Waste-to-Energy Potential in the Western Province of Saudi Arabia

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ABSTRACT: Waste-to-Energy (WTE) is a viable option for Municipal Solid Waste (MSW) management and a renewable energy source. The MSW practices in KSA are simple: collect and get rid of it by dumping it in open landfill sites. This research aims to assess potential contribution of WTE facility to electricity demand in three main cities in the Western Province of Saudi Arabia and as a solution to landfills problem. Three scenarios for WTE utilization were developed: Mass Burn, Mass Burn with recycling and Refused Derived Fuel (RDF) with Biomethanation. The analysis was completed for Jeddah, Makkah, and Madina cities; with total current population of about 7 million. The results show that Jeddah has the potential to produce about 180 MW of electricity based on incineration scenario; about 11.3 MW based on incineration with recycling scenario; and about 87.3 MW based RDF with biomethanation scenario in the year 2032. These values are based on theoretical ideals and help in identifying the optimal WTE techniques for each city.

INTRODUCTION

Municipal solid waste (MSW) management system aims to handle the health, environmental, aesthetic, land-use resources and economic concern related to improper disposal of waste (Nemerow 2009). Population, urbanization growth, the rise in the standards of living has all dramatically accelerated the MSW generation in developing countries (Minghau et al., 2009, Guerrero et al., 2013). Developing countries were not able to cope with the MSW generation growth and open landfills remains the dominant method of disposal (Ouda et al., 2013, Ouda 2013). The Kingdom of Saudi Arabia (KSA) is the world’s largest crude oil producer and possesses the largest oil reserves (Ouda et al., 2013). Crude oil revenue has come with substantial increase in population, urbanization and the standards of living in the country. The population growth of an average 3.4% over the last four decades coupled with an increase in the urbanization level from about 50% of the total population in 1970 to about 80% at present; has resulted in substantial growth of MSW generation in the country (CDSI 2010). The current municipal solid waste management system in the KSA is simple: collect and get rid of it by dumping it in open landfill sites. Most of the landfills are mature and are expected to reach their capacities within a few years. The substantial quantity generated by MSW and the high energy contents of its composition demonstrate the significant potential for WTE facilities in KSA. The KSA is planning to generate 54 GW from nuclear and renewable energy sources including WTE facilities within two decades (KACARE 2012). The potential contribution of WTE facilities to electricity demand in KSA has been rarely investigated.

OBJECTIVE AND METHODOLOGY

This paper aims to evaluate the potential electricity generation from WTE facilities in the three main cities in the Western Province of Saudi Arabia. The analysis will consider three scenarios for WTE development: Mass Burn, Mass Burn with recycling and RDF with Biomethanation. The Mass Burn scenario implies full utilization of MSW for WTE production. Mass Burn with recycling assumes removal of all potentially recyclable materials from the waste stream and utilizing the remaining MSW for WTE production. RDF with Biomethanation considers segregation of general waste stream into inorganic and organic waste. The inorganic waste is then considered for RDF methodology while organic for biomethanation.
The year 2012 was chosen as the starting year for forecasting. The MSW production rate was assumed to be 1.4 kg/capita/day (Ouda et al., 2013). There are three major cities in the Western Province of KSA, Jeddah with 3.4 million, Makka with 1.7 million, and Madina with 1.2 million (CDSI 2010). The population growth is projected to maintain its historical trend of 3.4% up to the year 2032 and MSW total generation for the three cities were forecasted accordingly.

The calorific energy content of the various types of waste is listed in Table 1 (Gilbert 2008). These measures were used to calculate the total energy content per kilogram of Saudi municipal waste. The most widely used and proven WTE is the process of producing energy in the form of heat and/or electricity from waste sources via combustion (ASME 2008, UNEP 1996, Cheng 2012, Rogoff 2011). The research literature has documented a combustion efficiency of 25% to 30% for operated WTE facilities in different places across the globe (Ouda et al. 2013, Kathirvale 2003, IPCC 1996) and around 18% for RDF (Metro Waste Authority, 2013). Methane conversion efficiency to energy is reported to be around 30% (Chakraborty et al. 2013).

**TABLE 1. Energy content of different components of solid wastes.**

<table>
<thead>
<tr>
<th>Type of waste</th>
<th>Energy Content (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed Paper</td>
<td>15820</td>
</tr>
<tr>
<td>Mixed Food Waste</td>
<td>5583</td>
</tr>
<tr>
<td>Mixed Green Yard Waste</td>
<td>6281</td>
</tr>
<tr>
<td>Mixed Plastic</td>
<td>32570</td>
</tr>
<tr>
<td>Rubber</td>
<td>26056</td>
</tr>
<tr>
<td>Leather</td>
<td>18612</td>
</tr>
<tr>
<td>Textiles</td>
<td>18844</td>
</tr>
<tr>
<td>Demolition Softwood</td>
<td>16983</td>
</tr>
<tr>
<td>Waste Hardwood</td>
<td>15122</td>
</tr>
<tr>
<td>Coal</td>
<td>28615</td>
</tr>
<tr>
<td>Fuel, Oil</td>
<td>42574</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>55137</td>
</tr>
</tbody>
</table>

**Estimation of Methane.** The annual methane emission from Saudi’s three landfill sites can be estimated using the US-EPA LandGEM model. LandGEM is based on a first-order decomposition rate equation for quantifying emissions from the decomposition of landfilled waste in municipal solid waste (MSW) landfills. The software provides a relatively simple approach to estimating landfill gas emissions. Model defaults are based on empirical data from U.S. landfills. Field test data can also be used in place of model defaults when available.

\[
Q_{\text{CH}_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} k L_0 \left( \frac{M_i}{10} \right) e^{-kt_{ij}}
\]

where \(Q_{\text{CH}_4}\) is the annual methane generation in the year of the calculation (Gg/y), ‘i’ is the 1-year time increment, ‘j’ is the 0.1-year time increment, ‘n’ is the (year of the calculation) - (initial year of waste acceptance), ‘k’ is the methane generation constant (y\(^{-1}\)), \(L_0\) is the potential methane generation capacity (m\(^3\)/Mg), ‘\(M_i\)’ is the mass of waste accepted in the \(i^{th}\) year (Mg), ‘\(t_{ij}\)’ is the age of the jth section of waste mass ‘\(M_i\)’ accepted in the ith year.

**Heat to power generation potential calculations.** In order to evaluate the energy generation potential from MSW, table 1 is used to calculate the lower heating value of the waste by considering the dry solid waste without moisture content. For bulk incineration process the average value of the total waste is considered as a lower heating value while for incineration with recycling, all types of waste that could be recycled are excluded from the calculations. In case of RDF with biomethanation, the waste is segregated between organic and non-organic waste. In order to calculate the LHV for this process, the organic waste is excluded from the general stream and the calculations are performed on the remaining waste stream.
including paper, plastic, glass, wood, textiles and others. The energy recovery potential (GWhr/day), Power generation potential (MW) and Net generation potential (MW) are given by equations (2)-(4).

\[
\text{Energy Recovery Potential (GWhr/day)} = \frac{(\text{Dry waste (tonnes day)} \times \text{LHV of waste (kW.hr/kg)})}{1000}
\]  

(2)

\[
\text{Power Generation Potential (MW)} = \frac{(\text{Dry waste (kg day)} \times \text{LHV of waste (kW/kg)})}{1000}
\]  

(3)

\[
\text{Net Power Generation Potential (MW)} = \eta \times \text{Power Generation Potential}
\]  

(4)

where \(\eta\) is the efficiency of the process. Efficiency for incineration is taken as 25% and for RDF is taken as 18%.

**Heat to power generation potential calculation by biomethanation process.** The biomethanation process is preferred for organic waste stream with moisture content to allow for microbial activity. The typical conversion efficiency for this process is taken as 30% (Chakraborty et al. 2013). The values for the total land fill gas (LFG) generation are taken from LandGEM model.

\[
\text{Power Recovery Potential (MW)} = \frac{(\text{Total Methane Generation (m}^3\text{ day)} \times \text{NCV} \times 365.25)}{(0.042 \times 1000 \times 24)}
\]  

(5)

\[
\text{Net Power Generation Potential (MW)} = \frac{\text{Total Methane Generation (m}^3\text{ day)} \times \text{NCV} \times \eta \times 365.25}{1000}
\]  

(6)

Where NCV is the Net Calorific Value of LFG and lies in the range 0.194-0.242 kW/m\(^3\) and \(\eta\) is the efficiency for the bio-chemical process.

**RESULTS AND DISCUSSION**

**MSW Composition and Quantity Forecast.** The waste composition for Saudi Arabia is tabulated in the table 2 along with the LHV values for each type of waste using the values from table 1. The MSW wastes of the KSA include 37% organic materials, 28.5% paper, 5.2% plastics, 8.3% mineral, 4.6% glass, 8% wood, 6.4% textile, and 2% others (Ouda et al., 2013, AFED 2008).

<table>
<thead>
<tr>
<th>Material</th>
<th>Waste Composition (%)</th>
<th>Energy (Btu/lb)</th>
<th>Content kW.hr/kg in Material</th>
<th>kW.hr/kg in Waste LHV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>28.5</td>
<td>15820</td>
<td>4.39</td>
<td>1.21</td>
</tr>
<tr>
<td>Plastic</td>
<td>5.2</td>
<td>32570</td>
<td>9.05</td>
<td>0.46</td>
</tr>
<tr>
<td>Glass</td>
<td>4.6</td>
<td>0</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Wood</td>
<td>8</td>
<td>16983</td>
<td>4.73</td>
<td>0.24</td>
</tr>
<tr>
<td>Textiles</td>
<td>6.4</td>
<td>18844</td>
<td>5.20</td>
<td>0.22</td>
</tr>
<tr>
<td>Organic</td>
<td>37.0</td>
<td>5583</td>
<td>1.55</td>
<td>0.10</td>
</tr>
<tr>
<td>Others</td>
<td>10.3</td>
<td>12097</td>
<td>3.36</td>
<td>0.28</td>
</tr>
</tbody>
</table>

**Total energy for Mass Burn with recycling scenario (kW.hr/kg)**  
0.3772

**Total energy content of Mass Burn scenario (kW.hr/kg)**  
2.5121

The forecasted MSW quantity per year for the three cities and up to year 2032 is presented in Figure 1. The figure shows that by the year 2032, about 6730 thousand tons of MSW will be generated in the three cities, out of which 55% will be from Jeddah city. This is a huge quantity and should be managed properly otherwise a severe environmental consequence can be anticipated in the long-term.  

**Methane Gas Generation.** For the estimation of methane from the landfill sites, user specified inputs are used in the LandGEM model. The methane generation potential, \((L_0)\) has been specified as a default value of 61 m\(^3\)/Mg, while the methane generation constant \((k)\) has been specified as 0.026 per year. The methane and carbon dioxide in the LFG have been considered to be 50%. For the purpose of this study it
is assumed that the three landfill sites Makkah, Madina and Jeddah are started operation in 2012 and the waste is accumulated up to the year 2032. Biomethanation for this study is applied with RDF which takes in organic waste as input. The result for the total LFG generation in Jeddah landfill site is shown in Figure 2. The total LFG for Makkah, Madina and Jeddah have been calculated as 31.97, 22.53 and 65.96 Mg/year respectively. The methane generation for Makkah, Madina and Jeddah have been calculated as 8.06, 5.67 and 16.62 Mg/year and for carbon dioxide as 23.43, 16.52 and 48.35 Mg/year respectively.

![Graph showing waste generation forecast for three main cities in the Western Province of Saudi Arabia for the years 2012-2032.](image1)

**FIGURE 1.** Waste Generation Forecast for the three main cities in the Western Province of Saudi Arabia for the years 2012-2032.

![Graph showing landfill gas emission estimation for RDF with Biomethanation technology for Jeddah site for the years 2012-2152.](image2)

**FIGURE 2.** Landfill gas emission estimation for RDF with Biomethanation technology for Jeddah site for the years 2012-2152.

**WTE Scenario Results.** Three scenarios for WTE development were developed and analyzed: Mass Burn, Mass Burn with recycling and RDF with Biomethanation. The forecast results for three scenarios for Jeddah City is presented in Figure 3. It was observed that for the Mass Burn Scenario, there is a potential to generate about 87.0, 61.3 and 92.0 MW in Makkah, Madina and Jeddah cities respectively in
the year 2032. The Mass Burn with recycling scenario shows a potential to produce about 5.45, 3.84 and 11.25 MW in 2032 from Makkah, Madina and Jeddah cities respectively. The RDF with Biomethanation Scenario shows a potential to produce about 42.4, 29.9 and 87.3 MW in 2032 from Makkah, Madina and Jeddah cities respectively.

The figure also shows that Mass Burn Scenario has the highest power generation capacity over the other three scenarios. Additionally, the three scenarios provide a viable disposal option for MSW and, if implemented, will alleviate the landfills problem in the area.

The decision to select among the three scenarios will require further financial, social, technical, and environmental analysis. The decision to select between the two scenarios is crucial and should be taken at a political level based on the results of intensive research.

![Figure 3: Power Generation Potential (MW) for Jeddah City for the years 2012-2032](image)

**CONCLUSION**

The MSW practices in KSA are simple: collect and get rid of it by dumping it in open landfill sites. This practice has created a chronic MSW disposal problem in the Kingdom. The electricity demand grew on average at a rate of 5.8% over the last five years and is expected to increase from about 55 GW at present to about 120 GW by the year 2032. KSA is considering WTE as a potential renewable energy source that can contribute to electricity demand in the Kingdom and alleviate the MSW disposal problem. This research aims to assess potential contribution to WTE facility to electricity demand in the three main cities in the Western Province of Saudi Arabia and as a solution to landfills problem. Three scenarios for WTE development were developed and analyzed: Mass Burn, Mass Burn with recycling and RDF with Biomethanation. The scenario was forecasted up to year 2032. The research results show that Mass Burn Scenario has the highest power generation capacity over the other three scenarios. Additionally, the three scenarios provide a viable disposal option for MSW and, if implemented, will alleviate the landfills problem in the area. The decision to select among the three scenarios will require further financial, social, technical, and environmental analysis. The decision to select between the two scenarios is crucial and should be taken at a political level based on the results of intensive research.
REFERENCES


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