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Feasibility of Anaerobic Digestion of Potato peels for Biogas as Mitigation of Greenhouse gases Emission Potential

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ABSTRACT: Processing of round potatoes (*Solanum tuberosum* (L.) into chips in Tanzania and particularly Dar es Salaam city is a growing business that attract low wages employees and unemployed occupants. Proliferation of chips vendors with low knowledge, poor attitude and practice towards environment have resulted into poor management of potato peels waste which are haphazardly disposed of thus causing unhealthy environment, health risks and dilapidated infrastructure. In this paper, the contribution of potato peels to emission of greenhouse gases (GHGs) was analyzed for Dar es Salaam city adapting the UNFCCC baseline scenario model. Based on the 2012 city population of 4.37million with 5.6% growth rate, peels generation and GHGs emission potential have been quantified and projected for 20 years. The global warming potential as CO_2 equivalent cumulatively stands at 2 kilotons of peels to 1 ton GHGs emission. Field investigation to assess feasibility of using the peels for biogas production as mitigation measure for the GHGs emission was conducted. Availability, quantitative and qualitative attributes of the peels for the biogas production in Dar es Salaam are hereby presented.

Key words: *Kilimo kwanza*, Potato peels, Baseline scenario, Resource recovery, Dar es Salaam

INTRODUCTION

In its 2012 food production report, the Ministry of Agriculture, Food and Cooperative of Tanzania ranked round potatoes (Solanum tuberosum (L) third (13%) in production after maize (33%) and pulses (14%); and first but one in consumption (URT, 2012). This is a commendable effort by National resolve to accelerate agriculture transformation that Tanzania embarked in 2009 known as "Kilimo kwanza" in Swahili language, meaning giving agriculture first priority. There has been an increase in production of previously neglected food crops including the round potatoes since then. Regions that were referred to as minor producers including Mara, Kigoma, Rukwa, Ruvuma and possible elsewhere have nowadays increased and/or started production (Godfrey, 2012; Mpogole, 2012). Round potatoes usually packed in sacks of between 115-120kg enters Dar es Salaam city mainly from Mbeya, Njombe, Iringa, Kilimanjaro, Tanga regions and Nairobi Kenya (Anderson, 1996; Ktheisen, 2008; Namwata *et al*., 2010; Coulson and Diyamett, 2012). Whole sellers and retailer customers purchase potatoes according to their demands and preferences from five traditional open markets namely Ilala, Buguruni, Temeke, Mbagala and Urafiki-Mabibo. In Dar es Salaam almost 90% of round potato harvested is processed into chips (food made by deep oil frying of sliced round potato tubers). Changes in society's eating habit in favor of readymade fast foods fueled by globalization, urbanization and growth of tourism sector is the reason for the growing demand of chips (Anderson, 2008). Other factors such as shorter preparation time with simple processing steps that involve peeling of the potato tubers, slicing of the tubers, cleaning and finally deep oil frying (Fig. 1) have made chips a popular fast food.

Chips processing is a growing business in Tanzania and particularly in Dar es Salaam city. The business has attracted both unemployed occupants and low wages employees as a means of diversifying and increase earnings. This has resulted into proliferation of kiosks almost in every street of Dar es Salaam city processing and selling round potatoes based products. With such unplanned expansion of chips business, two environmental challenges have so far emerged. Firstly is poor management of the

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Peeling, slicing and cleaning | Deep oil frying of the slices | Chips ready for consumption

Fig. 1. Main steps involved in chips making process

peels due to diverse knowledge, attitude and practice of the vendors. There has been haphazardly dumping of the peels at the closure of chips business causing dilapidation of infrastructure, poor environmental sanitation, greenhouse gases emission and contamination of environmental components all together posing great challenge to human health. Secondly, there has been an increase in wood fuel extraction for charcoal and firewood as energy sources required for frying potato slices.

Dar es Salaam is a political and commercial city of Tanzania. The city occupy an area of 1590 sq.km of land with population of 4.37million (equivalent to 10% of the total Tanzania population) and 5.6% annual growth rate (URT, 2013). About 65-70% of Dar es Salaam inhabitants mostly self-employed rather than wage earners live in unplanned and squatter settlements (Kyessi, 1994; Anonymous, 2011). Geographically, the city is on a natural bay along the shoreline in front of the stretch of Indian Ocean at between 6°36' and 7°S latitude and between 39°and 33°33'E longitude (DCC, 2004). The city is under tropical climate with 29°C mean annual temperature and about 1100mm mean annual rainfall that comes in March to May (long rainy season) and short rainy season between October to December (Kassenga and Mbuligwe, 2012). The city is divided into three municipalities namely Ilala, Kinondoni and Temeke which are in charge of delivering services including the day-to-day management of solid wastes. Municipal solid waste (MSW) generation in the city is estimated at 1533Kt per year or 0.962kg per capita per day (kg/c/day) with hardly 40% collection efficiency (Breeze, 2012). Poor waste management has rendered most of the remaining waste portion to remain long at the transfer stations and/or scatted in the streets causing pollution and health problems with over 70% of diseases attended in health centers relating to water and sanitation. Studies reported among others by Yhdego (1993), Kasseva and Gupta (1996), Chaggu, *et al.*, (1998), Mbuligwe and Kassenga (2004) estimated 60-78% of MSW produced in Dar es Salaam to be organic fraction. Food leftovers hardly find their way into normal waste dumping systems. This is because the small amount obtained is usually collected and fed to domestic non-ruminant animals, pets and fowls. Currently potato peels have no use in Dar es Salaam. Unless cooked, the peels seem unpalatable to both ruminant and non-ruminant animals including pigs (Braude and Mitchell, 1951). Continual feeding to animals has been reported to affect other feed intake and induces blotting. Similarly, the peels have been found to have low digestibility and in most cases due to prolonged exposure to sun light, have been reported to contain alkaloid toxins and trypsin inhibitor all together having impact in animal physiological performance (Whittemore, 1977). Higher water content of about 70-85% in the peels disqualifies the possibility of using them as feed material for composting process (Mbuligwe *et al.*, 2002). Anaerobic digestion of the OFMSW has been so far accepted as means for stabilizing of decomposable organic matter. Apart from biogas which is an environmentally friendly and renewable energy source (Bush, *et al.*, 2009; Medina-Herrera, *et al.*, 2014), anaerobic digestion offers digestate (effluent from bioreactor) which is a very useful bio-fertilizer that can be used for land application thus replenish nutrients in soil.

This study explore therefore the best management option for the resulting potato peels by looking at the climatic impact based on contribution of greenhouse gases emission from daily generation and dumping of thousands of tons of potato peels in Dar es Salaam. The work covered includes prediction of GHGs emissions as tCO_2 equivalent from aerobic and

anaerobic decomposition of dumped potato peels, and estimation of the quantity and quality of the peels readily available for biogas production project.

MATERIALS & METHODS

Information on consumption figures for round potatoes in Dar es Salaam that could be used in estimating the quantity of peels disposed of as inputs for the Baseline scenario (UNFCCC, 2008b) were difficult to find. This is because the product is entirely for domestic market and does not enter the normal official marketing system (Nyunza and Mwakeja, 2012). Therefore the quantity of round potatoes entering the five tradition open market of Dar es Salaam in 2013 proportional to the current city population was used for the same purpose based on estimated average potato consumption per person in a year. In the first experiment, daily peels generation coefficient G_R (kg/day) was derived from the pre-established potato consumption rate. Other inputs including percent annual population growth (r) and current population of Dar es Salaam city (P_o) were used to estimate the peel generated (tons/year) applying the following equation:

$$\text{Peels (tons/yr)} = \sum_{t=0}^{n} G_R P_0 (1+r)^t X\, 10^{-3} X\, 365 \quad (1)$$

Whereby:

G_R = peels generated rate; P_o= Dar es Salaam population; r= population growth; t= time (yr)

Baseline scenario model for 20 years time (2013-2032) prediction of Methane and Carbon dioxide emissions as result of anaerobic and aerobic decomposition of dumped potato peels as part of OFMSW was used with assumption of 100% disposal without any treatment as suggested elsewhere (Batool and Chuadhry, 2009). A simplified mathematical model based on first order decay of organic matter according to UNFCCC (2008a) was used taking into account of other default constants as described in the following mathematic model equation:

In this scenario, it was taken that generation rate for GHGs depend mainly on the content of degradable organic carbon, decay rate (k) of the potato peels component (j), humidity and temperature (Table 1).

The second experiment involved qualitative and quantitative analysis of peels readily available for biogas production in Dar es Salaam. Qualitative analysis of the peels was based on the physicochemical attributes of the peels that have direct relation to the amount of biogas expected. A

$$tCO_{2,y}e = \varphi_y.(1-OX).GWP_{CH_4}.\frac{16}{12}F.DOC_{f,y}.\sum_{x=1}^{y}.\sum_{j}W_{j,x}.DOC_j.e^{-kj.(y-x)}.(1-e^{-kj}) \quad (2)$$

Table 1. Input parameters used in the model for prediction of CH_4 emission from peels

Potato peels characterization			
	Degradable Organic Carbon (DOC_j)	Estimated peels disposed (Tons/yr) $W_{j,x}$	Tropical MAT>20°C MAR>1000mm Decay rate (kj)
Potato peels(j)	15%	31033	40%
Default parameters of the model			**Value**
?	Model correction factor to account uncertainties		0.9
F	Fraction of CH_4 during decomposition		0.5
CH_4/C	Constant molecular weight ratio		16/12
DOC_f	Fraction of degradable organic carbon		0.5
OX	Oxidation factor		0.1
GWP-(CH_4)	Global Warming Potential of Methane (20 yr)		56

MAT = Mean Annual Temperature; MAR = Mean Annual Rainfall

field survey was carried out for the purpose of establishing the quantity of peels feasible for the anaerobic digestion process. During the survey, the three Municipality were sub-divided into eight strata (Fig. 2) based on wards population and easy road connections. A total of 486 chips kiosks were visited within the eight strata to identify the major and minor chips processors.The Daily potato peels generation rate was estimated based on a 4:1 ratio (weight of fresh potato tubers to weight of peels) quantity established during the field survey. The decision on who are the major or minor processors was categorically based on the quantity of potato sacks that a chips vendor can process on a daily basis where 2 sacks per day was considered minimum to qualify under major processors category.

RESULTS & DISCUSSION

The results for estimation of GHGs emission followed direct relation for which 2 kilotons of peels cumulatively generate an equivalent of 1 ton of GHGs for almost all 20 years (Fig. 3). The GHGs emission is expected to increase proportional to the increase in peels generation and disposal as a result of rapid increase in population which proportionally dictate an increase in potatoes consumption rate. The estimated results for 20 years time to the end of 2032 (period suggested by the Global Warming Potential), about 550 tons of GHGs are expected to be emitted from the disposed peels given the existing waste management option in Dar es Salaam with no consideration to other organic fractions of MSW which are dumped and similarly decompose giving out CH_4 and CO_2.

Exploitation of peels waste for biogas production would be the best option in reducing the amount of waste that needs to be collected and disposed of as well managing ecology, diversity and forest resource from degradation. In Tanzania, environmental degradation caused by removal of CO_2 sink and emission of greenhouse gases mostly from poorly managed organic waste fractions are the key reasons

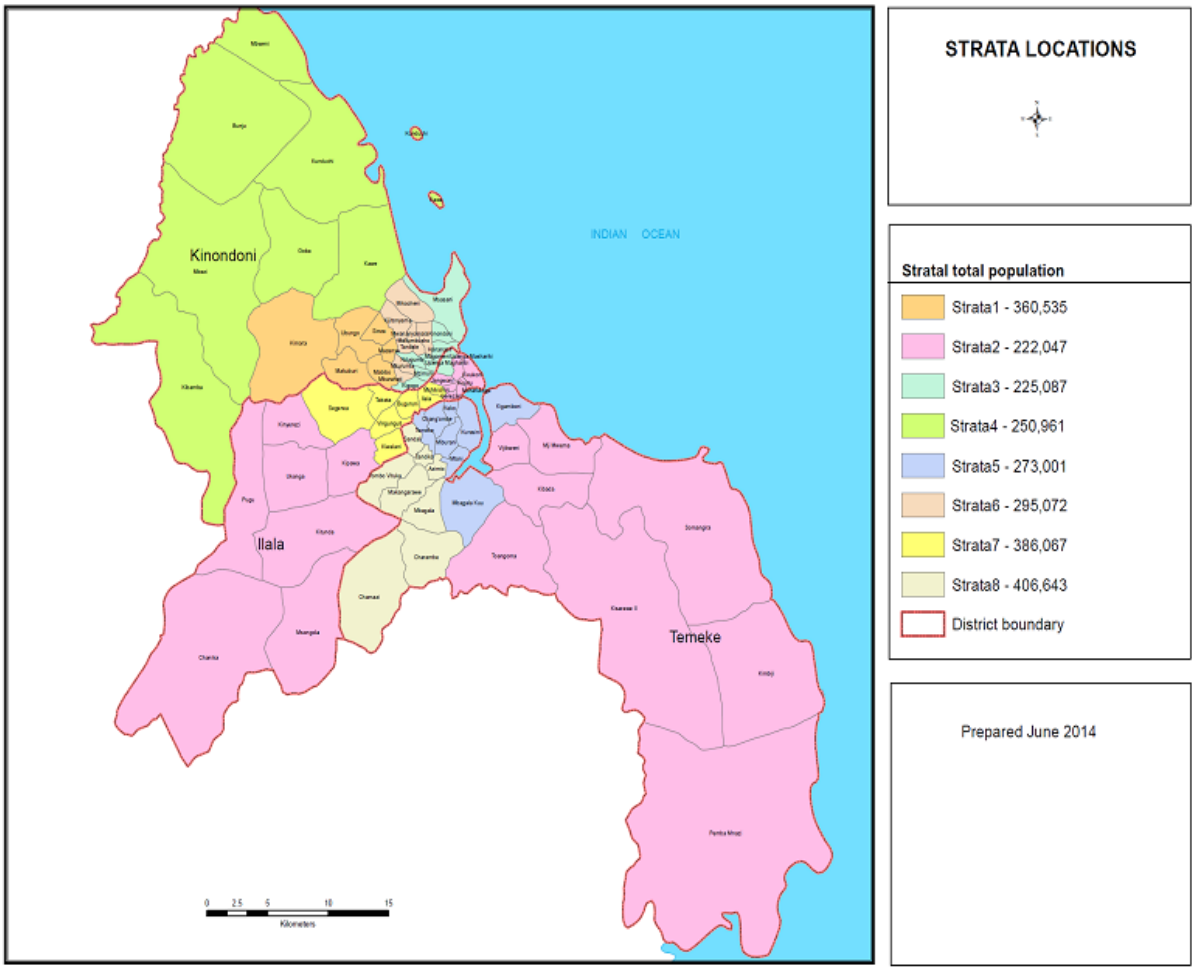

Fig. 2. Strata used for sampling: Map of Dar es Salaam showing Wards during field survey

behind the experienced weather variability and climate change impacts. In recent years, recurring floods incidences (Fig. 4 and 5) have become common reality in Tanzania and particularly more in Dar es Salaam. Others include salt water intrusion in shallow wells and rise in temperature which according to Tanzania Meteorological Agency records from 1961 -2012; it is estimated that 0.031°C is increasing every year.

Based on t results from the conducted field survey, it was established that on average 2960 Sacks of potatoes are sold in Dar es Salaam city per day. This amount is equivalent to 340 tons of round potatoes consumed per day. A total of 310 potato customers were interviewed at the five tradition open market out from which 80% of the customers were identified to be chips vendors, 10% claimed to purchase potatoes for making *mchemsho* (food recipe prepared by boiling meat with round potatoes), 26 customers bought potatoes for their small markets (retailers), 3 others claimed to purchase for crisps making, and 2 customers came to buy for social ceremonies.

With the stated city population (URT, 2013), a consumption rate was derived at 28.5Kg/person/year amount which is higher compared to 10-15kg/person/year estimation by FAOSTAT (www.faostat.fao.org). In another survey, 486 chips vendors were physically visited to identify major producers of potato peels. With the pre-destined criteria, 259 vendors were

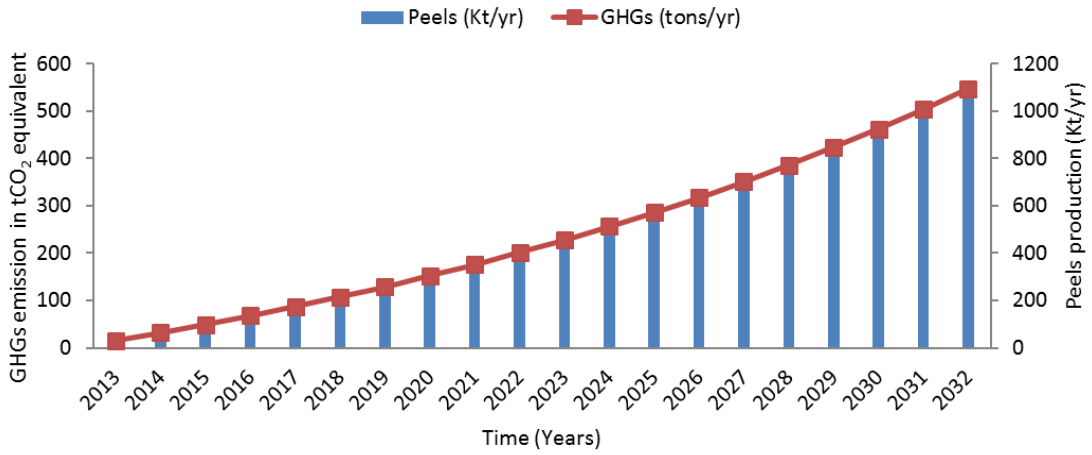

Fig. 3. Baseline scenario of GHGs emission (tCO_2 equivalent) for 20 years from disposed potato peels without processing

Fig. 4. Flooded residential area in Kinondoni Municipal

Fig. 5. Flooded traditional open market in Ilala Municipal

identified as major producers of the peels. These vendors reported to process between 2-4 sacks of potatoes per day. Applying the established ration of 4:1 (potatoes: peels), a total of 22.5 tons of peels per day were estimated for which 9.8 tons was estimated to come from 114 vendors in Kinondoni, 8.1tons from 92 vendors in Ilala and 4.6 tons from 53 vendors in Temeke. If well organized these chips vendors can be used as initial collection points (cells) for the peels to be used for biogas production process. Potato peels are far better and easy to handle during biogas production due to the fact that the peels are always found fresh and not mixed with other waste fraction making waste segregation stage not necessary. Some of the reasons for why organic fraction of municipal solid waste are not preferred for biogas production is due microbial pathogens and chemical contamination levels high enough to cause health risks to waste handlers during collection, transportation, treatment and biogas processing especially where the idea of pre-treatment is not in implementation, and the fact that the wastes are always commingled thus necessitates a tedious waste separation stage. The established quantity is much higher compared to the 15.2 tons per day amount of waste estimated by Mbuligwe and Kassenga (2004) that could be collected from market waste for biogas generation project.

The results on physicochemical characterization of potato peels (Table 2) indicate that anaerobic digestion would be an economical worthwhile and an ideal decision towards management of these waste resources in Dar es Salaam and will save as a solution for as many problems associated with environmental sanitation and pollution.

Table 2. Physicochemical attributes of potato peels

Parameter	Value	Units
Moisture	77.1±0.9	%
Total solids	32.6±3.3	%
Ash	5.8±1.3	%
pH-H_2O	6.8±0.1	-
pH-$CaCl_2$	5.8±0.2	-
COD	974.2	g/kg
C/N ratio	16:1	-

As pointed out by Mbuligwe and Kassenga (2004) from Metcalf and Eddy (2003), the amount of CH_4 produced per unit of COD anaerobic digested at mesophilic temperature 35±2°C is 0.40 L CH_4/ gCOD. The COD observed reveal that for every 1kg of the peels anaerobic digested there is a production of 0.3897m^3 of CH_4 that would be used as energy for cooking and improve the living situation of urban poor in Dar es Salaam. The pH determination using water is closer to neutral zone which is good for microbial survival and function, even when $CaCl_2$ was used as solvent the observed small change in pH signifies good buffering capacity exhibited by the peels as the reactor feed materials. The observed decrease in pH was a result of extractable macro and micro nutrients in the peels which is an indication of presence of mineral salt required for good metabolic function of the microbial cells performing fermentation in the biogas reactor. Although the C/N ratio in peels was found less from the recommended range of 20-30 (Cooperband, 2002), it only implies that the peels are nitrogen-rich. This means that nitrogen will be metabolized to release gaseous compounds of ammonia and nitrous oxide. In order therefore to bring the peels to favorable microbial biodegradation ratio, co-digestion of the peels with other materials containing more Carbon such as yard and agriculture waste can upgrade the C/N ratio as well as minimize the formation of nitrogen compounds (Haug, 1993; Cooperband, 2002).

CONCLUSION

The study on contribution of potato peels to emission of greenhouse gases based on baseline scenario model provided information which required action taking as far as mitigation of climate change and weather variability is concerned. The common practice of waste collection, transportation and disposal without processing is no longer recommended as environmentally acceptable option for waste management. In recognition of the environmental degradation and problems of solid waste management facing Dar es Salaam city and the potential for resource recovery from solid waste, anaerobic digestion of the generated potato peels is considered a prudent and sustainable decision. The present study seeks encouragement, promotion and implementation from the decision making authorities. Together with recovery of energy in the form of biogas that eventually reduces dependence to wood fuel, other benefits includes stabilization of peels waste with controlled anaerobic and aerobic decomposition thus mitigating GHGs emission. Similarly, during biogas production, there is production of organic fertilizer (digestate) useful for land application, environmental sanitation and elimination of diseases as a result of minimized contamination to the environmental components and environmental protection through reduction of solid waste and costs of managing the waste that requires

attention and municipal budget which is always limited.

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