a community was randomly sampled. Nine small-scaled mills were sampled from the three communities using proportional sampling. The lone medium and large-scaled mill in the study area represented the other scales of milling. For small and medium-scaled mills, the volume of POME generated was measured from the dimensions of the vessels where POME was stored, while that of large-scaled mill was obtained from industrial records. Independent sample T-test revealed an average of 17.574±0.408m3 POME/day and 15.509±0.465m3 POME/day in wet and the dry seasons respectively ($p<0.01$). Similarly, within milling-scales, ANOVA and T-test showed that significant variations occur ($p<0.01$). Wilcoxon's test revealed that there was no significant difference ($p>0.05$) in the median functional small-scaled mills across seasons, hence functionality did do not influence the volume of POME generated across seasons. The findings revealed the copious volume of POME generated in the area and the required volumetric requirements to planning its collection and transformation to wealth.

Contribution/Originality: The study has provided empirical data for cumulative POME generated per day for a wider scale of milling (small, medium and large-scaled mills) and across seasons (wet and dry). Also, following the location-specific need for such data in bio-methane planning in the study area, no research had provided such data.

© 2024 Conscientia Beam. All Rights Reserved.

1. INTRODUCTION

Waste generation is a footprint of every human activity, and its growing volumes challenge the prospect of a healthy and productive planet. One of the sectors that generate waste is agriculture, such as in oil palm industry, where copious volumes of wastewater termed palm oil mill effluent (POME) are being generated in the course of processing fresh fruit bunches (FFB) to palm oil (Hoyle & Levang, 2012; Elijah Ige Ohimain & Izah, 2014). In some regions of the world, the generated POME is indiscriminately disposed while others are transforming it to wealth (Chotwattanasak & Puetpaiboon, 2011; Edward, Idowu, & Oyebola, 2015; Koura, Kindomihou, Dagbenonbakin, Janssens, & Sinsin, 2016). The need to transform POME to wealth is associated with increasing environmental concerns linked to fossil fuel usage and the search for renewable energy options to sustain economies and human wellbeing. Consequently, the poor environmental practice of indiscriminately disposing POME is not only losing the valuable energy embedded in POME, but also weakening the quality of the immediate environmental compartments in the regions where it is produced, hence undermining the prospect of achieving human goals and aspirations (Eno, Antai, & Tiku, 2017; United Nations, 2020).

In order to chart a sustainable pathway in managing the agricultural wastewater, define the future we want, and preserve the ecological base for development, a determination of POME generation is essential in defining the volumetric capacity to collect and process the wastewater to bio-methane (Franco, 2013; Koura et al., 2016; Poh, Yong, & Chong, 2010; Zupančič & Grilc, 2012). However, POME generation varies in space and time. Consequently, determining the volume produced in a particular location and period can provide a unique tool and is an essential requirement in planning POME to bio-methane for that area and promote access and utilisation of green energy.

The link between the volumes of POME generated, collection, bio-methane development and sustainable energy developments are captured in sustainable development goals and human sustainability agenda (United Nations, 2017, 2020). According to United Nations (2017) on the highlight of the sustainable development goals, sustainable energy development captures goal number 7 on affordable and clean energy; goal number 11 on sustainable cities and communities; and goal number 12 on responsible consumption and production. These goals also embrace the tenets of climate-smart agriculture, which is premised on agricultural practices that demonstrate increased productivity, reduced emissions and enhanced resilience (Klauser, 2021; Leakey, 2019). Following the interconnectedness of all the sustainable development goals (Anukwonke, Tambe, Nwafor, & Khired, 2022; Cramer et al., 2018) relegating the pathways of achieving sustainable energy development weakens their contributions to the attainment of these goals and impedes the progress of society. This means that if the tenets necessary for the collection of POME and transformation to biogas energy are relegated, such as absence of POME data and its dynamics for informed decision making in the oil palm industry, the wastewater will be indiscriminately disposed and poorly managed (United Nations, 2020). Consequently, the POME producing communities will continue to practice unsustainable agriculture, suffer environmental degradation, face insufficiency in energy access and increase vulnerability to poverty.

Ohaji/Egbema Local Government Area (LGA) of Imo State, Nigeria is one of the many POME generating community and energy-stressed LGAs of the country, though it is the home of the largest industrial palm oil mill, Agricultural Development Authority Palm (ADAPALM) in Southeast Nigeria with milling capacity of 30 tonnes FFB/hour (Anyaoha, Sakrabani, Patchigolla, & Mouazen, 2018). The large-scale mill has an agricultural land surface area of 4,310ha, with the catchment communities having a medium-sized mill and many small-scaled palm oil processors. While these palm oil processing mills are partially dependent on fossil fuel (diesel) which usually experiences price hikes and scarcity, the mills also produced copious volumes of POME. The produced POME in these mills is indiscriminately disposed, especially in small-scaled mills. This approach is interconnected to impacts on environmental health, human wellbeing and challenges the aspirations of realising climate-smart agriculture (Anukwonke et al., 2022; Crippa et al., 2021). However, the generated POME could be collected and harnessed to

© 2024 Conscientia Beam. All Rights Reserved.

produce bio-methane for cooking fuel or added to national grid to boost electrical energy access in communities, derive other values (such as soil nutrient), hence averting its degrading effects on the environment.

Tambe, Okonkwo, and Eme (2022) has developed a model on the determinants (milling scale, seasons, type or variety of FFBs, volume of crude palm oil) of volume of POME generated by any mill at an instance in ADAPALM and surrounding communities. However, a cumulative estimate of the average volume of POME generated in these mills (all the mills in ADAPALM and surrounding communities) per day and across seasons had not been addressed. This study therefore has addressed this gap with a view to defining an initial volumetric capacity required to guide resource allocation for POME collection, bio-methane planning in the area and promote climate-smart agriculture.

2. MATERIALS AND METHODS

Study area: The study was carried out at Ohaji/Egbema LGA. The headquarters of the LGA is Mmanhu-Egbema. The coordinates of its location is between latitudes 5°10'0"N and 5°20'0"N of the equator and longitudes 6°30'0"E and 6°50'0"E (Figure 1). It is among the twenty-seven LGAs that make up Imo State of Nigeria and also the location of the largest oil palm producing area in Southeast Nigeria. Here, the palm oil processors operate three levels of milling scales -small, medium and large-scaled mills. Several communities constitute the LGA. However, the study focused on the eight catchment communities of the largest oil palm plantation (ADAPALM). They include Amafor, Ohoba, Etekwuru, Obille, Obosima, Agwa, Oloshi and Assa. The surface area of Ohaji/Egbema is 897.996km^2. As at the year 2006, the population of the area was 182, 891 with a population growth rate of 3.19% (National Population Commission, 2010).

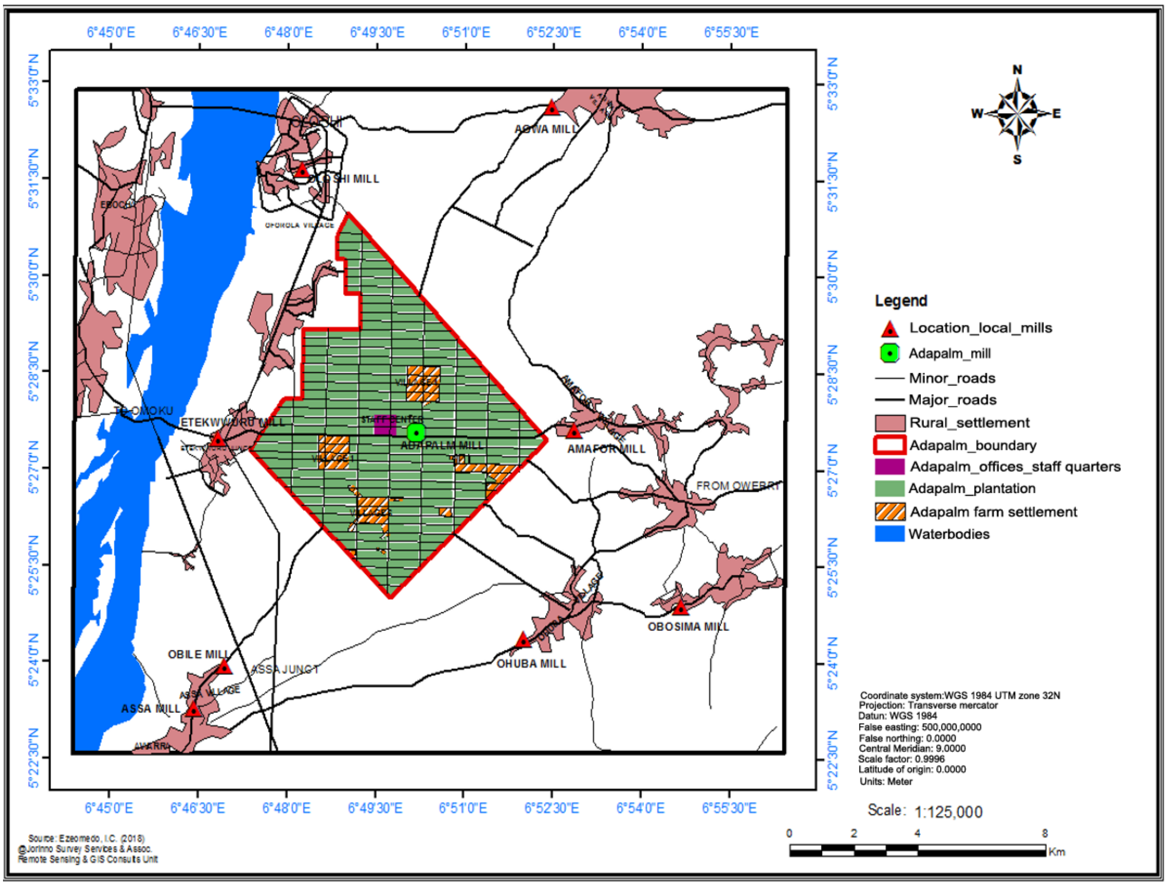

Figure 1. Map of Ohaji/Egbema LGA showing ADAPALM and catchment communities.

Source: Ezeomedo (2018).

© 2024 Conscientia Beam. All Rights Reserved.

Research design, sampling techniques, data collection and statistical analysis: The study employed survey research design. The catchment communities of ADAPALM were grouped into three strata based on number of small-scaled mills found in each of the community. Based on this grouping method, the strata were: 1-5, 6-10 and 11-15 small-scaled mills (Table 1). From each of the strata, one community was randomly sampled. From the sampled communities (Ohoba, Amafor and Etekwuru), nine small-scaled mills were sampled in total. The number of mills sampled in each community was in proportion to the number of mills in the community. The single large and medium-scaled mills represented the other levels of milling scales. Since the generated POME was usually stored in cylindrical vessels for small and medium-scaled mills, it was measured using the dimensions of the vessels ($\pi r^2 h$; $\pi = 22/7$, r=radius, h=height of vessel)- volume of cylinder (Elijah I Ohimain, Izah, & Obieze, 2013; Poh et al., 2010). For the large-scaled mill, data on POME generated was obtained from the industry. For each of the sampled small, medium and large-scaled mills, a total of twenty-one volumes of POME samples were measured. The measurements were done in consecutive days for each crop seasons (June to September 2020, low crop season – low levels of production of palm oil) and (January to March 2021, high crop season – high levels of production of palm oil). This was done in order to understand non-functional day (s) in these mills due to technical failures, cultural practices among others and their effects on average volume of POME generated. In each of the eight communities, all the small-scales mills and functional mills were counted in both low and high crop seasons.

Data was analysed using Statistical Package for Social Science (SPSS, version 22). Mean difference of daily generation of POME across seasons was determined using independent sample T-test. Within milling-scales, ANOVA and T-test were used to determine if significant variations occur in POME generation. Wilcoxon's test for matched pairs was used to determine the average (median) variation of functional small-scaled mills across crop seasons in order to assist in decision making when allocating resources for POME recovery.

Table 1. Sampling small-scale mills from communities for measuring volume of POME.

Number of mills in communities	Name of communities	Name of sampled communities	Number of sampled small-scale mills for volume of POME measured in each sampled community
1-5	Etekwuru, Obille	Etekwuru	1
6-10	Obosima, Amafor, Assa, Oloshi,	Amafor	3
11-15	Ohoba, Agwa	Ohoba	5

3. RESULTS AND DISCUSSION

3.1. Overall Generation of POME per Day Across Seasons

The overall findings revealed that the volume of POME generated per day in ADAPALM and palm oil mills in its catchment communities significantly ($p<0.01$) varied across seasons, with more wastewater being produced in the wet season (Tcal=3.341, Df=40, Ttab=2.021, p=0.002) (Figure 2). In the wet season, $17.574 \pm 0.408 m^3$ of POME was generated per day while in the dry season; $15.509 \pm 0.465 m^3$ of POME was generated per day. This means that for an initial allocation of volumetric vessels to collect POME in ADAPALM and catchment communities, volumetric vessels of minimum cumulative capacity of$17.574 \pm 0.408 m^3$ is required at the mills. The variation of average volume of POME generated per day and across seasons in the study area could be attributed to increasing moisture content from dry to wet season.

© 2024 Conscientia Beam. All Rights Reserved.

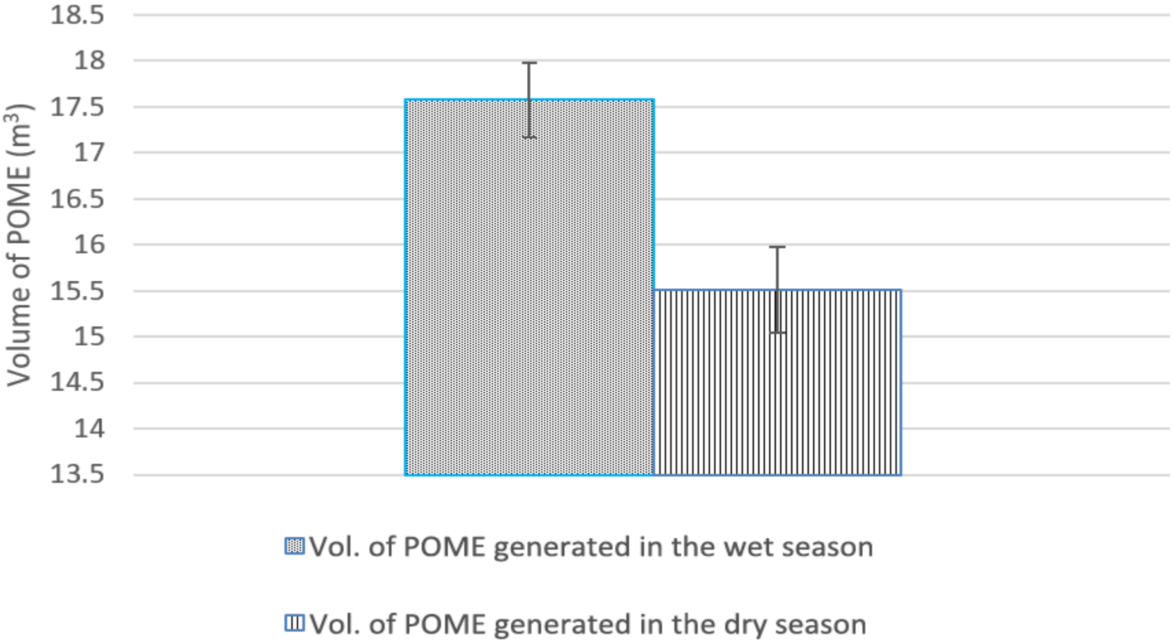

Figure 2. Volume (m^3) of POME generated per day in study area across seasons.

3.2. Volume of POME Generated per Day in Milling Categories

Volume of POME generated in small-scaled mills and functionality of the mills: Considering individual small-scaled mills and the variation of volume of POME generated, the mean volume of POME produced per day for the nine sampled small-scaled mills were compared using One-way Analysis of Variance (ANOVA). The study revealed that the volume of POME generated per day significantly ($p<0.01$) varied across mills (Df=369, F=6.326, p=0.000) (Table 2).

Table 2. ANOVA of the volume of POME generated per day in small-scaled mills.

Test	Sum of squares	Df	Mean square	F	Sig.
Between groups	538093.991	8	67261.749	6.326	0.000
Within groups	3923673.185	369	10633.261		
Total	4461767.176	377			

Pairwise comparison using Duncan Multiple Range Test (DMRT) revealed that there was a significant difference ($p<0.05$) in the volume of POME generated per day between mill 9 and all other mills sampled for the study (Table 3). Mill 9 was observed to be relatively well organised when compared to all the other sampled small-scaled mills in the study area. This small-scaled mill (mill 9) was found to be spacious for visitors to sit, has concreted floor and conveniently accommodate the activities and products of the millers. These values of mill 9 could be some contributing and favourable factors that were attracting millers in the mill, hence significant contribution to POME generated per day from this mill.

Table 3. Mean difference of volume of POME generated per day across small-scaled mills.

Small-scale mills	Mill 1	Mill 2	Mill 3	Mill 4	Mill 5	Mill 6	Mill 7	Mill 8	Mill 9
Mean	76.51^{ab}	34.26^{a}	61.49^{ab}	87.71^{b}	69.29^{ab}	62.23^{ab}	97.92^{b}	83.35^{ab}	177.36^{c}

Note: a, b, c: Means with similar or overlapping subscripts indicate no significant difference. Mean value of POME generated per day is statistically significant at p=0.05 using Duncan multiple range test (DMRT) for pairwise comparison.

On the other hand, DMR Test also revealed that there was no significant difference in the volume of POME generated per day between mills 1, 3, 4, 5, 6, 7 and 8. Similarly, the volume of POME generated per day in mill 2 was similar to those of mills 1, 3, 5, 6, and 8; however, significantly different ($p<0.05$) from those of mills 4, 7 and 9. The variation in the volume of POME generated across mills could be attributed to the frequency of utilising the mill and other factors that determine volume of POME generated. This significant variation in the volume of POME generated per day across the mills has implications on the allocation of resources such as capacity of volumetric vessels in collecting POME for possible translation to bio-methane.

The mean volume of POME produced in the wet and dry season for small-scale mills was compared using independent sample T-test. The study revealed that there was a significant difference (Tcal=8.112, Ttab=2.326, Df=376, p=0.000) in the volume of POME generated daily in small-scale mills across seasons (Figure 3). In the wet season, an average of 41.51±4.4.68L of POME was generated per small-scaled mill compared to 125.37±9.22L per small-scaled mill in the dry season. The difference in the average volume of POME produced daily per mill could be attributed mainly to seasonal variations, as the palm fruits thrive in the dry season (high crop production season) compared with the wet season. The dynamic in the volume of POME generated in these small-scaled mills across seasons also has implications on the allocation of volumetric vessels in collecting POME for possible translation to bio-methane and other resources.

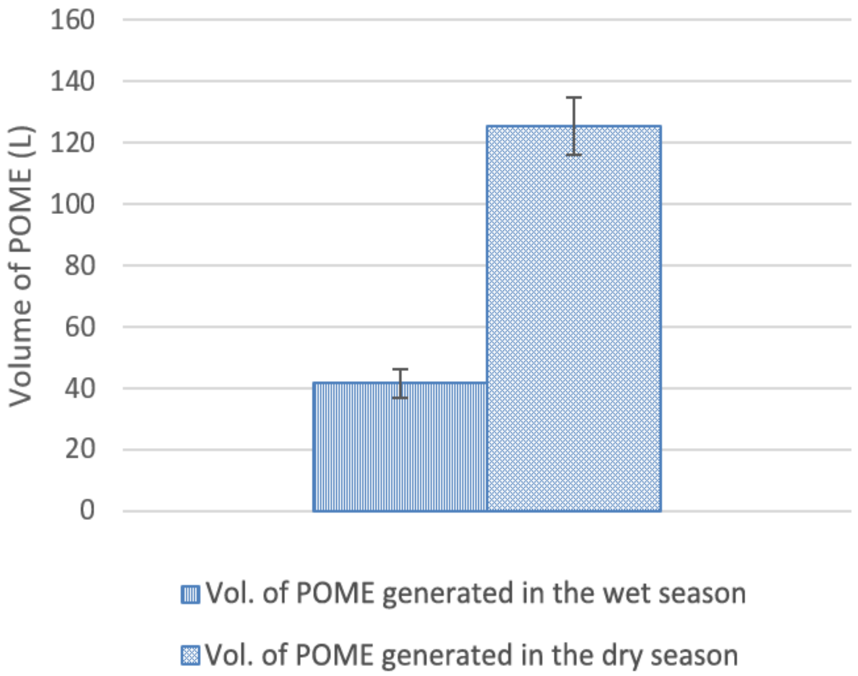

Figure 3. Volume (L) of POME generated per mill daily in small-scaled mills across seasons.

It is also important to determine the functional status of these small-scaled mills in the wet and dry seasons in view of understanding its implications on volume of POME generated per day and how this could contribute to seasonal variations of POME in this sector. In this regard, Wilcoxon's test for matched pair was employed. Wilcoxon's test is a non-parametric statistic employed when it is necessary to determine the median (average) of matched samples (count data -functional small-scale mills, compared over time). In using the Wilcoxon's test, when the test statistic, T (Tcal) is less than or equal to the critical value in the table (Ttab), the null hypothesis is rejected at the particular level of significance. Thus, the number of functional small-scaled mills in each community was counted in both seasons and compared (Table 4).

© 2024 Conscientia Beam. All Rights Reserved.

Table 4. Proportion of functional small-scaled mills across the wet and dry seasons.

Communities	Number of small-scale mills	Proportion of functional mills in the wet season (%), A	Proportion of functional mills in the dry season (%), B	d=B-A (%)
Oloshi	10	100	90	-10
Asa	9	88.89	100	+11.11
Obosima	8	100	100	0
Amafor	10	100	100	0
Agwa	13	100	100	0
Ohuba	11	100	100	0
Etekwuru	4	100	100	0
Obille	4	100	75	-25
Total	69	98.61	95.63	-2.98

The study revealed that there was no significant difference ($p>0.05$) in the median (average) functional small-scale mills across the wet and dry seasons (Tcal= 2; N=3; Ttab≤0; p=0.564) (Table 5).

Table 5. Functional status of small-scale mills across seasons.

Test	N*	Tcal	Ttab	p-value	Sig.
Wilcoxon test for matched pairs	3	2	≤0	p=0.564	0.564

Note: *Number of pairs less the number of pairs for which d=0.

Here, Tcal is greater than Ttab, hence the average (median) functional small-scale mills in the wet and dry season were not different. Therefore, the statistical difference in the average volume of POME generated per day for small-scaled mills in the wet and dry season cannot be attributed to the number of functional small-scaled mills across seasons. That is, irrespective of the season, these mills were functional. In the wet and dry seasons, there were respectively 68 and 67 functional small-scaled palm oil mills in these catchment communities of ADAPALM. With the known average daily volume of POME generated per mill across seasons (Figure 3), and the number of functional mills, these catchment communities were therefore producing $2.82\pm0.32m^3$ POME/day in the wet season and $8.40\pm0.62m^3$POME/day in the dry season.

Volume of POME generated in the medium-scaled mill: Using One-sample T-test, the average volume of POME generated by the lone medium-scaled mill in the wet season was determined to be within 39.6642±18.2856L ($t_{cal}=2.169$; $t_{tab}=2.086$; df=20; $p<0.05$) (Table 6). With quite a small volume of POME generated per day in this scale of milling (due to irregularity of the medium-scaled mill in the wet season), and comparable with the average generated by small scale mills, and its subsequent shut down prior to the end of the study, the sustainable provision of POME by this scale of milling for translation to bio-methane was found not to be guaranteed in the study area.

Table 6. Volume of POME generated per day for medium-scale mill in the wet season.

Parameter	N	Mean±SE	t_{cal}	Sig.
Volume of POME generated per day for medium scale mill	21	39.6642±18.2856	2.169	0.042

Volume of POME generated in the large-scaled mill (ADAPALM): The volume of POME generated from ADAPALM was determined from the industrial record. According to ADAPALM mill management authority, 20 metric ton of FFBs were processed every hour. In this process, crude palm oil CPO constituted 50% (estimated to be 2.5 to $3m^3$) of the mixture (oil and wastewater) in the wet season, and the other 50% was wastewater (POME). In the dry season, CPO constituted up to 75% (3.5 to $4m^3$) of the mixture and 25% was wastewater. Following 44hours processing hour per week and some non-functional days within the 21-day study period (three days in the wet season and two days in the dry season) due to system failure, the average daily generation of POME in ADAPALM

© 2024 Conscientia Beam. All Rights Reserved.

was computed using independent sample T-test. It was found that, there was a statistically highly significant difference ($p<0.01$) in the volume of POME generated per day in ADAPALM across seasons. Due to higher water content of FFBs during the wet season when compared to the dry season, and a constant processing rate of 20metric ton FFB/hour in ADAPALM irrespective of the season, less CPO and significant volume of POME was being produced in the wet season when compared to the dry season. Although the volume of POME generated varied with seasons in small and large-scaled mills, the overall total indicated that lesser volume of POME was produced in the dry season when compared with the wet season (Table 7).

Table 7. Seasonal variation of volume of POME generated per day in ADAPALM.

Production season	Volume of POME (m^3/Day) ±SE
Wet season	14.816±1.347
Dry season	7.109±0.474

3.3. Significance of Daily POME Generation in the Bio-methane Planning Process

The volume of the generated wastewater in the study area per day provides a clue on the digester capacity in a biogas project. Lower volumes of POME generation in the dry season in the study area (Figure 2) could be due to a significant drop in POME generation in the large-scaled mill during the dry season (Table 7), following extraction of more oil and less water in the process. However, increasing the rate of milling in this large-scaled mill during the dry season due to increasing availability of FFBs and more crude palm oil production could increase POME generation (Poh et al., 2010; Tambe et al., 2022). The relationship between digester volume (V), hydraulic retention time (HRT) and influent flow rate (Q) for sustainable management of substrate in waste-to-energy has been well established (IRENA, 2016). Again, several authors have reported that 5 to 10 days for hydraulic retention time (HRT) constitute an efficient duration for digester operation in CH_4 production (Abdurahman, Azhari, & Rosli, 2013; Chotwattanasak & Puetpaiboon, 2011; Loh et al., 2013; Wang et al., 2015). In this regard and considering anaerobic digester for treating POME with HRT $\geq 5 \leq 10$ days, the digester capacity to accommodate the POME produced in the study area is computed with the following mathematical equation (Equation 1).

$$Digester\ volume\ (V)\ =\ HRT\ (d)\ \times Q \qquad (1)$$

Where

HRT=Hydraulic retention time.

Q=Influent flow rate (m^3/d), volume of POME produced per day.

Thus, from the maximum volume of POME generated per day of 17.574±0.408m^3 (Figure 2), which is related to the flow rate (Q) for daily management in a digester, and the role of HRT (Equation 1) in determining digester capacity, a bio-digester with capacity of $17.574\pm0.408\times\geq 5\leq 10\ m^3$ was the estimated initial required capacity to accommodate and treat the POME being produced in the study area. Tambe et al. (2022) showed that a unit increase in the volume of crude palm oil produced in the study area significantly increases the volume of POME generated by 0.226. This means that with increasing production rate of palm oil in Nigeria of 2.2% per year (Global Palm Oil Conference, 2015) and the relationship between POME generation and palm oil production, the design of digester capacity in the area needs keen consideration of this dynamics. To determine the required volume of a bio-digester to accommodate substrate and subsequent transformation to bio-methane, two key parameters are important – hydraulic retention time (HRT) organic loading rate (OLR) (Loh et al., 2013; Wang et al., 2015). In this determination, the least HRT and the maximum OLR are the parameters that need keen consideration in digester restructuring. These mathematical information which capture digester and substrate availability provide decision making that will reduce cost, appropriate the digester capacity, ensure that only the necessary amount of masonry needed is utilised, while taking into cognizance the energy needs of the residents and sustainable functioning of the digester (Florentino, 2003). A relegation of the substrate-digester volume relationship, for example, when the volume of the generated POME is lower when compared to the capacity of the digester, the

© 2024 Conscientia Beam. All Rights Reserved.

plant will be underused, hence challenging its sustainability. This is supported by Mukumba, Makaka, and Mamphweli (2016) who argued that the volume of a bio-digester should be sized in cognisance with the volume of the generated substrate if sustainability of the project is pursued. This relationship is aligned with the theory of material (mass) balance which accounts for mass losses and is anchored on equilibrium between the material entering a system and that leaving the system. Therefore, for a keen integration of material balance in the study area for sustainable management of the wastewater, quantification of the volume of POME is an indispensable prerequisite. This will assist in defining volumetric vessels in collecting POME in ADAPALM and catchment communities, primary pond pre-treatment capacity and digester volume in biogas planning, hence averting environmental degradation associated with POME disposal and promote green energy development.

4. CONCLUSION

Successful wastewater management requires estimates of its rate of generation in its early planning stages. These estimates provide useful guides in determining the total volumetric capacity required to accommodate the total wastewater generated per day, and the pre-treatment and bio-digester capacity for biogas generation in the area. The findings on the copious volume of POME generated in ADAPALM and catchment communities have shown an initial feasibility of transforming the wastewater to wealth. This pathway is essential in reducing greenhouse gas emissions associated with indiscriminate disposal of POME, strengthen energy access, promote climate-smart agriculture, build resilient communities and facilitates in realising human goals and aspirations.

Funding: This study received no specific financial support.
Institutional Review Board Statement: Not applicable.
Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

REFERENCES

Abdurahman, N., Azhari, N., & Rosli, Y. (2013). Ultrasonic membrane anaerobic system (UMAS) for palm oil mill effluent (POME) treatment. *International Perspectives on Water Quality Management and Pollutant Control*, *1*, 36-40. https://doi.org/10.5772/54459

Anukwonke, C. C., Tambe, E. B., Nwafor, D. C., & Khired, T. (2022). Climate change and interconnected risks to sustainable development. In S. A. Bandh, Climate change: The social and scientific construct. In (pp. 71-78). India: Springer International Publishing.

Anyaoha, K. E., Sakrabani, R., Patchigolla, K., & Mouazen, A. M. (2018). Evaluating oil palm fresh fruit bunch processing in Nigeria. *Waste Management & Research*, *36*(3), 236-246. https://doi.org/10.1177/0734242x17751848

Chotwattanasak, J., & Puetpaiboon, U. (2011). Full scale anaerobic digester for treating palm oil mill wastewater. *Journal of Sustainable Energy & Environment*, *2*, 133-136.

Cramer, W., Guiot, J., Fader, M., Garrabou, J., Gattuso, J. P., Iglesias, A., & Xoplaki, E. (2018). Climate change and interconnected risks to sustainable development in the Mediterranean. *Nature Climate Change*, *8*(11), 972-980.

Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F. N., & Leip, A. (2021). Food systems are responsible for a third of global anthropogenic GHG emissions. *Nature Food*, *2*(3), 198-209. https://doi.org/10.1038/s43016-021-00225-9

Edward, J. B., Idowu, E. O., & Oyebola, O. (2015). Impact of pam oil mill effluent on physic-chemical parameters of a southwestern River, Ekiti State, Nigeria. *Journal of Natural Sciences Research*, *4*(14), 26-30.

Eno, E., Antai, S., & Tiku, D. (2017). Microbiological and physicochemical impact of palm oil mill effluent on the surrounding soil at selected factory location within Calabar and Uyo. *Imperial Journal of Interdisciplinary Research*, *3*(10), 760-773.

© 2024 Conscientia Beam. All Rights Reserved.

Ezeomedo, I. C. (2018). *Map of Ohaji/Egbema LGA showing ADAPALM and catchment communities*. Uli: Chukwuemeka Odumegwu Ojukwu University.

Florentino, H. d. O. (2003). Mathematical tool to size rural digesters. *Scientia Agricola*, *60*, 185-190. https://doi.org/10.1590/s0103-90162003000100028

Franco, M. (2013). Methane capture and use potential at palm oil mills in Indonesia. Methane Expo 2013. In (pp. 1-25). Vancouver: TETRATECH.

Global Palm Oil Conference. (2015). *Background document- An overview of palm oil sector: Countries and companies*. Bogota: Global Palm Oil Conference.

Hoyle, D., & Levang, P. (2012). *Oil palm development in Cameroon. An ad hoc working paper*. Yaounde: WWF/IRD/CIFOR.

IRENA. (2016). *Measuring small-scale biogas capacity and production*. Abu Dhabi: International Renewable Energy Agency (IRENA).

Klauser, D. (2021). *Climate-smart, resilient agriculture -Improving smallholders' resilience, mitigation and profitability in all we do*. Basel: Syngenta Foundation for Sustainable Agriculture.

Koura, T. W., Kindomihou, V., Dagbenonbakin, G., Janssens, M., & Sinsin, B. (2016). Quantitative assessment of palm oil wastes generated by mills in Southern Benin. *African Journal of Agricultural Research*, *11*(19), 1787-1796. https://doi.org/10.5897/ajar2013.8124

Leakey, R. B. (2019). *A holistic approach to sustainable agriculture: Trees, science and global society*. Cambridge: Burleigh Dodds Science Publishing.

Loh, S. K., Lai, M. E., Ngatiman, M., Lim, W. S., Choo, Y. M., Zhang, Z., & Salimon, J. (2013). Zero discharge treatment technology of palm oil mill effluent. *Journal of Oil Palm Research*, *25*(3), 273-281.

Mukumba, P., Makaka, G., & Mamphweli, S. (2016). Biogas technology in South Africa, problems, challenges and solutions. *International Journal of Sustainable Energy and Environmental Research*, *5*(4), 58-69. https://doi.org/10.18488/journal.13/2016.5.4/13.4.58.69

National Population Commission. (2010). *2006 population and housing census*. Abuja: NPC.

Ohimain, E. I., & Izah, S. C. (2014). Potential of biogas production from palm oil mills' effluent in Nigeria. *Sky Journal of Soil Science and Environmental Management*, *3*(5), 50-58.

Ohimain, E. I., Izah, S. C., & Obieze, F. A. (2013). Material-mass balance of smallholder oil palm processing in the Niger Delta, Nigeria. *Advance Journal of Food Science and Technology*, *5*(3), 289-294. https://doi.org/10.19026/ajfst.5.3259

Poh, P. E., Yong, W.-J., & Chong, M. F. (2010). Palm oil mill effluent (POME) characteristic in high crop season and the applicability of high-rate anaerobic bioreactors for the treatment of POME. *Industrial & Engineering Chemistry Research*, *49*(22), 11732-11740. https://doi.org/10.1021/ie101486w

Tambe, E., Okonkwo, A., & Eme, L. (2022). Determinants of volume of POME generation in palm oil mills for planning wastewater recovery in biogas energy development. *Journal of Applied Sciences and Environmental Management*, *26*(3), 369-376.

United Nations. (2017). *The sustainable development goals report 2017*. New York: United Nations.

United Nations. (2020). *Pathways to sustainable energy. Accelerating energy transition in the UNECE region*. Geneva: United Nations.

Wang, J., Mahmood, Q., Qiu, J.-P., Li, Y.-S., Chang, Y.-S., & Li, X.-D. (2015). Anaerobic treatment of palm oil mill effluent in pilot-scale anaerobic EGSB reactor. *BioMed Research International*, *2015*, 398028. https://doi.org/10.1155/2015/398028

Zupančič, G. D., & Grilc, V. (2012). Anaerobic treatment and biogas production from organic waste. *Management of Organic Waste*, *2*, 57-63.

Views and opinions expressed in this article are the views and opinions of the author(s), International Journal of Sustainable Energy and Environmental Research shall not be responsible or answerable for any loss, damage or liability etc. caused in relation to/arising out of the use of the content.

© 2024 Conscientia Beam. All Rights Reserved.