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Determinants of Volume of POME Generation in Palm Oil Mills for Planning Wastewater Recovery in Biogas Energy Development

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ABSTRACT: Wastewater volume is a necessary prerequisite for planning transformation to valuable resource and averting environmental degradation. This study investigated the dynamics of POME volume generation in palm oil mills in relation to types of fresh fruit bunches (FFBs), seasons, milling scales and volume of crude palm oil (CPO) produced in ADAPALMS and catchment communities, Ohaji/Egbema LGA, Imo State. The eight catchment communities of ADAPALMS were categorised into three strata in relation to the number of small-scale mills in each community (1-5mills, 6-10mills, and 11-15mills). In each stratum, a community was randomly sampled. A total of nine small-scale mills were sampled from the three sampled communities (Ohoba, Amafor and Etekwuru) in proportion to the average number of mills in each stratum. The lone medium and large scale mill (ADAPLAMS) in the study area represented the other scales of milling. For small and medium scale mills, the volume of POME generated was measured from the dimensions of the vessels where POME was stored, while that of large scale mill was obtained from industrial records. Data was analysed using multiple linear regression of SPSS. The volume of POME generated is significantly related to milling scales and volume of CPO produced ($p< 0.01$); $R^2=0.788$. Within small scale mills, the volume of POME is significantly related to types of FFBs ($p< 0.01$), different small milling scales ($p< 0.05$), and volume of CPO produced ($p< 0.01$); $R^2=0.762$. Thus, these independent variables are the principal determinants of POME volume generation in the area. The result has implication on the necessity of predictive models in managing the dynamics of POME volumes for efficient recovery and transformation of the wastewater to bioenergy.

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Keywords: POME dynamics, independent variables, volumetric vessels, bioenergy, ADAPALMS.

Waste generation is one of the footprints of human activities, and managing the generated waste is posing severe challenges to global environmental security. With innovation in technology, recovering and transforming the waste to wealth in ways that reduce environmental degradation constitute a contemporary approach in achieving sustainable development (Chotwattanasak and Puetpaiboon, 2011; Mukumba *et al*., 2016). Across the world, especially in developing countries, there is increasing use of agricultural lands for oil palm plantations and its subsequent production of palm oil (Global Palm Oil Conference, 2015; Nwalieji and Ojike, 2018; Ohimain *et al*., 2014). This activity is a source of livelihood for many in these regions and also providing valuable needs for humans (Hoyle and Levang, 2012; Ohimain and Izah, 2014). However, the sector is energy (fossil fuel) dependent, and is generating, besides other wastes, huge quantities of liquid waste termed palm oil mill effluent (POME). With an annual global production of palm oil exceeding 50 million tonnes, equating to 39% of world production of vegetable oils, it has become the most important vegetable oil globally, greatly exceeding soybean, rapeseed and sunflower (Global Palm Oil Conference, 2015; Izah and Ohimain, 2013; USDA, 2017). The South-east Asian economies, especially Indonesia (36 million tonnes) and Malaysia (21 million tonnes), contributes more than 85% of global production, while Nigeria (0.970 million tonnes) is ranked 5th and producing one-half of Africa's total production (Hoyle and Levang, 2012; Malaysian Palm Oil Board [MPOB], 2008; USDA, 2017). In this

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regard, huge volumes of POME are being generated in these developing countries (Chotwattanasak and Puetpaiboon, 2011; Poh, *et al*., 2010). Anaerobic decomposition of POME emits methane into the atmosphere and contributes in the unhealthy warming of our planet, while its disposal on soil and streams alters the quality of these environments to sustain life (Aziz and Hanafiah, 2017; Edward *et al*., 2015; Loh *et al.,* 2013). With growing energy insecurity, especially in these developing countries, some of them are considering harnessing the POME as a renewable energy resource, and it has become a viable substrate for transformation to bioenergy (Chotwattanasak and Puetpaiboon, 2011; Loh *et al*., 2013; Mekhilef *et al*., 2011). This consideration is aligned to reducing the quota of fossil fuel use with a view of protecting environmental health and achieving a resilient and productive society (International Energy Agency, 2014). However, understanding the dynamics of the volume of POME and strategies to allocate vessels in recovering it is the first fundamental step in planning waste recovery to wealth (Franco, 2013; Madaki and Seng, 2013; Loh *et al*., 2013; Tambe *et al*., 2016). In the palm oil industry, the various palm oil milling scales that produce POME and other wastes have been categorised into traditional methods, small-scale mechanical units, medium-scale mills and large industrial mills depending on the degree of complexity (Hoyle and Levang, 2012; Nchanji *et al*., 2013). The volume of POME generated in these mills is dependent on several variables such as variation in the processes of CPO production in these milling scales, types of FFBs, seasons, proportion of water used among others (King and Yu, 2013; Koura *et al*., 2016; Ohimain *et al*., 2013; Poh *et al*., 2010). Similarly, the extraction efficiency of the mills determines the volume of CPO and POME produced (Hoyle and Levang, 2012; Nchanji *et al*., 2013; Poku, 2002). While different studies have analysed and/or stated the relationship between the volume of POME and these independent variables (milling scales, types of FFBs, seasons and volume of CPO), a single study that has captured this relationship, with a model embracing these independent variables still remain at infancy. Consequently, identifying the independent variables that influence the volume of POME generated within the confines of the area where it is produced is essential in defining allocation of volumetric vessels for recovering the wastewater. This constitute an indispensable prerequisite in waste to bioenergy planning (Zupanic and Grilc, 2012). Relegating this tenet in waste management undermines efficient recovery of the waste and its concomitant implications on environmental health. In ADAPALMS, largest oil palm plantation in South-east Nigeria, and palm oil mills in its catchment communities, located in Ohaji/Egbebma LGA of Imo State, Nigeria, there are three main palm oil processing scales (small-scale, medium-scale and large-scale). Despite production capacity in the area, data on volume of POME and its relationship with milling scales, types of FFBs (Duru and Tenera varieties), crop seasons and volume of CPO that could assist in defining allocation of volumetric vessels for recovering the wastewater has not been uncovered. Consequently, the wastewater, a potential energy source is indiscriminately disposed while these communities and mills are facing energy insecurity. Following the dynamics of such data in space and time, and several independent variables that influence it, it is imperative to develop models that capture key variables with a view of strengthening planning in recovering the POME for biogas energy generation in this area.

MATERIALS AND METHODS

Study Area: The study was carried out in ADAPALMS and its eight catchment communities, located in Ohaji/Egbema LGA of Imo State, Nigeria (Figure 1). The communities are Amafor, Obosima, Ohoba, Assa, Obille, Oloshi, Etekwuru and Agwa. They are part of the communities that make up the local government area. Ohaji/Egbema LGA, which has its headquarters in Mmanhu-Egbema, is one of the 27 LGAs that constitute Imo State. It has a total surface area of 897.996km^2 and from its base population of 182, 891 in 2006 and 3.19% population growth rate for the State (National Population Commission [NPC], 2010), the population of the LGA is estimated to be 292,925 in the year 2021.

The local government area is located between latitudes 5º10'0"N and 5º20'0"N of the equator and longitudes 6º30'0"E and 6º50'0"E. Furthermore, ADAPALMS and catchment communities are below 70m elevation above sea level, and their location meet the required biophysical conditions for growth and development of oil palm (Better Crops International, 1999, Okorie, 2015, Poku, 2002). With these favourable conditions of the oil palm in the study area, and the implication of the activity to improve on rural livelihood and the economy of Nigeria (Nwalieji and Ojike, 2018; Ohimain *et al*., 2014), it is therefore imperative to deploy environmental friendly practices that could sustain the sector.

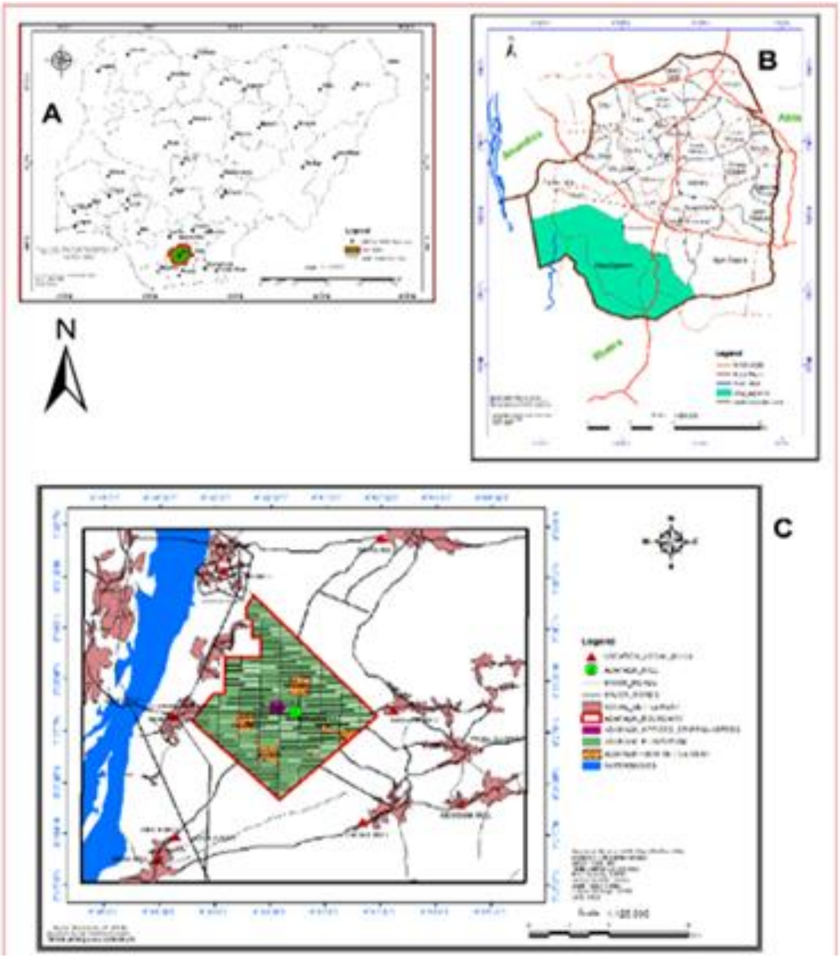

Fig 1. Map of Study Area in Imo State, Nigeria

Sampling Methods and Data Analysis: The eight catchment communities of ADAPALMS (large scale palm oil industry) were categorised into three strata in relation to the number of small-scale mills in each community (1-5mills, 6-10mills, 11-15mills). In each stratum, a community was randomly sampled. A total of nine small-scale mills were sampled from the three sampled communities (Ohoba, Amafor and Etekwuru) in proportion to the average (median) number of mills in each stratum (Table 1). The lone medium and large scale mill (ADAPLAMS) in the study area represented the other scales of milling. For small and medium scale mills, the volume of POME generated was measured from the dimensions of the vessels where POME was stored (Ohimain *et al*., 2013), while that of large scale mill was obtained from industrial records (Poh *et al*., 2010). These measurements were conducted for each crop season; low crop season (within June to September 2020) and high crop season (within January to March 2021). The volume of POME generated for each milling scale is the dependent variable while the corresponding types of FFBs, crop seasons, milling scales and volume of crude palm oil generated are the independent variables. Data was analysed using multiple linear regression of SPSS (version 22.0). The relationship between the dependent and independent variables is tested at p<0.05.

Table 1. Sampled Communities and Mills for Measuring Volume of POME and its Independent Variables.

Number of mills in communities	Names of communities	Names 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
>10≤15	Ohoba Agwa	Ohoba	5

RESULTS AND DISCUSSION

Determinants of Volume of POME Generated: The study reveals that, with reference to the Duru and Tenera variety (mixed variety), processing the Tenera variety (high breed) of FFB tend to reduce the volume of POME by -31.04L while the Duru (local) variety tends to reduce the volume of POME by -6.24L (Table 2). However, this is not significant ($p>0.05$). The mixture of Tenera and Duru variety significantly increase ($p<0.01$) the volume of POME by 1155.18L, as indicated by the intercept. The relative increase in the volume of POME when processing Duru variety as compared to the Tenera variety of FFB could be associated to the use of more water to flush out CPO from low grade Duru variety of FFB in the milling process. During the wet season (low crop season for palm oil production), there is a relative increase (23.49L) in the volume of POME produced with reference to an equivalent process in the dry season. However, this is not significant ($p>0.05$) when compared to the dry season (high crop season for palm oil production). This relative increase in the volume of POME in the wet season (though not significant) could be attributed to the increase moisture content of the fresh fruit associated to the wet season. In the dry season, there is a significant increase ($p<0.01$) (indicated by the intercept) in the volume of POME generated. This could be attributed to the increasing rate of milling, which is aligned to high crop production in this season.

Table 2. Relating Volume of POME Produced and Type of FFBs, Seasons, Milling Scales and Volume of CPO

Independent variables	B	Std. Error	T	Sig.
Intercept	1155.180	119.629	9.656	.000
Duru variety	-6.235	22.310	-.279	.780
Tenera variety	-31.042	15.955	-1.946	.053
Duru/Tenera (mixed) variety	0^a	.	.	.
Wet season	23.494	16.194	1.451	.148
Dry season	0^a	.	.	.
Small scale	-1103.726	111.168	-9.928	.000
Medium scale	-1064.891	121.090	-8.794	.000
Large scale	0^a	.	.	.
Volume of crude palm oil	.266	.032	8.395	.000

a. This parameter is set to zero because it is redundant. Adjusted R Squared = 0.788

Small scale mills tend to significantly ($p<0.01$) lower the volume of POME generated by -1103.73L during production of CPO in the small scale mills when compared to the large scale mill (redundant variable). Similarly, the medium scale mill tends to significantly ($p<0.01$) lower the volume of POME generated by -1064.89L. The decrease in the volume of POME generated in small and medium scale mills, could be associated to limited water access and use in these scales of milling. Large scale mill tends to be more organized and have more resources to facilitate water access (when necessary) than small and medium scale mills in the course of milling. The medium and large scale mills also employ steaming to cook the fresh fruits. This process is confined, limited evaporation of water vapour and efficient cooking occurs compared to small scale mills where boiling is done in large open vessels for several hours. Thus, in small scale mills, there is increase tendency of evaporation and decrease efficiency of coking the fresh fruits. Hence, these mills (medium and large scale mills) have the tendency to retain more water in the cooking process and generate larger volumes of the wastewater (POME). A unit increase in the volume of CPO significantly ($p<0.01$) increases the volume of POME generated by 0.266L. Some of these independent variables, such as milling scales and volume of CPO tend to significantly influence the volume of POME generated. The variation of the dependent variable explained by the model is 78.8% ($R^2=0.788$). Therefore, other independent variables other than those investigated could be accounting for the other 21.2% of the independent variables determining the volume of POME. These independent variables could include health of the fresh fruits (how many rotten fruits were there?), status of fruits before harvesting (were the fruits fully ripe?), age of the fruit, amount of water used among others. Therefore, in the study area, volume of POME produced at an instance can be predicted if one knows the type of FFB, crop season, milling scale and the volume of CPO produced. This relationship is summarized in a multiple linear regression equation (Equation 1).

$$\text{Vol. of POME} = 1155.18 + X_1\text{FFB} + X_2\text{Crop Season} + X_3\text{Milling Scale} + 0.266\text{Volume of CPO} \ldots\ldots 1$$

Where: 1155.18= intercept and it is the estimated value of the redundant parameters (parameters set to zero); X_1, X_2, X_3 = Coefficient of the respective independent variables. It is the effect of an independent variable on the dependent variable when all the other independent variables are zero.

Table 3. Relationship between Volume of POME Produced and Type of FFB, Seasons, Various Small Mills and Volume of Oil.

Independent variables	B	Std. Error	T	Sig.
Intercept	26.479	11.531	2.296	.022
Duru variety (local)	11.197	9.237	1.212	.227
Tenera variety (agric)	-36.428	7.788	-4.677	.000
Duru/Tenera (mixed)	0^a	.	.	.
crop season (wet season)	11.920	6.543	1.822	.070
crop season (dry season)	0^a	.	.	.
small mill 1	-1.547	12.357	-.125	.900
small mill 2	.797	13.772	.058	.954
small mill 3	17.317	13.733	1.261	.208
small mill 4	14.960	12.310	1.215	.225
small mill 5	2.581	12.722	.203	.839
small mill 6	-15.743	12.752	-1.235	.218
small mill 7	-24.937	12.476	-1.999	.047
small mill 8	16.616	13.469	1.234	.218
small mill 9	0^a	.	.	.
Volume of crude palm oil	.377	.015	25.260	.000

a. This parameter is set to zero because it is redundant. Adjusted R Squared = .762

Determinants of Volume of POME Generated within Small Scale Mill: Similar result is obtained when analysing the independent variables influencing the volume of POME within small scale mills (Table 3). The volume of POME is significantly ($p<0.05$) related to various small scale mills. For example, with reference to mill 9 (redundant category), mill 7 significantly ($p<0.05$) reduces the volume of POME by -24.937L, while the decrease or increase in the volume POME made by other mills is not significant ($p>0.05$). This variation could be attributed to the number of millers making use of the mills, the quantity of FFB brought to the mill, customer services provided by the mill owners, accessibility to the mill, and quantity of water use during milling process, efficiency in pressing among others. The coefficient of contribution of these small scale mills to the volume of POME generated range from -24.937 (mill 7) to +26.479 (mill 9). Again, when all other small scale mills, other than mill 9 is held redundant (reference category), the volume of POME generated in this mill (mill 9) is significant ($p<0.05$). This is indicated by the intercept.

Similarly, the Tenera variety (high breed) of FFB significantly ($p<0.01$) reduces the volume of POME by -36.428L. Duru (local) variety tend to increase the volume by 11.197L, however, this is not significant ($p<0.05$). During the wet season (low crop season for palm oil production), there is a relative increase in the volume of POME produced. However, this is not significant ($p>0.05$) when compared to the dry season (high crop season for palm oil production). This relative increase in the volume of POME in the wet season (though not significant) could be attributed to the increase moisture content of the fresh fruit associated to the wet season. In the dry season, there is a significant increase ($p=0.022$) (indicated by the intercept) in the volume of POME generated. This could be attributed to the increasing rate of milling, which is aligned to high crop production in this season. Furthermore, a unit increase in the volume of CPO significantly increases the volume of POME generated by 0.377L in these small scale mills.

The variation of the dependent variable that can be explained by the model is 76.2% ($R^2=0.762$). That is, the factors (independent variables) that determine the volume of POME produced as outlined in the model account for 76.2% of the determining factors of POME volume. In this regard, other factors other than these account for the other 23.8% of POME volume determining factors. These factors could include health of the fresh fruits (how many rotten fruits were there?), status of fruits before harvesting (were the fruits fully ripe?), age of the fruit, amount of water used among others. Therefore, for every small scale milling process in Ohaji/Egbe LGA in Imo State, Nigeria, the volume of POME produced at an instance can be predicted if one knows the type of FFB, crop season, volume of oil produced and the coefficient of contribution of small scale mills to its volume. This relationship between the volume of POME generated in small scale mills and its associated independent variables is summarized in a multiple linear regression equation (Equation 2).

Vol. of POME = 26.479 + X_1FFB + X_2Crop Season + X_3Small mill + 0.377Vol. of CPO…... 2

Where 26.479 = intercept and it is the estimated value of the redundant parameters (parameters set to zero).

X_1, X_2, X_3 = Coefficient of the respective independent variables. It is the effect of an independent variable on the dependent variable when all the other independent variables are zero.

Predictive Models for POME and Volumetric Vessel Allocation in Recovering the Wastewater for Bioenergy Development: The predictive models developed from the study are essential in the study area in determining volume of POME produced for any CPO milling process and its associated independent variables. With an understanding from the model that the Tenera variety of FFB tends to generate lower volumes of POME when compared to the mixed (Tenera and Duru) variety or Duru variety (though not significant), any program to recover POME for biogas from small scale mills in the catchment communities of ADAPALMS will ensure the allocation of slightly larger vessels in communities commonly processing Duru and mixed varieties (e.g. Obille and Asa). However, such decisions on the volume of vessels allocation in communities of these small mills should take into consideration the independent variables that significantly influence the volume of POME generated. The result obtained from this study on the decreasing volume of POME associated with the Tenera variety of FFB and increasing volume of POME associated with mixed (Tenera and Duru) variety or Duru variety agrees with the findings of Ohimain *et al*., (2013). The study argues that the Tenera variety is superior to the Duru variety, and the low yield associated to the poor variety is linked to larger volumes of wastewater produced during the process. The significant relationship ($p<0.05$) in the volume of POME generated within some small scale mills is similar to different studies relating the volume of POME generated per tonne of FFBs (Environmental Fabrics 2009; King and Yu, 2013; Loh *et al*., 2013).

Again, the significant relationship between the volume of POME and volume of CPO produced has implication on the increasing volume of POME with growing CPO production. According to Global Palm Oil Conference (2015), Nigeria's annual growth rate in palm oil production has been estimated at 2.2%. Thus, the necessity for these models are aligned to the dynamics of POME generation and the need to allocating appropriate volumetric vessels to respond to these dynamics through efficient POME recovery, primary pond pre-treatment capacity and defining anaerobic digester volume. This is to avoid overflow of the wastewater and its subsequent impacts on environmental health. For example, larger scales of milling produce more CPO and will require larger vessels for POME recovery. Small scale mills that tend to produce significant volumes of CPO when compared to similar mills will require larger vessels for POME recovery. The utilization of mathematical tools in transforming wastewater to energy can appropriate digester capacity, reduce cost and minimise the necessary amount of masonry, in ways that will respond to energy needs and sustain functionality of the plant (Florentino, 2003). Where this relationship is overlooked, such as when the volume of POME is below the digester capacity due to poor planning in determining wastewater volume and dynamics, the digester is said to be underused and weakens its efficiency and subsequent collapse of the system. Mukumba *et al.* (2016) posit that biogas digesters should be sized in relation with the availability and volume of the substrate. The authors argue that relegating this tenet in biogas planning could lead to under-feeding the digester and a subsequent collapse of the plant. Consequently, the volume of the subtrate (POME) and its independent variables in ADAPALMS and its catchment communities provide vital tools if we seek sustainable recovery of the wastewater and for possible transformation to bioenergy. The relationship between substrate volume and its associated independent variables, volumetric vessel for recovery, capacity for primary pond pre-teatment and digester capacity is aligned to the theory of mass balance. The theory accounts for mass losses and is based on the premise on equilibrium between mass entering a system and mass leaving the system (Gumilar, 2009). The theory can provide explanation on the interconnectedness between the independent variables of POME generation and primary pond pre-treatment capacity facility in recovering POME for bioenergy generation. From the various milling facilities and their corresponding volume of POME generated (V_i), which is related to several independent variables (types of FFBs, seasons, milling scales, volume of CPO among others) (Equation 3), the theory is capable of defining, within the confines of POME dynamics, the primary pond pre-treatment capacity of POME (V_{ppc}) (Equation 4). V_{ppc} should be directly proportional to the sum of all the volumes of POME generated from the various mills in the study area (Fig 2).

Thus,

$$V_i = f\,(X_j + X_k + X_l + X_m +, \ldots X_z) \qquad 3$$

V_i= varying volumetric vessels to recover POME from mills (i=1,2,3, 4, 5……. z); X_j, X_k, X_l, X_m,…X_z= independent variables influencing volume of POME at the various mills.

$$V_{ppc}\ \alpha \sum^{z}{}_{i} V_i \qquad 4$$

Similarly, in designing digester capacity for biogas production from POME, the theory is employed to account for the input of the slurry (feedstock) from the primary pond, while taking into consideration the feedstock's hydraulic retention time (International Renewable Energy Agency, 2016). Therefore, the developed models on the volume of POME generated capture the fundamental planning tools for efficiently recovering the wastewater for sustainable biogas development.

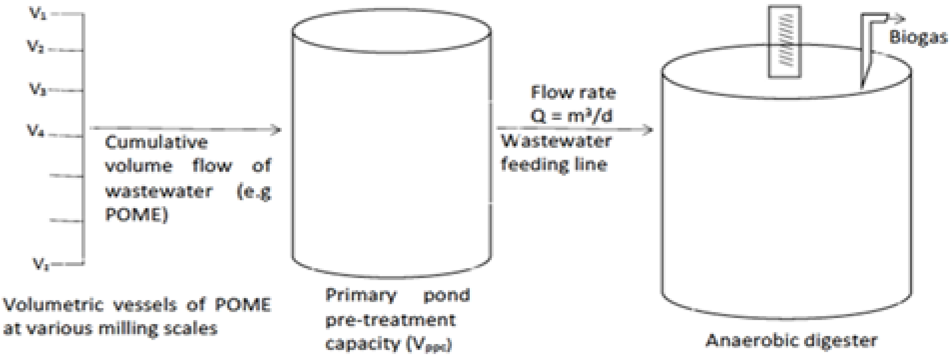

Fig 2. Vessel Capacity for Wastewater Recovery and its Independent Variables.

Conclusion: Strengthening the efficiency of recovering wastewater for planning waste-to-energy requires understanding the variables that determine its dynamics. The dynamics of POME volume generation in oil palm producing communities can vividly be captured with a wider scope of independent variables. The outlined relationships have defined the dynamics of POME volume in the study area and provide useful information on prediction and allocation of varying volumetric vessels to appropriately respond to POME dynamics and facilitate recovery of the wastewater for biogas energy development.

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