Waste to Energy: Developing Countries' Perspective



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Abstract About 4.2 million tons of solid waste is generated daily from urban centres in developing countries, most of which are disposed in open dumps and uncontrolled landfills. These wastes are composed of renewable energy materials with energy value of about 9.87×10^9 kWh/day. Capturing the energy embedded in these wastes is one of the sustainable ways of reducing the quantity of wastes to be landfilled while producing electricity, heat and fuel to meet basic needs. Investment in Waste to Energy (WTE) sector has increased over the years in developed countries, and its applicability to developing economies has been hampered by several constraints such as lack of records of waste quantity and composition, low calorific heating value, financial incapability, unsupportive local policies, and technological know-how and adaptability. For a start, there is need to conduct feasibility studies, upgrade the predominant open dumps in developing countries to sanitary landfills and later seek financial and technical assistance. Establishment of a vibrant WTE market in developing countries will have enormous social, economic and environmental benefits.

Keywords Solid waste · Management · Energy and developing countries

1 Introduction

Energy is vital for socio-economic development while several human activities result in the generation of materials which are no longer of use otherwise called solid wastes. Global energy demand is continuously increasing due to rapid population growth and urbanization [6], and it is projected to keep rising especially

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in developing countries [8]. Consequently, energy affordability and energy poverty are two major challenges facing developing countries. According to the UK Parliamentary Office of Science and Technology report of December 2002, about 1.6 billion people in developing countries are still without access to energy services, 80% of which live in rural areas of sub-Saharan Africa and South Asia. Fossil fuels remain the principal form of energy powering global expansion by providing about 60% of the additional energy requirement and in future, may account for almost 80% of total energy supplies in 2035 [1]. In view of rising long-term energy demand, renewable energies and energy efficiency play vital roles particularly in fulfilling climate targets and commitments towards energy access and security [25].

Managing the enormous amount of municipal solid waste generated has being a challenging task to municipal authorities in both developing and developed countries. Population increase, changing lifestyle, industrialization, economic development and a host of other variables are responsible for the worldwide increase in solid waste generation. The urban population of the world is expected to increase from 3.6 billion in 2011 to about 4.6 billion in 2025 [20], while world cities generate about 1.3 billion tonnes of solid waste per year, and this quantity is expected to increase to 2.2 billion tonnes by 2025 [7].

Over the years, several methods which seek to effectively and efficiently manage these wastes have been proposed. Solid waste management activities involve technologies associated with the control of waste generation, handling, storage, collection, transfer, transportation, processing and transformation, and final disposal [18]. Throughout the world, there is growing emphasis on the integrated solid waste management hierarchy which places an order of preference for waste management actions according to what is desirable for human beings and the environment. The European Union's five-step waste management hierarchy places prevention as the best option followed in decreasing order of priority by reuse, recycling, recovery, and disposal as the least preferred option [3, 4].

Obviously, it is advisable to prevent or reduce the generation of wastes. However, if waste is inevitable, it is desirable to reuse or recover materials from the waste stream. Chalmin and Gaillochet [2] observed that only 25% of the total quantity of municipal solid waste produced yearly in the world is recycled or recovered. In developed countries, landfilling and thermal treatment are disposal methods of waste that cannot be used or recycled. Wastes that cannot be practically reused or recycled or those that escape the predatory claws of scavengers in developing countries end up in open dumps and uncontrolled landfills.

As the global level of solid wastes and demand for energy continue to rise, Waste to Energy (WTE) technology plays a dominant role in solving these two challenges. WTE technologies consist of methods/processes to extract valuable energy contained in waste streams for the production of electricity, heat or transport fuel [24], and it is a vastly underutilized resource throughout the world [11]. Presently on a global scale, there are over 1200 WTE plants in operation across more than 40 countries [10]. WTE as a thermal treatment option in many countries

of the Organization for Economic Cooperation and Development (OECD) has replaced the traditional incineration of waste, in addition yielding energy in form of electricity or heat [22].

2 Income Classification of Economies

The classification of economies by the World Bank in July 2016 according to 2015 Gross National Income (GNI) per capita is presented in Table 1. From this classification, 31 countries are low-income countries, 52 are lower-middle income countries, 55 are upper-middle income countries, while 79 are high-income countries. This criterion (economic status) forms a key indicator of a country's development and may reflect similar solid waste generation rate, composition, and management technique of a group of countries in the same class. In this study, any country that falls within the low, lower-middle or upper-middle income group is termed a developing country. Hence, there are a total of 5.861 billion people living in 138 developing countries and having GNI per capita less than $12,476.

3 World Energy Situation

The total energy consumption in the world between 1997 and 2015 is illustrated in Fig. 1. Energy consumption has continuously grown over the years. It grew from 9,530 Mtoe in 1997 to 13,778 Mtoe in 2015 representing 30.8% increase in demand. This increase in energy consumption may be as a result of the expanding world economy which is associated with higher levels of activities and living standards. Therefore more energy will be required in the next twenty years to support world economy growth and prosperity [1]. In developing countries, demand for energy services is expected to increase considerably and primary energy demand presumed to triple and form up to two-thirds of total global demand by 2050 [15].

Table 1 Classification of economies based on income and associated population

World Bank classification	Low income	Lower-middle income	Upper-middle income	High income
No. of countries	31	52	55	79
GNI ($)	1,025 or less	1,026–4,035	4,036–12,475	Above 12,476
Population (billion)	0.622	2.878	2.361	1.398

Adapted from http://siteresources.worldbank.org/DATASTATISTICS/Resources/CLASS.XLS

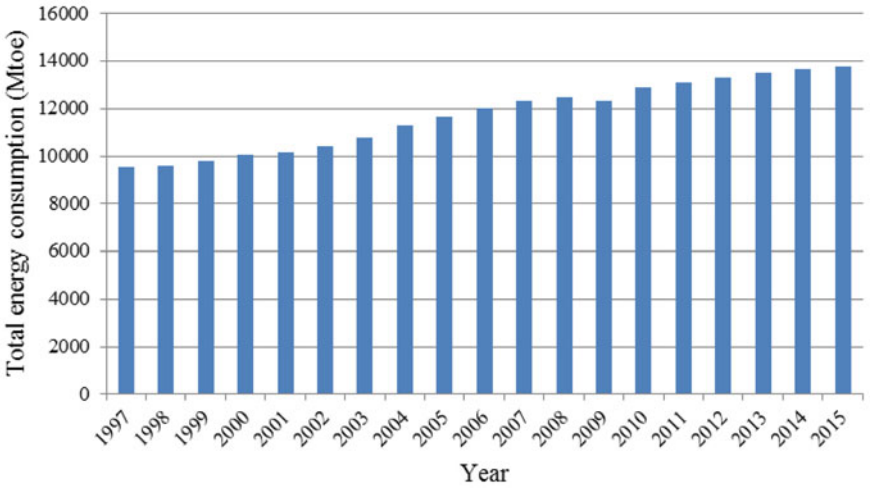


Fig. 1 World energy consumption. Adapted from Enerdata [5]

4 Generation and Composition of Solid Wastes from Developing Countries

Solid waste is generated primarily as a result of productive and consumptive activities from households, commercial establishments, institutions and industries. Several factors have been known to affect the output and characteristics of solid wastes in developing countries. Urban solid waste generation rates for developing countries are shown in Table 2. The per capita generation rate of solid waste is highest for upper middle income countries, followed by lower middle income countries, while low income countries have the lowest per capita generation rate. Specifically, the rate of generation of solid waste in upper middle income countries is almost double the amount generated by low-income countries. However, lower

Table 2 Waste generation in developing countries

Income level	Urban population	Waste generation rate (kg/capita/day)	Total (tons/day)
Low income	676,000,000	0.86	581,360
Lower-middle income	2,080,000,000	1.3	2,704,000
Upper-middle income	619,000,000	1.6	990,400

Source Hoornweg and Bhada-Tata [7]

Table 3 Waste composition by income level in developing countries

Income level	Composition					
	Organic (%)	Paper (%)	Plastic (%)	Glass (%)	Metal (%)	Other (%)
Low income	62	6	9	3	3	17
Lower-middle income	55	10	13	4	3	15
Upper-middle income	50	15	12	4	4	15

Source Hoornweg and Bhada-Tata [7]

middle income countries will have the highest total waste generation because the urban population is more than triple the upper middle income countries and low income countries. In totality 4,275,760 tons of solid waste is expected daily from developing countries.

Table 3 shows the composition of a typical solid waste from developing countries. It contains more organic materials, and less glass and metal. The organic materials have high moisture content (about 20–70%); hence, these wastes have low calorific heating value.

5 Energy Content of Solid Wastes from Developing Countries

Energy content of solid wastes from developing countries was calculated using established moisture content and calorific energy value of waste components contained in Tchobanoglous et al. [17] and Kamuk and Haukohl [10]. The calculated energy content based on dry matter of solid wastes from the three income groups that make up developing countries is presented in Table 4. The total energy potential of these wastes is 3.55×10^{13} kJ/day. This energy content translates to approximately 9.87×10^{9} kWh energy per day (i.e. 1 kWh = 3600 kJ).

Table 4 Overall energy content of urban solid waste from developing countries on dry matter basis

Income level	Energy[a] (KJ/kg)	Total energy[a] (kJ $\times 10^{12}$)
Low income	11381.90	3.96
Lower-middle income	13568.70	22.89
Upper-middle income	13794.20	8.69

[a]Excluding metals and glass

6 Constraints and Prospects of WTE Facilities in Developing Countries

6.1 Lack of Fundamental Records/Data

Planning for a WTE plant requires knowledge of the expected quantity and composition of solid wastes, potential WTE sites, funding opportunities and a host of other parameters. The net effect of lack of these fundamental statistics are often a source of confusion and cast doubt in the minds of investors who may want to do business or provide services in the waste management sector [14]. Hence, feasibility studies are necessary to assess waste characteristics, present solid waste management system, energy value, energy sales, existing laws and standards, potential stakeholders, WTE organization options/setup, ownership, needed expertise, and project economy, finance and implementation.

6.2 Composition of Wastes

Lower calorific value and high moisture content of waste from developing areas may attract extra heating fuel and put the facility at risk. Also, the composition of wastes is influenced by several factors which in the long run may affect its calorific value. Little variation in calorific value for a short period may be tolerable but wide variation will affect operation cost and performance of the WTE facility. However, from this study, wastes from developing countries have calorific value of approximately 11–13 MJ/kg which is greater than an annual minimum of 7 MJ/kg or seasonal minimum of 6 MJ/kg recommended by Kamuk and Haukohl [10].

6.3 Financial Constraints

Developing countries are known to have limited foreign exchange resources and financial sustainability of solid waste management systems. Most developing countries are debt ridden. According to the World Bank [26], at the end of 2014, the total external debt of developing countries stood at $5,294 billion with 28.8, 34.5 and 36.7% representing short term, private non-guaranteed, and public and publicly guaranteed debt respectively. The combined stock of external debt of low-and middle-income countries was $5.4 trillion at the end of 2014, the net debt flows totalled $464 billion, and Foreign Direct Investment (FDI) was $576 billion [27]. Half of the top ten foreign direct investment recipients in the world (in 2014) are from developing countries and multinational enterprises continue to acquire

foreign affiliates in the developing world [21]. FDI's significance to developing countries is in the area of transferring production technology, skills, innovative capacity, and organizational and managerial practices between locations, as well as of accessing international marketing networks in primary, manufacturing and services sector [12].

WTE plants in the USA and Europe require a capital cost of 2.90–7.70 million$/MW, operating cost of 90,000–200,000 million$/MW/year and the levelised cost of electricity is 80–210 million$/MWh [24]. Also, the World Bank estimates the costs associated with WTE facilities in lower middle-income and upper-middle income countries as $40–$100 per ton and $60–$150 per ton respectively [7]. More so, a modern WTE incinerator may require costs to maintain pollution control equipment and additional costs on supplementary fuel to burn a typical high-organic and relatively wet waste from developing countries [19]. This amount is on the high side for developing countries when compared to budgetary allocations to the waste management sector which is an average of $29,620,553 [19] representing 5.89% of municipal budget for the referenced cities. Years back the sharpest increase in investment flows into clean energy was through venture capital and equity, and investment in public capital markets [23]. Today, the same investment flow or partially/entirely donor funded assistance may be valid for WTE technologies.

6.4 Education/Training and WTE Technology Transfer

Several qualified and skilled staff are required for all the sections in WTE facilities. These staff include on-site and off-site workers as direct or indirect staff during plant construction, and permanent staff for operation and maintenance of these facilities. Majority of WTE facilities run 24 hours in a day and 7 days in a week. The pool of employees differs from facility to facility, but the pool normally comprises operative staff, technical staff, administrative staff and contractors. However, WTE technology should match existing local socio-economic conditions in developing countries in order to be successful. In the early 1987, the WTE plant set up in India by technical assistance from a Danish firm failed due to mismatch of quality of incoming feed with plant design. The waste that was available for the plant could not sustain combustion due to the difference in its composition in relation to design parameters [9].

Staff in WTE facilities require general training such as gas treatment, maintenance/operation optimization, asset management, regulatory compliance, emission monitoring, job ethics and safety. Also, some staff in waste handling, conversion and pollution control sections need advance training to acquire skills and knowledge to meet specific job requirements.

6.5 Government Policies

In reality, capital and operating costs of WTE facilities are more than other disposal methods. Several government initiatives such as tax credit, subsidies, emission restrictions, and renewable energy legislations/policies/targets are required to encourage domestic growth of WTE technology [8]. Also, infrastructure for waste collection and sale of energy is required for sustainability of WTE facilities.

6.6 Key Prospects

WTE offers three key benefits: reduction of waste volumes by at least 90%, recovery of metals and other materials, and the generation of renewable base load energy [11]. Proper investment in WTE technology has the potential to yield significant economic and environmental benefits in terms of revenues, employment, and pollution and greenhouse gas emissions reduction in many parts of developing countries. Revenues come from tipping fees, and sales of energy and recyclables. Though WTE is not yet financially competitive in a number of markets, the global market for thermal and biological WTE technologies may grow to about $29.2–$80.6 billion by 2022 [11].

In the USA, the WTE industry employs about 5,350 people nationwide and every dollar of revenue generated by the industry puts a total of 1.77 dollars into the economy through intermediate purchases of goods and services, and payments to employees [13]. Developing countries are characterized by cheaper labour costs than the USA; hence, there are opportunities for more earnings from WTE plants.

Also, the WTE process is CO_2 neutral because it saves fuel that would have been used in traditional plants, and it is relatively cheap in comparison with biomass, wind and photovoltaic power; i.e., the WTE process costs only EUR 7–12 to save one ton of CO_2 [16].

Other advantages of WTE facilities are [10]:

- Most efficient way of reducing waste volume and the demand for landfilling.
- Flexibility in location thereby reducing the need for transportation.
- Sustainable renewable energy source to substitute fossil fuels.
- Environmentally beneficial without greenhouse gas generation.
- WTE facility bottom ash can serve as substitute for virgin aggregate.

7 Conclusion

Waste to energy (WTE) technologies play a significant role in solving waste disposal and energy shortage challenges. In WTE technologies, wastes are combusted for the production of electricity, heat or transport fuel. These technologies provide tremendous socio-economic value and less negative environmental impacts on host communities. Over 4.2 million tons of solid wastes with combined energy content of approximately 9.87×10^9 kWh are generated daily from developing countries. There is also the availability of cheap labour to meet some specific semi-skilled or unskilled job demands.

However, composition variability, high moisture content and low calorific value of solid waste from developing countries affect its combustibility. WTE applicability to developing economies is hampered by lack of records on waste quantity and composition. Huge capital cost is also needed to start up and maintain a WTE facility. Local policies are equally unsupportive and technological know-how and its adaptability to local conditions is a prerequisite. Today, the same investment flow or partially/entirely donor-funded assistance may be valid for WTE technologies. To invest in WTE technologies, developing countries need to upgrade the predominant open dumps to sanitary landfills, closely followed by collection optimization, and education/training before WTE technology transfer.

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