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Electricity generation from municipal solid waste in some selected cities of Nigeria: An assessment of feasibility, potential and technologies

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ABSTRACT

In this paper, the potential of municipal solid waste (MSW) for electricity production in twelve selected metropolises in Nigeria using Landfill Gas to Energy (LFGTE), Incineration (INC) and Anaerobic Digestion (AD) technologies is presented with the aim of evaluating the energy potential for each location as well as determining the economic viability of possible waste to energy project. Waste profile of each location was determined using population data obtained from National Population Commission (NPC) located in Ibadan and the per capita waste generation gathered from literature. The economic viability of the projects was determined using levelised cost of energy (LCOE) and Net Present Value (NPV) methods. Some of the key results revealed that Port Harcourt (M6), Abuja (M7), Benin (M5) and Ilorin (M8) are potentially feasible and economically viable for waste-to-energy project. However, Abakaliki (M4), Bauchi (M9) and Jalingo (M10) are less viable for such a project. INC and LFGTE technologies provide the best technological option for waste-to-energy project in term of quantity of electricity that can be generated in the cities located in the Northern part of Nigeria based on the kind of wastes that are being generated at the locations while AD present itself as the technology of choice in the cities located in the Southern region. However, from the point view of economic viability, AD is the best option in all the locations followed by LFGTE. INC technology present the highest LCOE and hence less economical for electricity generation in all the locations. This paper is useful to the investors, policy makers, scientist etc. as it could serve as a source of scientific information for decision making which could lead to optimal investment in waste-to-energy project in Nigeria.

1. Introduction

Some of the causes of unprecedented increase in the rate of municipal solid waste (MSW) generation and energy demand in recent years have been attributed to population increase, changing consumption pattern, increased level of urbanization, fast improving industrialization and economic growth [1]. Energy and clean environment are crucial to the development and living standards of any nation. Therefore, effective management, utilization and conversion of MSW to useful energy (*Waste-to-Energy*) could be a potential means of providing a sustainable and environmental friendly solution to bridging the gap between energy and the environment. Waste -to -energy involves thermal and biological processes that extract the usable energy stored in the organic portion of solid waste to produce heat (steam) or electricity or both (combine heat and power) [2]. This involves recovery of landfill gas, incineration, gasification, production of H_2, pyrolysis and anaerobic digestion of the organic fraction of the waste [3]. Therefore, utilization of MSW as a renewable energy source could overcome waste disposal issues, generate electric power and mitigate GHG emissions.

In Nigeria, inadequate waste management and poor electricity generation are some of the main challenges facing the country. There is an increase in the rate at which solid wastes are being generated in recent time as a result of population growth and increasing urbanization. This rate outweighs the current waste management infrastructure and is taking a negative turn on the environmental health related problems. Also, there is a high gap between the electricity generation and demand resulting into energy poverty [4]. The average electrical energy and power per capita in Nigeria are in the range of 107 kW h per annum and 12 W, respectively. This is considered inadequate when compared to some other developing countries such as South Africa (4347 kW h and 496 W) and Malaysia (3310 kW h and 377 W) [4]. Therefore, encouragement of waste-to-energy projects for electricity generation in the country could be a promising environmentally friendly and sustainable strategy to overcoming the duo of waste generation problem and inadequate power supply. However, for

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optimal investment in any waste-to-energy projects, there is need to have concrete background information on the potential of possible energy generation from available waste regime in the country as well as its economic benefits. Currently, more than 800 thermal waste-to-energy plants are operated in nearly 40 countries globally; they treat approximately 11% of MSW generated worldwide and produce up to about a total of 429 TW h of power [2].

Generation of energy from MSW is gaining increased attention around the world in recent time: Fazeli et al. [5] performed extensive analysis of potential energy recovery waste treatment techniques from MSW in Malaysia. It was concluded that land fill to gas to Energy (LFGTE) technology is of potential interest in Malaysia compared to other waste incinerator technology because it is cheaper and requires less time. The authors are also of the opinion that an upgraded Feed-in-Tariff that would enhance increasing utilization of waste-to-energy technology will enhance the ratio of renewable energy mix in the country. Tozlu et al. [6] discussed the management of MSW for the production of Land Fill Gas for power generation in Gaziantep metropolitan city. The authors also provided an overview of recent technologies and methods applied to MSW management around the world. In the same vein, Shehzad et al. [7] presented a synthetic natural gas (syngas) production for Pakistan using MSW gasification system in which circulating fluidized bed gasifier was utilized. The authors developed a process model using ASPEN PLUS simulator. The results were obtained on the basis of the reference plant capacity of 50 MW with a significant total energy potential of 30 MW. A comparative Life Cycle Assessment (LCA) of two approaches for integrating MSW management system into the province of Gipuzkoa, Spain has been studied by Bueno et al. [8]. The approaches are the prioritize energy recovery from mixed residual waste in an incinerator and the material recovery of separate collected waste. It was concluded that the formal presented a better results compared to the latter when LCA framework was applied. The roles which MSW could play in providing energy to African urban areas using incineration and land fill gas technologies have been presented by Scarlat et al. [9]. The authors projected that electricity generation from MSW in Africa could reach 122.2 TW h by 2025. They also provided a vision for spatial distribution of energy from waste based on the population in major cities in Africa.

In Nigeria, waste-to-energy practice has been limited to the use of traditional biomass (wood fuel and charcoal) to meet off grid heating and cooking especially in the rural areas [10]. However, attempts have been made by some indigenous researcher in evaluating the potentials of MSW in some part of the country: Amoo and Fagbenle [11] have carried out the potential of MSW to generate electrical and heat energy in selected cities in Nigeria, but limited their work to few localities and did not consider the economic benefits of the technologies. Akintayo et al. [12] are concerned with the energy potential in the combustion of MSW in Ibadan without considering the economic analysis associated with the technology. Feasibility study for the recovery of landfill gas to generate electricity in two existing landfill sites in Nigeria (Abuja and Ibadan) has also been reported by Center for People and Environment (CPE) [13], however, this work is limited to LFGTE technology only. Adeoti et al. [14] studied the biogas potential from livestock manure and its climate change value in Nigeria by considering only anaerobic digestion.

In most of the aforementioned studies, only a single waste-to-energy technology is considered which does not give room for technology comparison. As such, most suitable technological option for any given location are not easily determined. The objectives of this work are therefore to

i. quantify the potential of MSW in 12 selected cities covering all the six geographical zones of Nigeria
ii. provide a holistic assessment of the technical and economic potential of three different waste-to energy technologies (i.e INC, LFGTE and AD) for electricity generation in each of the 12 selected locations
iii. carry out comparison of the three waste-to-energy technologies with the intention of determining the best cost effective technology option for each of the selected locations.

This paper renders itself as a source of scientific information that could lead to optimal investment in waste-to-energy project in the developing economy such as Nigeria. It could also help to increase the share of renewable energy in the energy mix of the country.

2. Overview of solid waste

Solid wastes are usually classified based on their sources. In general, they can be classified into municipal solid waste, hazardous waste and infectious waste. These classifications are reviewed in this section; however, the main focus of this study is the municipal solid waste.

2.1. Municipal solid waste

Municipal solid waste (MSW) consists of refuse from household, market waste, yard waste, and street sweepings which may be in solid, liquid or gaseous form [11]. This garbage is generated mainly from residential and commercial complexes. A typical MSW consists of organic (biodegradable and non-biodegradable) and inorganic (recyclable) components. The organic (biomass) portion of the waste stream includes materials such as food waste, yard waste, paper, cardboard, textiles, leather and wood. Inorganic waste components include glass, ceramics, plastics, rubber and metals. These inorganic waste components can be recycled. The rate of waste generation is highly influenced by the population and income [15] as well as level of industrialization, socio-economic status of the citizens and the kinds of commercial activities predominant in the area [16].

2.2. Hazardous waste

Industrial and hospital waste are generally considered hazardous as they may contain toxic substances. Certain types of household waste are also hazardous. Hazardous wastes (could be highly toxic to humans, animals, and plants) are corrosive, highly inflammable, or explosive; and react when exposed to certain things e.g. gases [17]. Household wastes that can be categorized as hazardous waste include old batteries, shoe polish, paint tins, old medicines, and medicine bottles. Hospital waste contaminated by chemicals used in hospitals is considered hazardous. These chemicals include formaldehyde and phenols, which are used as disinfectants, and mercury, which is used in thermometers or equipment that measure blood pressure. In the industrial sector, the major generators of hazardous waste are the metal, chemical, paper, pesticide, dye, refining, and rubber goods industries. Direct exposure to chemicals in hazardous waste such as mercury and cyanide can be fatal [16].

2.3. Infectious waste

Infectious wastes are the hospital waste generated during the diagnosis, treatment, or immunization of human beings or animals or in research activities in these fields or in the production or testing of biologicals [18]. It may include wastes like sharps, soiled waste, disposables, anatomical waste, cultures, discarded medicines, chemical wastes, etc. These are in the form of disposable syringes, swabs, bandages, body fluids, human excreta, etc. This waste is infectious and can be a serious threat to human health if not managed in a scientific and discriminate manner [17].

3. Energy conversion pathways from MSW

Energy contained in the organic portion (biodegradable and non-