Waste Characterisation and Recoverable Energy Potential Using Waste Generated in a Model Community in Nigeria

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ABSTRACT

Reclaimable energy generated from waste is a major source of environmentally sustainable energy that is not yet explored in Nigeria. This study therefore, investigated the energy recoverable potential from waste, using waste materials generated in a model community in Nigeria. For the model community of the country, Covenant University, Ota, Nigeria was used, because of its existing form of waste management system. Solid waste generated in this model community was characterised into its separate components and this was then subjected to an estimation model by which the recoverable energy potential from the waste was evaluated. For this, method of waste to energy calorific value evaluations were employed for predicting equivalent energy availability from the waste in kWh and in equivalent tonnes of oil. Results obtained from the study show abounding viability of favourable energy potential that could be as high as 8967.13 MJ day$^{-1}$, equivalent to 2490.87 kWh day$^{-1}$ or 0.8227 tonnes of oil equivalent per day. These findings bare suggestions of the need for the development of waste management system infused with energy reclamation policy, from waste, for supplementing communal energy needs and annexing other social benefits accruable from such policy implementation.

Key words: Solid waste characterisation, calorific value, waste energy recovery potential, equivalent energy, sustainable environment

INTRODUCTION

The provision of sufficient amount of energy is a global challenge faced both by developed and developing countries (Mehrzad et al., 2007). However, the greater of the crunch of global energy crisis is felt more by developing nations, like Nigeria, where lack of adequate energy had been identified as the source of social and economic poverty (Fagbenle et al., 2011). Reason for this has been linked to the use of conventional sources which have remained grossly unsustainable due to its finite nature, for energy generation. Presently, in Nigeria, tackling the energy crisis had been the expectation of the populace from the government and many political campaigns also capitulate on this by setting energy generation as a principal agenda to lure votes for political offices from the populace. Despite the lofty promises of adequate energy provision to the populace by past government administrations, however, incessant power outages find sustenance throughout the country. The high cost of industrial recurrent spending invested in the provision of alternative energy supply (Ajayi, 2009) has driven many viable industries into neighbouring countries, thus aggravating more the social vices of unemployment, in the nation. The fact that the generated
energy supply, of about 4000 MW for the whole nation has not been sufficient for the urban areas connected to the national grid has not made the expansion of energy provision for rural communities possible. This is such that, communities could remain unconnected to sustainable source of energy provision for economic growth except drastic approach of energy sourcing is employed.

The challenge of inadequate energy provision in the country might have remained insurmountable because much of the responsibility of seeking sustainable sources of energy had been saddled on the government alone. This had left the government with little choice other than seeking energy provision from the unsustainable conventional sources that had weakened the country’s economic growth at the detriment of its populace. However, the ability to tackle the energy crisis in the country would have to be a concerted effort, whereby communities might have to look inward to sustainable energy sourcing through which it can partner with the government or other requisite private sector for energy supplement. One of such energy sourcing could be from waste generated within the community. This is the motivation for channelling this research study towards the waste characterisation and recoverable energy potential estimation using waste generated from a model community, Covenant University, Ota, Nigeria.

This model community, Covenant University, Ota, is located in Ado-Odo Ota Local Government, Latitude 6°41’ N and Longitude 3°41’ E, Ogun State, Nigeria. As, at March 2009, over 7000 students and about 1000 staff are accommodated in the university residence. In spite of the inconsistent power supply pervading the nation (Gahlawat et al., 2009) the proprietor of the private university still uphold the commitment of ensuring 24 h electric power generation for the university community. To achieve this, resort is usually made to heavy duty diesel-powered generators of electricity power, consisting thirteen 500 kVA (Mikano generator) and two 1000 kVA (Cummins generator), to supplement the epileptic supply of electricity predominant throughout the country (Gahlawat et al., 2009; Kofoworola, 2003). With hardly any day within a month without electric power outage, the generators are often running more than half of the times in a given day such that the standby roles of the generators and the expected constancy of electricity supply from the main grid stand interchanged (Gahlawat et al., 2009; Okafor, 2008). Consequently, catering for the energy needs of the university community culminates in high fossil fuels consumption.

Supplementing the energy needs of this model community using fossil fuels is costly from many considerations (Anomohanran, 2011; Nahar and Sunny, 2011; Asplund, 2008; Demirbas, 2008; Lvovsky et al., 2000). The institution spends over three million Naira (i.e., over twenty thousand dollars) monthly procuring a minimum 33,000 L (= 33 m³) of diesel per month. While this fossil fuel, usually attendant with incessant price fluctuations (Ahmad et al., 2011a; Agboue and Yobou, 2007), is well known to emit varieties of airborne pollutants that are hazardous to human health its emissions are also not environmental-friendly but rather portend serious negative implications against the sustainability of our environment (Anomohanran, 2011; Nahar and Sunny, 2011; Muis et al., 2010; Gahlawat et al., 2009; Asplund, 2008; Demirbas, 2008; Lee, 2007; Lvovsky et al., 2000). These necessitate the need to explore alternative means of supplementing energy requirements, especially, such supplementary means from which other environmental benefits could be derived (Muis et al., 2010; Agboue and Yobou, 2007). Energy recovery from Municipal Solid Waste (MSW) has been identified in studies as a source of sustainable energy for supplementing communal energy needs, reducing dependency on fossil fuel sources (Ahmad et al., 2011b; Muis et al., 2010; Seemann, 2007; Klein and Themelis, 2003; Themelis et al., 2002) and achieving sustainable waste management system (Bani et al., 2011).
Energy generation from waste sources is potent not only with energy cost savings but also with attendant benefits including reduction in landfill space requirements and unfriendly ecological emissions (Seemann, 2007; Farret and Simoes, 2006; Omrami et al., 2005; Klein and Themelis, 2003). Energy recovery from waste can also constitute a system of energy sourcing which could be replenished as more waste is generated. According to the Energy Commission of Nigeria ECN (2005), however, a clear overview of these recoverable energy potential from waste, the process of its sustainability and management as an energy resource are still non-existent in Nigeria. Since all human produce waste (Goyal and Sindhu, 2011; Shepherd and Shepherd, 2003), waste generation is also inevitable in the model community of Covenant University, Ota. The university, apart from the population of its residents, also co-host along with Living Faith Church, its proprietor and sister community, congregations of four services, each in the order of the 50,000 capacity church edifice, every week and other biannual and annual spiritual gatherings with millions of human attendees. From these and other endowments of waste generation potentials there is a need to annex the energy from this bonus source even by this university community, a feat through which it could become the model for the replication of waste energy reclamation for the country. However, energy resource viability, utilisation and management from waste sources require detailed and adequate waste characterisation for requisite initiation of its economic assessment and development (Nabegu, 2010; Fobil et al., 2005). While waste characterisation has been considered in recent studies for households, markets and cities in some parts of Nigeria (Nabegu, 2010; Oyelola and Babatunde, 2008; Ogedengbe and Oyedele, 2006; Bamgboye and Ojolo, 2004), such study involving recoverable energy analysis has not been done for any part of the nation. This study, therefore, focus on investigating the characterisation of waste generated in Covenant University, Ota, used as a model community for Nigeria, with the intent to use the characterisation to study model of recoverable energy potential from the generated waste. By this, it is opined that viability of energy that could be annexed towards supplementing the energy needs of the waste generating community could be ascertained from the estimated recoverable energy potential of the characterised waste of the model community.

**MATERIALS AND METHODS**

**Waste characterisation:** Waste characterisation method as described and employed in literature (Oyelola and Babatunde, 2008; Bernache-Perez et al., 2001) was used in this study. Generated solid waste was obtained from bins and waste disposal sites from selected academic, residential and cafeteria buildings of Covenant University, Ota. This was done before the delivery of the waste materials to landfills by the university operated truck disposal systems. The waste materials were then sorted according to material types which include: paper/cardboard, plastic food pack, plastic bottles, metal cans, food waste, polythene bags, polystyrene food pack and other combustible miscellaneous waste materials. Each of these is then weighed to obtain the mass-based characterisations. This monitoring approach was carried out over a period of 10 weeks, between the months of January and March and the average of waste taken in kg per day.

**Recoverable energy potential estimation:** Waste calorific values, as proposed in Smith and Scott (2005), Shepherd and Shepherd (2003) and Biffaward Programme on Sustainable Resource Use (2008), were used to estimate the recoverable potential energy from each characterised waste. This calorific value for each waste characterisation is presented in Table 1.
Table 1: Calorific value used for waste to energy modelling

<table>
<thead>
<tr>
<th>Waste characterisation</th>
<th>Calorific value (MJ kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper and cardboard</td>
<td>14.6</td>
</tr>
<tr>
<td>Plastic food pack</td>
<td>38.0</td>
</tr>
<tr>
<td>Plastic bottles</td>
<td>22.0</td>
</tr>
<tr>
<td>Metal cans</td>
<td>-</td>
</tr>
<tr>
<td>Food wastes</td>
<td>6.7</td>
</tr>
<tr>
<td>Polythene bag</td>
<td>27.3</td>
</tr>
<tr>
<td>Polystyrene food pack</td>
<td>38.0</td>
</tr>
<tr>
<td>Miscellaneous (others)</td>
<td>17.6</td>
</tr>
</tbody>
</table>

From this the recoverable energy potential \( E \) in MJ day⁻¹ for each waste characterisation was obtained from:

\[
E = m \times CV
\]  

(1)

Where:

CV = Calorific value of each characterised waste

\( m \) = Mass of each characterised waste

And the total equivalent energy in unit of MJ day⁻¹ \( (E_i) \) was obtained for the \( n \) numbers of characterised waste as:

\[
E_i = \sum_i E_i = \sum_i CV_i \times m_i
\]  

(2)

The equivalent energy in kWh per day \( (E_{\text{eq}}) \) from the recoverable potential energy is:

\[
E_{eq} = \frac{1}{3.6 \times 10^6} E_i
\]  

(3)

The tonne of oil equivalent (toe) per day for this daily equivalent energy is:

\[
toe = \frac{1}{4000} E_{eq}
\]  

(4)

RESULTS AND DISCUSSION

The average mass-based distribution of the characterised waste in different sites studied in the university community is presented in Table 2, this include the total average waste generated in each site in kg day⁻¹ and the average generation, also in kg day⁻¹, of each characterised waste component.

From Table 2, it could be observed that the student hall of residence generated the highest mass of waste in the sites of study chosen. This is due to the high population density of students resident in the hall compared to the other selected parts of the institution in this study. The table also shows that food waste constitutes the highest waste component generated in the institution (134.77 kg day⁻¹) followed by polythene bag (99.31 kg day⁻¹) and then by plastic bottles (69.94 kg day⁻¹).
Table 2: Average mass-based distribution of solid waste materials

<table>
<thead>
<tr>
<th>Site</th>
<th>Paper/card board (kg day⁻¹)</th>
<th>Plastic food pack (kg day⁻¹)</th>
<th>Plastic bottles (kg day⁻¹)</th>
<th>Metal cans (kg day⁻¹)</th>
<th>Food wastes (kg day⁻¹)</th>
<th>Polythene bag (kg day⁻¹)</th>
<th>Polystyrene food pack (kg day⁻¹)</th>
<th>Others (kg day⁻¹)</th>
<th>Site Total (kg day⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>College building I</td>
<td>7.65</td>
<td>0.00</td>
<td>2.00</td>
<td>0.50</td>
<td>0.00</td>
<td>1.70</td>
<td>0.75</td>
<td>3.30</td>
<td>15.90</td>
</tr>
<tr>
<td>College building II</td>
<td>1.70</td>
<td>0.25</td>
<td>0.39</td>
<td>0.08</td>
<td>1.90</td>
<td>0.36</td>
<td>0.13</td>
<td>0.00</td>
<td>7.81</td>
</tr>
<tr>
<td>Departmental workshop building</td>
<td>1.20</td>
<td>0.05</td>
<td>1.40</td>
<td>0.20</td>
<td>1.20</td>
<td>1.70</td>
<td>0.05</td>
<td>9.00</td>
<td>15.30</td>
</tr>
<tr>
<td>Cafeteria (student)</td>
<td>0.00</td>
<td>0.00</td>
<td>7.92</td>
<td>6.24</td>
<td>50.40</td>
<td>4.20</td>
<td>0.50</td>
<td>0.00</td>
<td>69.26</td>
</tr>
<tr>
<td>Cafeteria (general)</td>
<td>0.00</td>
<td>0.00</td>
<td>8.00</td>
<td>14.90</td>
<td>17.30</td>
<td>10.04</td>
<td>7.18</td>
<td>0.00</td>
<td>57.32</td>
</tr>
<tr>
<td>Chapel</td>
<td>1.50</td>
<td>1.00</td>
<td>1.20</td>
<td>1.00</td>
<td>1.20</td>
<td>2.00</td>
<td>1.20</td>
<td>1.00</td>
<td>10.10</td>
</tr>
<tr>
<td>Guest house</td>
<td>2.00</td>
<td>0.00</td>
<td>1.50</td>
<td>1.00</td>
<td>5.20</td>
<td>2.20</td>
<td>0.00</td>
<td>0.00</td>
<td>11.90</td>
</tr>
<tr>
<td>Students residence I (male)</td>
<td>10.32</td>
<td>5.68</td>
<td>6.08</td>
<td>14.40</td>
<td>10.40</td>
<td>18.40</td>
<td>4.80</td>
<td>0.00</td>
<td>70.08</td>
</tr>
<tr>
<td>Students residence II (male)</td>
<td>18.70</td>
<td>11.90</td>
<td>13.09</td>
<td>9.97</td>
<td>0.00</td>
<td>22.10</td>
<td>7.48</td>
<td>2.55</td>
<td>85.79</td>
</tr>
<tr>
<td>Students residence III (female)</td>
<td>1.74</td>
<td>17.16</td>
<td>25.74</td>
<td>8.59</td>
<td>2.58</td>
<td>25.74</td>
<td>4.32</td>
<td>0.00</td>
<td>85.87</td>
</tr>
<tr>
<td>Staff quarters I</td>
<td>0.54</td>
<td>0.00</td>
<td>0.17</td>
<td>0.60</td>
<td>12.00</td>
<td>3.00</td>
<td>0.72</td>
<td>0.00</td>
<td>17.03</td>
</tr>
<tr>
<td>Staff quarters II</td>
<td>0.56</td>
<td>0.00</td>
<td>0.24</td>
<td>0.40</td>
<td>15.69</td>
<td>0.37</td>
<td>0.49</td>
<td>0.00</td>
<td>17.75</td>
</tr>
<tr>
<td>Staff quarters III</td>
<td>0.49</td>
<td>0.06</td>
<td>0.21</td>
<td>0.62</td>
<td>12.60</td>
<td>2.40</td>
<td>0.45</td>
<td>0.00</td>
<td>16.73</td>
</tr>
<tr>
<td>Staff quarters IV</td>
<td>2.00</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
<td>4.40</td>
<td>2.60</td>
<td>0.00</td>
<td>3.20</td>
<td>13.20</td>
</tr>
<tr>
<td>Library</td>
<td>5.50</td>
<td>1.00</td>
<td>2.00</td>
<td>0.00</td>
<td>0.00</td>
<td>2.50</td>
<td>1.00</td>
<td>6.60</td>
<td>18.60</td>
</tr>
<tr>
<td>Waste component total</td>
<td>59.90</td>
<td>37.10</td>
<td>69.94</td>
<td>59.40</td>
<td>134.77</td>
<td>90.31</td>
<td>29.07</td>
<td>29.15</td>
<td>512.64</td>
</tr>
</tbody>
</table>

Table 3: Recoverable energy potential of characterised wastes in Covenant University

<table>
<thead>
<tr>
<th>Waste characterisation</th>
<th>Recoverable energy potential (MJ day⁻¹)</th>
<th>Comparative energy contribution potential (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper and cardboard</td>
<td>787.03</td>
<td>9</td>
</tr>
<tr>
<td>Plastic food pack</td>
<td>1499.80</td>
<td>16</td>
</tr>
<tr>
<td>Plastic bottles</td>
<td>1838.70</td>
<td>17</td>
</tr>
<tr>
<td>Metal cans</td>
<td>0.00</td>
<td>0</td>
</tr>
<tr>
<td>Food wastes</td>
<td>902.96</td>
<td>10</td>
</tr>
<tr>
<td>Polythene bag</td>
<td>2711.05</td>
<td>30</td>
</tr>
<tr>
<td>Polystyrene food pack</td>
<td>1104.55</td>
<td>12</td>
</tr>
<tr>
<td>Miscellaneous (others)</td>
<td>513.04</td>
<td>6</td>
</tr>
<tr>
<td>Total equivalent energy</td>
<td>8967.13</td>
<td>100</td>
</tr>
</tbody>
</table>

The estimated value of recoverable energy potential per day for each characterised waste is presented in Table 3 along with the computed value, using Eq. 2, of total equivalent energy \( E_i = 8967.13 \text{ MJ day}^{-1} \).

Also, using Eq. 3 the total energy produce \( E_{oil} = 2490.87 \text{ kWh day}^{-1} \). And from Eq. 4 the tonne of oil equivalent, \( \text{ toe} = 0.6227 \text{ tonnes day}^{-1} \).

From the results in Table 3, it could be observed that thermoplastic related materials constitute majority of solid waste with the highest potency of energy contribution in the model community of Covenant University, Ota. These include non-biodegradable waste such as polythene bag, plastic bottles, plastic food pack and polystyrene food pack. These thermoplastic related materials are generated as waste, respectively, at average values of 99.31, 69.94, 37.10 and 29.07 kg day⁻¹ constituting 19, 14, 7 and 6% of all the generated solid waste. These waste materials also
possess the potential to respectively contribute recoverable energy of 2711.05, 1538.70, 1409.80 and 1104.55 MJ day\(^{-1}\) constituting 30, 17, 15 and 12% of recoverable energy from all the waste.

The recoverable energy potential from bio-degradable food waste, though generated as waste at an average of 134.77 kg day\(^{-1}\) and by which it constitutes the highest percentage (28%) of all the solid waste, is however at a value of 902.96 MJ day\(^{-1}\) constituting 10% of recoverable energy from all the characterised waste materials. Despite its higher value of mass-based generation as waste, the recoverable energy potential from food waste is lower in value than those from the thermoplastic related waste. This is because food waste possess much lower caloric value of 6.7 MJ kg\(^{-1}\) than all the thermoplastic related materials, where plastic bottles, valued at 22.0 MJ kg\(^{-1}\), possess the lowest caloric value.

The recoverable energy potential from the characterised waste totals 8967.13 MJ day\(^{-1}\). At full energy recovery, this can produce equivalent energy of 2490.87 kWh day\(^{-1}\). With this amount of recoverable energy potential, about 1000 resident staffs in the institution could cook with a 1000 W electric cooker for two hours in a day. However, according to Shepherd and Shepherd (2003), about 20 to 50% of this energy may be reclaimable, subject to the amount of energy extractable. By this, energy reclaimable at 50% on the higher side (equivalent to 1245.44 kWh day\(^{-1}\)) will still suffice for an hour of cooking in a day for the same number of staffs while on the lower side 20% of the recoverable energy (equivalent to 1793.43 kWh) will power a 1/8 horsepower (≈0.06821 kW) refrigerator unit for about 19 h of the day for each of the 1000 staff residents.

Reclaiming energy from the solid waste generated in the selected model community of Covenant University and in such similar communities such as tertiary institutions, densely populated cities and even rural communities could lead to energy bonus availability. With relevant waste energy reclamation technology, this available energy bonus could be annexed for the communities towards supplementing energy needs. Also, this recoverable energy approach could also be an avenue to reduce non-biodegradable waste from plastic materials which, though not environmentally friendly, is potent at forming the bulk of waste that is naturally and generally disposed as waste in a community. This is more so important because the alternative of recycling this thermoplastic waste could be difficult (Jonna and Lyons, 2005; Omran et al., 2005), for they could contain different types of polymer; they could also be contaminated, according to the findings of Omran et al. (2005), from their principal usage as materials for food related packaging. However, these non-biodegradable plastics possess high caloric value with consequent good recoverable energy potential (Omran et al., 2005) annexable using any of the existing technologies of co-incineration (Taiwo, 2011; Seemann, 2007), plasma pyrolysis (Taiwo, 2011; Nema, 2009; Ojolo and Bangboye, 2005), or gasification (Ahmad et al., 2011a; Ahmad et al., 2011b; Taiwo, 2011; Aznar et al., 2006; Klein and Themelis, 2003).

CONCLUSION AND RECOMMENDATIONS

Waste characterisation has been carried out in this work using waste generated in Covenant University, Ota, as a model community and this characterisation has been used for the evaluation of recoverable energy potential from the waste materials. From this the following conclusions could be drawn:
The waste characterisation identified biodegradable food waste as having the highest average waste characterisation of 134.77 kg day$^{-1}$ while discarded polythene bags, however, exhibit the highest potential of recoverable energy evaluation of 2711.05 MJ day$^{-1}$, due to its calorific value of 27.3 MJ kg$^{-1}$, a value that is comparatively much higher than that of food waste valued at 6.7 MJ kg$^{-1}$.

- In spite of its comparatively low calorific value, biodegradable food waste still exhibit recoverable energy potential of 902.98 MJ day$^{-1}$.
- Recoverable energy potential estimation from characterised plastic related materials showed that 1538.70 MJ day$^{-1}$ is evaluated as recoverable from plastic bottles, 1409.80 MJ day$^{-1}$ from plastic food pack and 1104.55 MJ day$^{-1}$ from polystyrene food pack.
- The overall considerations of these results is suggestive of the existence of good viability of an abounding potential of recoverable energy from the characterised waste even as the recoverable energy potential from waste estimated in this study totals 8867.13 MJ day$^{-1}$ which is equivalent to 2490.87 kWh day$^{-1}$ or 0.6227 tonnes of oil per day, at full (100%) reclaimable energy.

The foregoing results shows that inculcating the policy of recoverable energy from solid waste generated in Nigerian communities as part of the waste management and energy policy could improve the present energy sourcing from the untapped waste resources in the country. Such energy sourcing could be initiated by a system of segregated waste collection, from the source of waste disposal which would aid the characterisation of the waste into their different components. Also, energy conversion facilities, aimed at maximising energy reclamation from the waste generated in the Nigerian communities could be included in such waste management development to facilitate energy recovery from the waste. The reclaimed energy from such system can then be usefully annexed for supplementing the energy needs of communities in the nation. This approach of energy reclamation system, if well developed, is also potent with environmental benefits of job creation and eventual waste volume reduction that could have been disposed to landfill, along with its waste to energy which portend great advantage towards the attainment of a sustainable environment.

REFERENCES


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