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Quantification of the potential for biogas and biogas manure from the selected fruit wastes in Addis Ababa city, Ethiopia

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In this paper, the overall potential of biogas and biogas manure from the selected fruit wastes in the city of Addis Ababa was estimated (quantified). The prediction is based on the characterization and biogas yield results in a related study, using structured questionnaire and checklists during field survey. This study has shown a survey of the major sources of the fruit wastes and compiled the number of registered service providers in this particular sector by category. Consequently, this study has shown that the wasted biogas potential of the city from the selected 164.51 tons of daily fruit wastes alone was 20896 m^3 per day. This wasted energy material is equivalent to 9000 L of diesel fuel that currently would cost 9389 US dollars. Further, soil nutrients that could be obtained from use of anaerobic digestion of the selected fruit wastes are 366 kg/day of total phosphorus, 798 kg/day of total nitrogen and 565 kg/day of potassium, which are also lost in vain. Therefore, the study shows the importance of proper organic waste management for the recovery of clean energy and nutrients, while at the same time avoiding expenses to buy fossil fuel as source of energy and reduce the associated stress on our environment and more.

Key words: Biogas potential, fruit waste, quantification, prediction, biogas manure.

INTRODUCTION

The so-called wastes that we discard and suffer with the consequences of improper management are of course partly huge energy and fertilizer sources that can support energy demands of cities greatly. Urban waste disposal is a serious challenge in all cities in the developing world, and its accumulation is an additional health hazard (Young, 2012).

Food waste problem is not only in this part of the world, India or Africa. It is a problem in the whole world. In big and medium cities, the problem intensifies due to socio-economic factors. For example, consumption of fruits and vegetables along with the resulting waste increase with development mainly due to awareness and capability of the public (Kumar, 2005; Belloso and Fortuny, 2011)

Addis Ababa city inhabiting closer to four million people generates solid waste at a rate of 0.4 kg/head/day and 60% of the municipal solid waste is organic in nature (Tesema, 2010). The existing solid waste collection system of the city is inadequate and covers only 60% of the waste generated. This is due to lack of transportation facilities and financial matters as well as geographic inconvenience for collection signifying the unreliability of the system for waste items like easily decaying fruit and vegetable wastes (FVW) (Regassa et al., 2011).

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In relation to this, Ethiopia's horticulture has become one of big cash crop production. The production of fruit and vegetable (FVs), including root crops, was 2.16 million tones. The total FV production in 2008/2009 for the season comprises about 351 thousand tones of fruits (16%), 600 thousand tons of vegetables (28%), and 1.2 million tons of root crops (56%) (Ethiopian Horticultural Development Agency, 2011).

Tesema (2010) estimated that the city of Addis Ababa generates 23.1 tones of FVWs daily, in a study conducted earlier and it looks very much under estimated as it is done on household basis. Therefore, it could be simply additional to what 'point sources' discharge as the same waste. Moreover, these figures could increase with the growth of the horticulture industry year after year.

The sources for FVWs are diverse (Peavy et al., 1985; AbdAlqader and Hamad, 2012). FVWs in the city emanate from general store, open markets, FV markets, transporters, supermarkets, fruit juice houses, 'mobile' fruit sellers and consumer households. These wastes unnecessarily join municipal waste stream mostly in waste containers that are picked up using hauling and are transported to a local open dumpsite.

An important step towards a sustainable waste management system is to augment the waste reduction, reuse and recycle paradigm with processes that actually reduce solid waste accumulation (Pinderhughes, 2004). One of the compelling processes in this category is anaerobic digestion where little is done in this regard (Mshandete and Parawira, 2009). When fruit wastes (FWs) are collected at the outset, the operation would be easy to deal with.

FVWs are known to contain highly biodegradable compounds (70 - >80% volatile solid) and moisture strongly supporting their use for anaerobic biogas digesters' input. These wastes therefore holdup signifi-cant energy (Hawkins and Rains, 2008) and manure resource. However, these resources are wasted and left to decompose where a related problem arises in other areas (Gustavsson et al., 2011). Due to the decomposition, the wastes emit huge amount of CH_4 and CO_2 (green house gasses) to the atmosphere together with NH_3 and H_2S-noxious gases, causing environmental and health problems. Moreover, the wastes affect aquatic systems by depleting dissolved oxygen due to the biochemical strength of the wastes if washed with floodwater.

The reason for considering environment and methane gas in the management of such wastes can be explained (Esposito et al., 2012) considering mainly three factors. First, is the need to apply a process to dispose organic solid wastes in a more environmentally friendly manner along with useful soil conditions.

Secondly, the opportunity to obtain from this process a renewable fuel called biogas alternative to fossil fuel. Thirdly, the advantage of relatively low costs in starting up and managing this process as it mainly does not require oxygen supply, as well as, its feasibility of being even commercialized.

Though converting these wastes to a renewable energy/biogas and soil manure is proved to be magnificent, little is known on the quantity of the biogas potential of such wastes in the city. Therefore, this study is aimed at estimating the quantity of biogas and prediction of biogas manure that can be recovered from FW generated by Addis Ababa city. Thus, this finding could help many stakeholders interested in an Integrated Solid Waste Management (ISWM) activity that is geared towards city sustainability in terms of energy and environmental management.

METHODS AND MATERIALS

Description of the study area

Addis Ababa, the capital of Ethiopia, which is by far the largest in the country, is located almost at the geographical centre of the national territory. The city covers an area size of 530.21 square kilometres and a population of 3,059,000 million persons (CSA, 2006). Addis Ababa has a history of a little more than 100 years. In this short span of time, the city grew from a small traditional Ethiopian town to one of Africa's metropolises.

Astronomically, Addis Ababa is located at 09° 02' N latitude and 38° 44' E longitude. It is LOCATEDon the steep escarpment of Mt. Entoto in the North (2900 m) to the South with an average altitude of 2400 m. The central FVM is located in Arada sub city near the municipality and on the way from Piassa to Mercato, the largest commercial area (Figure 1).

Sampling

The study area covered the entire city where there are fruit retails, 'mobile' fruit sellers, fruit wholesales, juice houses, super markets including the major FV distribution centre, which is located at the heart of the city, where this study was focused. This study excluded FWs from households. The commercial facilities related to FWs are sampled randomly in the city. Up-to-date information was obtained on the number of registered FV related business firms from Trade and Investment Bureau of the City Administration.

Moisture resistant and baskets with cover were used to collect the selected FWs that were weighed daily to determine the average wastage in those sampling points for about two weeks as indicated in Figure 1.

Data collection and analysis

The quantification (estimation) was made based on supplementary data collected using structured questionnaire administered in a face-to-face interview and fieldwork made using observation checklists following letter communications with all respondents and daily weighted selected FWs.

Official letter communication was also made to the relevant government agency to obtain data on the number of the service providers. The TS and biogas yield calculators were obtained from a previous study by the same authors. The result was analyzed using Excel 2007 and discussed with related findings, journals and relevant literatures.

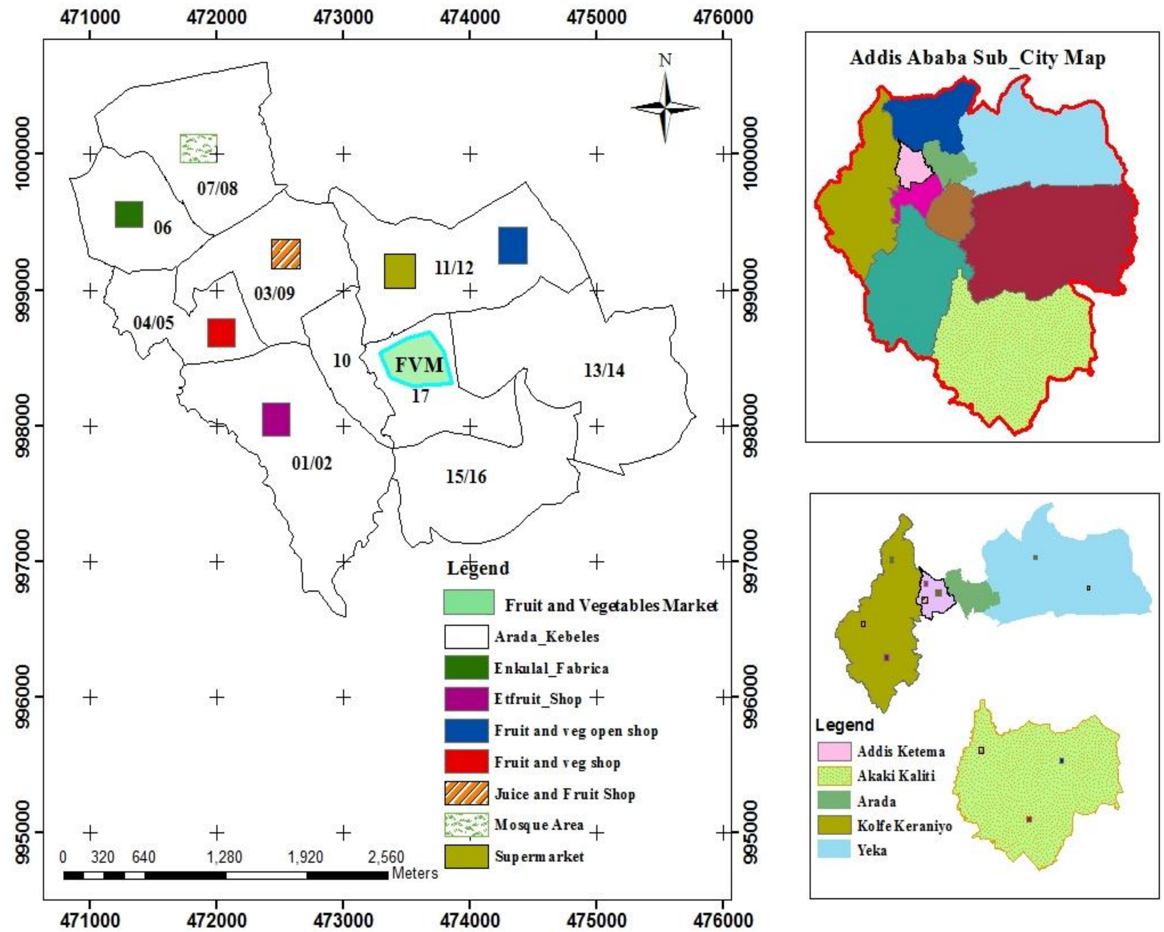


Figure 1. Map of the study area (GIS-2011).

Table 1. The summary of the number of fruit and vegetable juice, supermarkets and the subtotal in sub city in Addis Ababa city (data are up to the year 2010).

Business field	Sub city								
	Addis ketema	Akaki	Arada	Bole	Gulele	Kirkos	Kolfe	Lideta	Yeka and N/silk
FV juice	14	6	16	13	15	9	15	24	2
Supermarkets	157	19	54	114	23	121	94	37	87
Sub-total	171	25	60	117	28	130	109	41	89

Source: Extracted from Addis Ababa Trade and Industry Bureau (2010).

RESULTS AND DISCUSSION

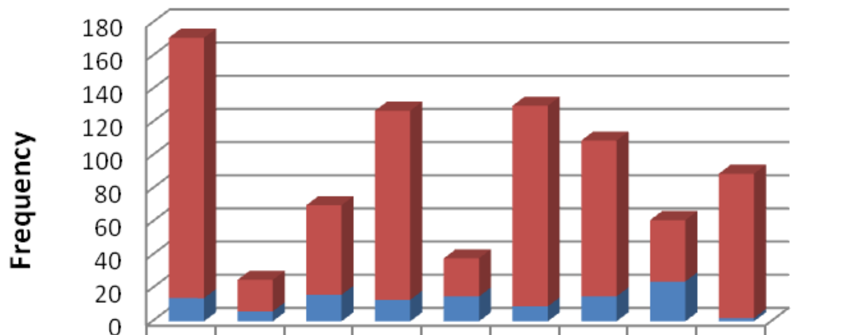
Basics

A related laboratory scale study on the potential of the selected FWs in the city was made for biogas and relevant results were brought (Gebreeyessus and Demissie, 2013), which triggered this further study. In fact, the magnitude of the resource wasted has to be quantified in order to show the relevance of related interventions to recover such resources.

General

Sources of such FWs are diverse. In this regard, is not only the formal sector that is running the FV business but also the informal people are involved. The Ethiopian government's agency in control of registering this group is also operating behind the existing distribution of the sector.

The distribution of the fruit juice houses in the city is uneven (Table 1) ranging between 2 and 24 in number among sub cities. The huge quantity is generated by



	Addis ketema	Akaki	Arada	Bole	Gulele	Kirkos	Kolfe	Lideta	Yeka/Nefasilk
Supermarkets	157	19	54	114	23	121	94	37	87
FV juice	14	6	16	13	15	9	15	24	2

Figure 2. Distribution of supermarkets and fruit and vegetable juice houses in Addis Ababa City, 2010.

“Atikilt tera” which is followed by fruit juice houses, based on personal observation.

Addis ketema sub city is the highest to have those super markets and FV juice houses followed by kirkos sub city. The least is Akaki sub city, as it is located at the out skirt of the city (Table 1 and Figure 2) (Trade and Industry Bureau of Addis Ababa, Ethiopia, letter communication, 2012).

In a related fact, the operation and waste generation is also variable temporally. The reasons for fluctuation of FVW generation are mainly the seasonality of supply of fruits in the market and the consumers factor which shows peak consumption in fasting days than others as well as location of the houses. In general, auditing of input versus wasted (locally called “marsh”) is almost uncontrolled by the private business makers except the state owned one (Etfruit).

Quantification of overall FVWs from major contributors

Rough estimation of the total FWs was made based on the number of firms involved in this trade field (registered and informal). The responses of focal persons and the approximate weight of the wastes in a given volume as well as approximate composition of the wastes were studied. However, it should be considered that supply and discharge are variable within days of a week and seasons of the year as mentioned earlier.

The grand share of FVWs in general and FWs in particular is generated by the central FV market-“Atikilt tera” as marked earlier. The reasons for wastage in particular to the site are partly due to physical damage, rotten fruits and improper temperature application for heating fruits to ripen the row. There divisions of private and shared FV companies in this zone are made based on types of FV commodities; mainly banana, mango and avocado, vegetables and root crops.

The tomato-dominated corner disposes nearly 1500 kg of waste daily. Regarding banana waste, there are 12 compounds in the two areas; one “Atikilt tera” and the other to the north in front of “Atikilt tera” commonly called “Talian sefer”. The hugest amount of FWs contributed is banana, including its holding stem and little rolling leaf 8 m^3 of FW is discharged every day from each store totalling 12 containers of the waste.

Within “Atikilt tera”, the mango FW discharge is also comparable to banana, however mango is more seasonally available as it is supplied for about only 8 months in a year to market. It is estimated that 4 to 7 number of an 8 m^3 container mango wastes are discarded daily from “Atikilt tera”.

The avocado FW is more contributed by juice houses and retailers than in “Atikilt tera”. In fact, over four 8 m^3 volume waste containers are emptied to dumpsite daily, and more during the supply season.

According to the Ethiopian FV Market Share Company (Etfruit) there are over 60 fruit shops within Addis Ababa city that are relatively evenly distributed. These fruit shops receive 60 kg of fruits daily on average. These shops unlike the private shops have to return almost 20 kg of avocado, banana, and mango FWs daily on average back to storage centre due to defect for disposal (Etfruit Ethiopia, personal communication, 2012).

In all other contributors (except “Atikilt tera” and mobile fruit sellers) the primary FWs discharged are avocado and mango followed by banana all accounting to 2/3 of

Table 2. Summary of generation rate (in tons/day) for the selected FWs by the identified contributors.

Fruit waste	Contributor sector				
	Atikilt tera	Etfruit	FV Juice	supermarket	Mobile
Avocado	43	0.3	30.	0.8	-
Banana	110	0.4	8	0.1	1
Mango	62	0.2	18	0.6	-

Table 3. Mean value of TS (g/l), VS (g/l) removal, and biogas productivity and average methane for the various conditions evaluated in batch experiment of 35 days of anaerobic digestion time.

System (digester)	TS Initial	VS Initial	TS Final	VS final	VS (%) removal	Biogas (m^3/kg VS)	Average CH_4 (%)
A_0	7.7	6.2	4.1	3.157	49	0.48	55.56
B_0	7.6	6.06	3.8	2.998	50.5	0.57	58.16
M_0	7.8	5.96	3.6	2.495	58.1	0.53	51.64
A_1	7.9	6.36	3.1	2.3	63.8	0.76	54.68
B_1	7.8	6.22	3.2	2.32	62.7	0.82	56.38
M_1	7.9	6.05	3.2	2.22	63.3	0.82	52.14

Source: Gebreeyessus and Demissie, 2013. TS, Total solids; VS, volatile solids.

Table 4. Summary of important information and prediction values for biogas (methane) per day.

Total FWs (kg)	TS average (%)	VS average (%)	VS total (kg)	Average biogas(m^3/kg VS)	Total biogas (m^3)	Average CH_4 (m^3/kg VS)	Total CH_4 (m^3/kg VS)
164510	20.2	78.6	26120	0.8	20896	0.44	11493

Source: Gebreeyessus and Demissie, 2013.

total. Roughly, over 144 fruit, vegetable and juice houses discard 0.3 m^3 FVWs daily dominated by mango and avocado (2/3) in the city.

Giving observatory check to those informal mobile sellers that range from 100-200 in number in the city, about 5 - 11 kg of banana waste is discarded daily by each seller. In addition to that, the low rate of discard is by the supermarkets, 706 in number, as most of them do have better facilities for storage, 3 kg of FWs per day each.

The amount of selected FWs reported in unit of volume can be expressed in unit of weight using the average respective densities of the selected FWs for subsequent calculations. The weight per day and the contributors for the selected FWs is summarized in Table 2.

The total quantity of these selected FWs when added amounts to 164.51 tons/day. Even this amount is exclusive of the same discharge from households. Thus, this huge resource should not be lost. Therefore, the objective of this paper was to predict possible recoverable biogas out of these resources thereby supporting decision makers and further studies from applying such recovery technologies in efficient manner in the following sections.

Estimation of possible biogas from these selected FWs

According to a recent bench scale experimental study, the biogas as well as methane yield obtainable from these FWs was found to be promising (Table 3).
Based on these data, rough estimate of the possible clean energy obtainable from the selected FWs in the city is calculated below. The necessary information to predict was the amount of such waste discarded daily, those FWs characterization results (moisture, TS and VS), and total biogas as well as methane yield from the preceding experimental work (Table 4).

The TS and VS values are average values for the selected FWs combined and are calculated the same way as shown in Table 3. The biogas volume estimated

Table 5. Summary of the total determinant nutrients quantification on daily basis.

Nutrient	Average gm/kg TS	Total amount (kg)
Total phosphorus	11	366
Total nitrogen	24	798
Potassium	17	565

recoverable by proper management of these wastes in the city is about 20896 m^3/day. This, with average methane content of 54.4% is estimated to give a total of 11496 m^3/day CH_4 (methane).In a related report, the fuel value of 0.24 m^3 biogas with 40% CH_4 content was reported to be equivalent to 0.1 L of diesel fuel (Department of Environment and Resource Management, Australia, 2011). This implies the city of Addis Ababa is wasting an equivalent fuel value of 9000 L of diesel fuel, which is about 9389 US dollar in terms of money. In other terms of comparison, the same amount of daily biogas yield could have be converted to 11.2 mega watt of electricity had it been managed using the anaerobic digesters.

Currently, interests in the use of biogas are increasing by the sub-Saharan African cities due to its economic and environmental benefits (Austin et al., 2011). The recovery of such huge resource needs attention by the various concerned parties. Basic biogas technology therefore can make a big difference (Environmental Health Perspect, 2006).

The issue does not end with only the lost of such resource but also the inevitable accompanying environmental stress the wastes bring in; emission to atmosphere and mainly water sources pollution. On the other hand, our dependence on fossil fuel as energy source and the synthetic fertilizer production adds much green house gas emissions in addition to the costs to buy the items (Young, 2012).

Obviously, the collection and transportation to dump site is not free as well. Based on the information from "Atikilt tera" merchants, 4.5 US dollar was spent to discard 1 m^3 of the wastes. However, collection and transportation of the wastes to gas centres will also not be free.

The biogas manure prediction

The advantage of applying biogas technology for management of such wastes is better than obtaining the clean and renewable energy. It can also provide opportunity for soil nutrient to recycle far better than applying the row waste to farm and more.

Based on the daily TS wasted which are 33, 231 kg and the amount of the soil fertility indicators determined in in a related study, the maximum obtainable nutrient is projected (Table 5).

Given the variability in the nutrient content among the different FWs, the average biogas manure could contain 366 kg/day of total phosphorus, 798 kg/day of total nitrogen and 565 kg/day of potassium. Had such nutrients been synthesized artificially, the cost and environmental implication would have been huge. In Cuba for instance, use of chemical fertilizers is prohibited in cities rather, the use of organic composting using a peri-urban horticulture imitative is encouraged (Young, 2012).

Undoubtedly, this amount is obtainable excluding other components of FVWs. The content of nutrient by the other vegetable wastes would probably be higher in this regard. Therefore, this prediction also adds to the need to recover such nutrients from the waste resources in addition to the clean energy obtainable.

In relation to this, if such waste is simply dumped on soils, it will give little humus due to consumption of the organic matter by microorganisms for their growth (Memon et al., 2012). Contrary to this, the biogas manure interrupts succession of plant parasites from year to year in addition to the best nutritive value it gives which can be considered also as an indirect benefit. Therefore, it is imperative to pay attention to issue for action not only to meet environmental demands but also for economic advantage as well.

Conclusion

Even though energy is a need in cities of developing countries, it is being disposed and unrecovered. Fruit and vegetable wastes are dumped in open field, discarded in adjoining streams and in cities including Addis Ababa in some locations. These known source wastes however hold huge energy potential. The quantity of fruit wastes discarded in the city of Addis Ababa is so huge (~164.51 tons/day) that its indiscriminate disposal or open dumping poses serious public and environmental health problem.

Nevertheless, using some technology these wastes can be converted to useful materials; energy and soil nutrients while at the same time avoiding the undesirable consequences of open dumping. Conversely, use of fossil fuels as energy sources would result in economic and environmental implications.

The renewable energy that would have been recovered is equivalent to 11.2 mega watt of electricity daily. The benefit from proper management is even greater. The anaerobic digestion of such wastes can also result to sustainability of soil nutrients, replacing significantly the synthetic fertilizers.

Thus, the various stakeholders in an integrated solid waste management should focus on to unhide such huge energy and nutrient potential in order to sustain cities; however, further studies have to be done in this regard.

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