# Abstract

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Student ID: 4D20200004
Name: Md. Shoriful Alam Mondal

## Study on the Technical Feasibility of Waste-to-Energy Incineration for Municipal Solid Waste Management in Developing Countries – Case in Dhaka City

### Background and rationale of research

Cities in developing countries mostly face serious environmental problems and public health risks due to the non-sanitary conditions of landfills and uncollected mass of Municipal Solid Waste (MSW). Dhaka City (i.e., case study area) has been facing almost similar problem. It is a megacity of 400-year-old and one of the topmost densely populated metropolises in the world[1]. Though about 7,000 tons of waste are generated daily, Dhaka City does yet not have formal resource recovery or waste-to-energy (WtE) facility, therefore, most of the waste is deposited in the landfills. The lives of existing landfills will end soon. The media keeps reporting on clogged sewers, waterlogging, mosquito breeding, and pollution of rivers by municipal solid waste. Recently, an organization has named Dhaka City's landfill as one of the major contributors to global warming, tracing methane emission rate 4 ton/hour[2].

In such a situation, WtE incineration system can be considered as a promising solution to diminish the current crisis due to its lower emission intensity, immobilization of hazardous substances, high-degree volume reduction (about 90%) and mass reduction (about 80%), and low space requirement. In addition, the energy can be recovered and used in the plant itself, and the excess amount can be sold or distributed through the national grid. But waste from cities in developing countries contains higher amount of moisture ($W$), that is a major problem for auto-thermal combustion and energy recovery from incineration plants. A waste with $W$ > 60% may not burn at 870 $^0$C autogenously[3]. The literature also says above 55% moisture is a challenge[4]. Incineration is suitable for waste within certain properties, such as $W$ < 50%, the inert rate or ash content (ignition residuals) < 60 %, the rate of fuel fraction or combustible fraction (ignition loss of dry sample) > 25 % and a sufficiently elevated energy content, i.e., a lower heating value ($LHV$)[5]. That appeals the need of the research as how to maximize the $LHV$ ($MJ/kg$) and how to ensure collection and supply of such waste for a sustainable WtE incineration.

Therefore, the focus of this research is to contribute to increase $LHV$ to enhance the *technical* feasibility of WtE incineration and improve sustainability of MSW management. To run the incineration with energy recovery, the certain quantity of MSW ($t/d$) and quality as ($MJ/kg$) are necessary. In addition, $LHV$ is one of the most critical needs to design the plant for optimal combustion and power generation. The exact range of $LHV$ for energy recovery depends on the several factors such as plant technology used, control of the incineration process, plant capacity ($t/d$), combustion rate ($t/h$) etc. $LHV$ is considered **equal to or greater than 6 $MJ/kg$** to start WtE incineration in this research as a feasible option **with energy recovery**. However, only to incinerate waste without energy recovery, $LHV$ less than 6 $MJ/kg$ may technically feasible.

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[1] *Population density by city*. (2014). Our World in Data. Retrieved January 10, 2023, from https://ourworldindata.org/grapher/population-density-by-city

[2] Dhaka Tribune. (2021, April 29). Dhaka landfill emits 4 tons of methane per hour. *Dhaka Tribune*.

[3] Kathirvale, S., Muhd Yunus, M. N., Sopian, K., & Samsuddin, A. H. (2004). Energy potential from municipal solid waste in Malaysia. *Renewable Energy*, *29*(4), 559–567.

[4] Kathirvale, S., Muhd Yunus, M. N., Sopian, K., & Samsuddin, A. H. (2004). Energy potential from municipal solid waste in Malaysia. *Renewable Energy*, *29*(4), 559–567.

[5] World Bank. (1999). *Municipal Solid Waste Incineration* (p. 112) [Technical Guidance Report]. The International Bank for Reconstruction and Development.

Thus, this research is concerned with how to realize MSW that exhibits equal to or greater than $6\ MJ/kg$ energy content with a certain collection amount ($t/d$) that can meet the daily WtE incineration plant's need. However, these property and performance are influenced by the prevailing management or *governance* system. For this reason, emphasis has also been placed on understanding the *governance characteristics* including **Governance Potential** such as plans and policies, who the stakeholders are, what their roles are, what the SWM systems or approaches are, etc. These qualitative management features (i.e., *governance*) can greatly affect the *technical* quantitative features (e.g., $t/d, MJ/kg$). Considering these factors, **Primary Collection Service Providers (PCSPs)** are included in the study who are one of the main actors of SWM in Dhaka City for collection. This study also includes the **Ward Based Approach (WBA),** a framework for planning, implementing, and monitoring the SWM process implemented at the community or ward level (e.g., grassroots level) in Dhaka City, and is examined from governance perspectives.

## Aim and objectives

The aim of this research is to **improve the sustainability of municipal solid waste management through enhancing the technical feasibility of waste-to-energy incineration.** To achieve this aim, two objectives are set. *First*, to develop an empirical model to determine the lower heating value of waste and investigate the feasibility of WtE incineration, and *second*, to investigate the governance characteristics to support the technical feasibility of WtE incineration and contribute to the sustainability of SWM.

## Hypothesis

"WtE incineration plant would be feasible in Dhaka City if **appropriate measures** are taken in **the near future**." Appropriate measure means optimizing $LHV$ ($\geq\ 6\ MJ/kg$) of waste and collection of waste considering different scenarios in **technical and governance aspects**. In **technical aspects,** scenarios are (a) *reduction of moisture content*, (b) *waste brought to the plant from specific areas*, and (c) *natural growth of LHV due to changes in the composition of waste over time*. In **governance aspects** scenarios are (a) functional stakeholders are in place, (b) certain quantity of collection with suitable quality ($LHV \geq 6\ MJ/kg$) waste is in place, and (c) SWM system is in place (i.e., WBA).

## Contents of the research

Technical aspect encompasses following three scopes of study: (1) analysis of the waste characteristics; (2) development of empirical model to predict lower heating value of municipal solid waste and (3) development and analysis of different scenarios to make WtE incineration technically feasible. Scopes under governance aspect to support technical aspects are (4) assessment of the governance characteristics to support WtE feasibility, (5) study of the policies and practices of PCSPs to enhance waste quality and quantity and (6) investigation of the roles of WBA to support WtE feasibility. How the **technical** and **governance** aspects relate, influence each other, and contribute to the achieve the aim and objectives are main contents of the research.

## Theories of feasibility in Waste-to-Energy incineration

This study addresses the feasibility of WtE in the context of a scoping review of literature. Problems with waste quality and quantity (e.g., lower calorific value), poor plant management, and inadequate institutional arrangements have been seen as reasons for hindering feasibility of WtE incineration plant[6]. Different organizations and scholars have proposed or investigated the feasibility of WtE in different angles and the most common dimensions are within the domain of sustainability

[6] EPA. (2012). *Municipal Solid Waste Generation, Recycling and Disposal in the US.* Environmental Protection Agency (USA).

science (e.g., technical, economic, social, and environmental factors considerations) with some process simulation where Lower Heating Value (*LHV*) has been an important parameter. IGES and UNEP summarized twenty-four (24)[7] critical feasibility criteria based on six (6) sustainability components including *Governance capability and Technological (i.e., LHV).* Scholars in Havana, Cuba, used Aspen plus & excel based model for process simulation on techno-economic aspects, that tells to develop feasible WtE project overcoming the six (6) barriers in underdeveloped countries *including informal sector; waste characteristics*[8]. For developing & emerging countries, GIZ[9] developed a decision matrix with twelve (12) essential parameters subdividing into forty-eight (48) criteria for feasibility which includes *waste management level; composition of waste; LHV; quantities of waste for WtE* etc. World bank devised seven (7) parameters in technical feasibility assessment[10]. These are further segmented into thirty-two (32) key criteria for assessment including *LHV* for energy recovery.

## Methodologies to undertake the research

A theoretical framework of the research is shown in Figure A-1. Case study is done in Dhaka City based on the scopes of study confirmation under *technical* and *governance* aspects.

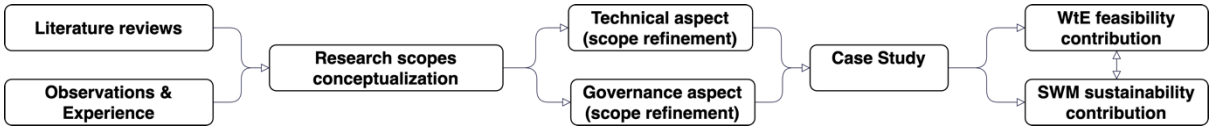


Figure A-1: Contextual framework of the study

### *Technical aspect's methodology*

90 composite data sets (i.e., wet basis physical composition as mass fractions) were prepared comprising percentage of waste components from extensive characterization surveys in two different seasons (8 days/season) between 2017 and 2018 following standard field and laboratory protocols. Households, restaurants, markets, offices, roads, and landfill wastes were considered as source categories. Waste was characterized in sixteen (16) categories after mixing and quartering. Moisture content was measured with 24 hours oven drying at 100°C. Three reference equations were used to find *LHV* of each data set and average of them was used as dependent variable where the components were used as explanatory variables to develop regression model. The three (3) different scenarios have applied to the model and checked the WtE incineration feasibility. Scenarios are improving *LHV* by (1) evaporative moisture loss and mixing in different proportions, (2) locational preferences for waste sources and (3) natural growth trend of *LHV*. An estimation is made for electricity production and compared with other studies.

### *Governance aspect's methodology*

*Governance potential* has been studied based on the past framework (i.e., indicator or paraments) of the study for *Governance Capability*. Existing literature have been reviewed and expert interviews were made and analyzed. *Institutional and Organizational* dimensions have been emphasized through expert interviews and literature reviews and conclusions have been drawn based on the contextual triangulation analysis. The *PCSPs*, as important key stakeholders of municipal SWM

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[7] Liu, C., Nishiyama, T., Gamaralalage, P. J. D., Onogawa, K., Hotta, Y., & Honda, S. (2020). Waste-to-Energy Incineration. *IGES, UNEP*, 45.

[8] Lorenzo L. J., & Kalogirou, E. (2019). Waste-to-Energy Conversion in Havana: Technical and Economic Analysis. *Social Sciences*, *8*(4), 119.

[9] Mutz, D., Hengevoss, D., Hugi, C., & Gross, T. (2017). *Waste-to-Energy Options in Municipal Solid Waste Management*. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), GmbH. Bonn and Eschborn, Germany.

[10] World Bank. (1999). *Municipal Solid Waste Incineration* (p. 112) [Technical Guidance Report]. The International Bank for Reconstruction and Development.

in Dhaka City, were studied through interviews, observational surveys, and a SWOT (strengths-weaknesses-opportunities-threats) analysis to capture the policies, strategies and practices. *WBA* (community level decentralized SWM process and approach) has been studied through online questionnaire surveys, web meetings, and online interviews. It covered how components of WBA's contribute to WTE feasibility; assessment of current state; ways to improve sustainability, likeliness of WBA's role on WTE feasibility; waste separation status; issues and hindrances for WBA promotion, and knowledge, skills, and motivational suggestions for WBA promotion. Information transcription, coding and triangulation for contextual summary is made using MaxQDA. Effort has been made to develop logical reasoning context with casual analysis to contribute theory of change in future.

## Results and discussions

### *Technical aspects to support WtE feasibility*

Waste characterization, heating value modeling and scenario analyses are done under technical aspect to support WtE feasibility through enhancing $LHV$. Following statistical processes for multiple liner regression, models are developed to predict $LHV_w$ with the proposition of simplified model. Aiming to determine regression coefficients against each physical component (i.e., explanatory variable), 90 composite datasets are applied in the three reference models based on globally distributed datasets and their average is used to develop models. Models derived in this study are the first ever models based on the physical composition of solid waste in Bangladesh. Data used in model development are based on extensive characterization surveys in DCCs. The developed and proposed model is shown in Eq. (1). The proposed model is used for future $LHV$ prediction, and it may also be used in other areas where waste characteristics are nearly similar.

$$\boldsymbol{LHV_w\left(\frac{MJ}{kg}\right) = 7.721 + 0.034F_o + 0.074P_a + 0.071W_d + 0.077T_x + 0.104R_l + 0.121P_l - 0.126W_w} \quad \text{Eq (1)}$$

Where, $LHV_w$, Lower heating value wet basis ($MJ/kg$); $F_o$, Food waste portion (%); $P_a$, Paper, cardboard portion (%); $W_d$, Wood portion (%); $T_x$,Textile portion (%); $R_l$, Rubber, leather portion (%); $P_l$, Plastic portion (%) and $W_w$, moisture content (%).

In general, around 60% of MSW of DCCs is household fraction which contains around 70% food waste with a moisture content $>$ 80%. Currently, its $LHV$ falls below the required limit of starting WtE (i.e., 6 $MJ/kg$), but household waste will acquire this property around 2030 according to the studied trend. This can be achieved earlier, if high income communities or wards having higher fraction of combustible wastes (i.e., having higher number of offices and businesses activities) are selected. However, 15% to 20% moisture reduction of household waste theoretically exhibits current feasibility. Waste from the wards with majority of offices and markets shows a feasible option to have stable supply (e.g., $>$ 500 t/d) by having their heating value equal or above 6 $MJ/kg$. $LHV$ is possible to increase by adopting different scenarios. Those can enhance feasibility for WtE incineration with power generation rate more than 6 $MW$ and 10 $MW$ for 500 t/d and 750 t/d plant lines, respectively. Restaurant waste may be targeted for bio-methanation with anaerobic digestions due to its high moisture content (74.1%) and street waste is to be avoided from incineration for its high sand proportion (28.7%). This study clarifies that current timing is rational to adopt WtE having feasible $LHV$ of waste from selected areas.

### *Governance aspects to support WtE feasibility*

It is possible to enhance the feasibility by exploring the hidden potential of *Governance capabilities* and get benefit from it. It can be difficult for externals unless a government agency is closely involved in the study and takes responsibility, as it is strongly driven by local policy and practice. Materializing the incentives as fiscal and monetary supports, policy supports contribute attractively

towards the feasibility of WtE incineration. There are many stakeholders for WtE incineration in Dhaka City who are directly and indirectly connected. Their roles in the project planning, approval, implementation, and operation level might differ. However, unless city corporations take the responsibilities of the quality-waste feed (e.g., certain energy content, physical compositions, quantity per day, etc.), the feasibility is deemed to be risky. The main challenges are lack of sufficient guiding documents; regulations and specifications for WtE and its operation, and local private investors and stakeholders may not have an exact experience. However, there are encouraging target of about 48 MW of electricity to be generated from WtE project by 2025 as per 8$^{th}$ Five-year plan of Bangladesh.

***Policies and practices of Primary Collection Service Providers***

The current collection rate in DCCs is about 80% is greatly contributed by the primary collection service providers (PCSPs) who mainly collect waste from households, buildings, stores, and offices on a regular basis. PCSPs take the waste to the municipal collection points from households, buildings, or business establishments, which helps to keep the city clean. The current issues are the timing, quality of rickshaws, type of waste separation, fees, lacking proper regulation etc. Formalization through the introduction of improved management and performance benchmarking is needed to overcome current issues and improve quality collection. Political hegemony and socio-political coercions have affected the quality of PCSPs' services. The administration has not been able to achieve the highest possible system in the permitting and registration due to the influence of social power and political power. There are confusions and contradictions between policies and practices regarding lack or unclear waste definitions, waste segregation, time and place-based harmonized collection systems. Special attention is needed by all stakeholders to reform policies through the creation of regulations. Socio-political hegemony shows that power groups can exert some control over authoritarian power, resulting in higher service fees, poor service quality, and the nonappearance of complaints. However, it is inevitable to streamline the approval process by rationalizing performance indicators, service fees, and PCSP contribution, and to try to continue governance practices (e.g., transparency, accountability, rule of law, inclusiveness, etc.) to realize high-quality collection.

***Roles of Ward Based Approach towards feasibility of Waste-to-Energy***

Study reveals that four (4) different components of WBA such as (1) functioning of ward SWM office (WBA-1), (2) work environment of the waste workers (WBA-2), (3) community based participatory SWM (WBA-3) and (4) modernizing and improving waste collection system (WBA-4) can contribute diverse ways on various aspects of WtE feasibility and improve local SWM. If WBA can be implemented optimally, there will be synergic effect towards SWM improvement and WtE sustainability. A mind-map is developed showing functional elements of WBA and its contribution towards SDGs. An effort is made to find out factors contributing to construct a theory of change where the result is considered to have a feasible WtE plant and contribution to sustainable SWM.

## Conclusions

***Conclusions on Technical aspect***

Currently, heating value of households' waste falls below the required limit of starting WtE but household waste is likely to acquire this property around the year of 2030. The areas where households waste comes with higher combustible fraction (e.g., higher offices, market waste) can exhibit feasibility criteria ($LHV > 6\ MJ/kg$) with stable supply (e.g., $>$ 500 t/d). However, 15% to 20% moisture reduction of household waste theoretically exhibits current feasibility. Those can enhance feasibility for WtE incineration with power generation rate more than 6 $MW$ and 10 $MW$ for 500 t/d

and 750 t/d plant lines, respectively as estimated by applying developed model and waste collection planning methods. Developed model values show consistency with other references model values.

***Conclusions on Governance aspect***

The roles of stakeholders may vary in planning, approval, installation and commissioning and operational phases. Stakeholders' capacity building is necessary towards a feasible WtE project. WtE incineration is positioned in an upper-level plan like SWM Master Plan, and the 8$^{th}$ Five-year plan of Bangladesh. Local government entities have strong willingness to consider WtE incineration. Local government can obtain support from expert committees and consultants to implement projects. Energy departments and electric power companies have developed technical standards and operations to sell and set the selling price for electricity. However, no feed-in-tariff is found as fixed, but power purchase rate was disclosed in 2021 as 21.78 cents for each $kW \cdot h$ for a project.

PCSPs are the key players in municipal SWM in Dhaka City. To improve the sustainability in SWM, there is an urgent need to pay special attention to formalize them through workable policies, and performance benchmarking to govern. Sociopolitical power plays key role in governing primary collection service (PCS). It hampers city authorities to optimally manage PCS. The lack of reliable regulatory document also leads to a lack of good governance. As sociopolitical hegemony exhibits, power groups can exert some control over authoritarian power, leading to higher service fees, poor service engagement, and the nonappearance of complaints. It is inevitable to rationalize the key performance indicators (KPIs), service fees and PCSPs deposit, and try to continue the practice of good governance. The needs for three sets of policy instruments are found: *(1) PCSPs' approval and management document as institutional document of DCCs, (2) PCSPs' monitoring and reporting management guideline, (3) PCSPs' standard operating procedures with clear benchmark indicators (KPIs) ensuring waste quality, efficient collection, and customer satisfaction*. If PCSPs are mobilized with capacity building effort, they can contribute to enhance the quality waste to the WtE plant.

WBA can hypothetically influence WtE feasibility through decentralization, community participation, collection improvement, etc. However, WBA must be implemented as routine work to ensure its maximum contribution to feasibility. Motivation of the staff members for promoting WBA is found as key factors for WBA sustainability which can be boosted by work recognition, salary structure modification, incentives, promotion etc. Ward SWM office (WBA-1) can be considered as an information, education, and communication center, as well as a community-level coordinating body for the other components of the WBA, but its numbers are fewer than its needs. Each ward should have one well-equipped SWM office to provide daily SWM service smoothly to the citizen. In Dhaka City, there are a total of 129 wards with only 51 SWM offices. WBA-2 (cleaners working environment and productivity) can help improving quality of waste by minimizing objectionable of waste (metal, stones, sands, construction waste, drain sludge etc.) and maximizing combustible fractions (e.g., papers, plastics, fabrics, garden trimmings, leaves etc.). WBA-3 (community SWM) can help for improved tariff structure, environmental education for waste sorting, waste signs and symbols. WBA-4 (waste collection) can facilitate to improve waste collection efficiency and effectiveness. Only compactor trucks should be destined to WtE incinerator, but there are insufficient compactors. And in some easily accessible places, compactor can collect and transport waste to WtE plant without PCSPs intervention.

***Limitations of the research and way forward***

It could be possible to improve the accuracy of model by incorporating laboratory test values. The governance characteristics examined may not be exactly same in other developing countries.

**Keywords:** feasibility study, waste-to-energy, incineration, lower heating value, technical aspect, governance aspect, solid waste management, Dhaka City