Doctoral Thesis

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

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Course of Regional Development Studies
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Dedication

I dedicate this work to my mother, the late Shamsunnahar Begum and my father, the late Md. Mahfuzar Rahman Mondal.

Acknowledgement

I was able to reach this position of my research through the help and encouragement of several people. Without the considerable time, effort, and kindness of my supervisor, Professor Dr. Hidetoshi Kitawaki, this would not have been possible. He provided me with constant support and guidance during the regular research meetings. I thank my co-supervisor, Professor Dr. Toshiya Aramaki, for his critical evaluations to improve the work in the mid-semester and end-of-semester presentations.

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Abstract

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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.

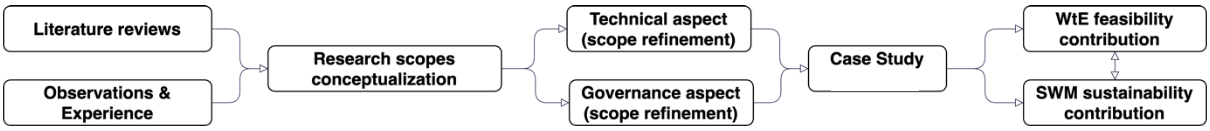

Figure A-1: Contextual framework of the study

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

[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 8th 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 8th 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

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List of abbreviations (as used)

3R	Reduce, Reuse, Recycle
3RINCs	3R International Scientific Conferences
ANN	Artificial Neural Network
BB	Bangladesh Bank
BOOT	Build, Own, Operate, and Transfer
BPDB	Bangladesh Power Development Board
CAP	Community Action Plan
CCC	Chattogram City Corporation
CDM	Clean Development Mechanism
CI	Conservancy Inspector
CO	Conservancy Officer
CUWG	Community Unit Working Group
DBO	Design, Build, Operate
DCCs	Dhaka City Corporations (DNCC & DSCC)
DNCC	Dhaka North City Corporation
DOE	Department of Environment
DPP	Development Project Proposal
DSCC	Dhaka South City Corporation
ECNEC	Executive Committee of National Economic Council
EIA	Environmental Impact Assessment
FIT	Feed In Tariff
FTFP	Fixed-Time Fixed-Place
GDP	Gross Domestic Product
GOB	Government of Bangladesh
HH	Household
IGES	Institute for Global Environmental Strategies
IETC	International Environmental Technology Centre
IPP	Independent Power Producer
ISWA	International Solid Waste Association
ISWM	Integrated Sustainable Waste Management
JCM	Joint Crediting Mechanism
JICA	Japan International Cooperation Agency
JSMCWM	Japan Society of Material Cycles and Waste Management
KM	Knowledge Management
LFS-A	Landfill Site - Amin Bazar
LFS-M	Landfill Site – Matuail
LGD	Local Government Division
LHV	Lower Heating Value
MAPE	Mean Absolute Percentage Error
MKT	Market

MOEJ	Ministry of Environment Japan
MoLGRDC	Ministry of Local Government, Rural Development and Cooperatives
MPEMR	Ministry of Power Energy and Mineral Resources
MRA	Multiple Regression Analysis
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
MW	Megawatt
NBR	National Board of Revenue
NGO	Non-Government Organization
NOC	No Objection Certificate
O&M Cost	Operation and Management Cost
OFS	Office
OJT	On the Job Training
PC	Primary Collection
PCS	Primary Collection Service
PCSP	Primary Collection Service Provider
PEC	Project Evaluation Committee
PET	Polyethylene Terephthalate
PESTEL	Political, Economic, Social, Technical, Environmental and Legal
PM	Proposed Model
PPA	Power Purchase Agreement
PPP	Public Private Partnership
PRA	Participatory Rural Appraisal / Participatory Research and Action
R/A	Residential Area
ROA	Real Options Approach
RES	Restaurant
SDGs	Sustainable Development Goals
SEE	Standard Error of Estimate
SM	Simplified Model
SREDA	Sustainable and Renewable Energy Development Authority
SWM	Solid Waste Management
SWOT	Strength, Weakness, Opportunity, and Threat
TOC	Total Organic Carbon
UNEP	United Nation Environment Programme
US EPA	United States Environmental Protection Agency
WB	World Bank
WBA	Ward Based Approach
WMD	Waste Management Department
WtE	Waste-to-energy (incineration)
YEC	Yachiyo Engineering Co., Ltd.

Glossary

Terms	Context, explanation
Dhaka City	The study area is Dhaka City, the capital of Bangladesh. And jurisdiction is City Corporation areas. There are currently two city corporations: Dhaka North City Corporation (DNCC)' and 'Dhaka South City Corporation (DSCC)' and both corporations are jointly terms as 'DCCs' in this dissertation. In November 2011, the one corporation, 'Dhaka City Corporation' known as 'DCC' was divided into DNCC and DSCC by the authority.
feasibility	The concept is the evaluation or assessment or appraisal of an endeavor such as a system, project, or service in terms of its usefulness, appropriateness, or practicality. The motivation is to look for ways to make the endeavor successful by examining its strengths and weaknesses as well as opportunities and threats. Feasibility is typically seen or assessed in different angles such economic feasibility, technical feasibility, governance feasibility, environmental feasibility etc. And again, within each of assessing areas there are many criteria and parameters.
governance	"The process of decision-making and the process by which decisions are implemented (or not implemented)." (UNESCAP, 2009). "Governance encompasses the values, rules, institutions, and processes through which people and organizations attempt to work towards common objectives, make decisions, generate authority and legitimacy, and exercise power." (Bhuiyan, 2010, mentioned citing CIDA)
solid waste management	"The functions related to reduction at source, segregation, collection, recovery, recycling, reuse, control, transfer, transportation, processing, and disposal of solid waste accordance with good policy for public health and environmental considerations (SWM Rules, 2021)."
waste-to-energy (WtE)	In this research, waste-to-energy means WtE incineration. "WtE incineration is the process of direct controlled burning of waste in the presence of oxygen at temperatures of 850°C and above, coupled with basic mechanisms to recover heat…" (Liu et al., 2020).
regression model	The equation showing the relationship between dependent and independent variables. In this study, the calorific value is considered as the dependent variable, while the physical components of municipal waste, such as paper, plastics, food, etc., are considered as dependent variables.
heating value or calorific value	To understand fuel efficiency of municipal solid waste, the energy content or calorific value within per unit mass is examined. It is estimation of heat realize from unit mass of waste. Understanding heating value is one of the most critical needs to design waste-to-energy plant and study the feasibility.
Primary Collection Service (PCS)	Collection of waste from door-to-door or households, buildings or from business establishments and then bring the waste to municipal collection point for subsequent transfer or transport. Typically, rickshaw vans are used but few cases hand trolleys are used in Dhaka City.
Primary Collection Service Provider (PCSP)	The entities who provide primary collection service typically using rickshaw vans and few cases hand trolleys in Dhaka city.
WBA	Ward Based Approach is the combination of four approaches aimed at promoting governance through decentralization and inclusivity of stakeholders for smooth municipal solid waste management functions in the community level.

Photograph of study area's solid waste management

Waste storage at downstair of a residential building

Primary collection using rickshaw-van

Primary transportation (after primary collection)

Open truck collection

Compactor collection from rickshaw van without container or dustbin

Compactor collection without rickshaw van and container (fixed-time fixed-place method)

Arm-roll container (secondary collection point)

Drain cleaning program

Waste transfer station, DNCC

Waste transfer station, DSCC

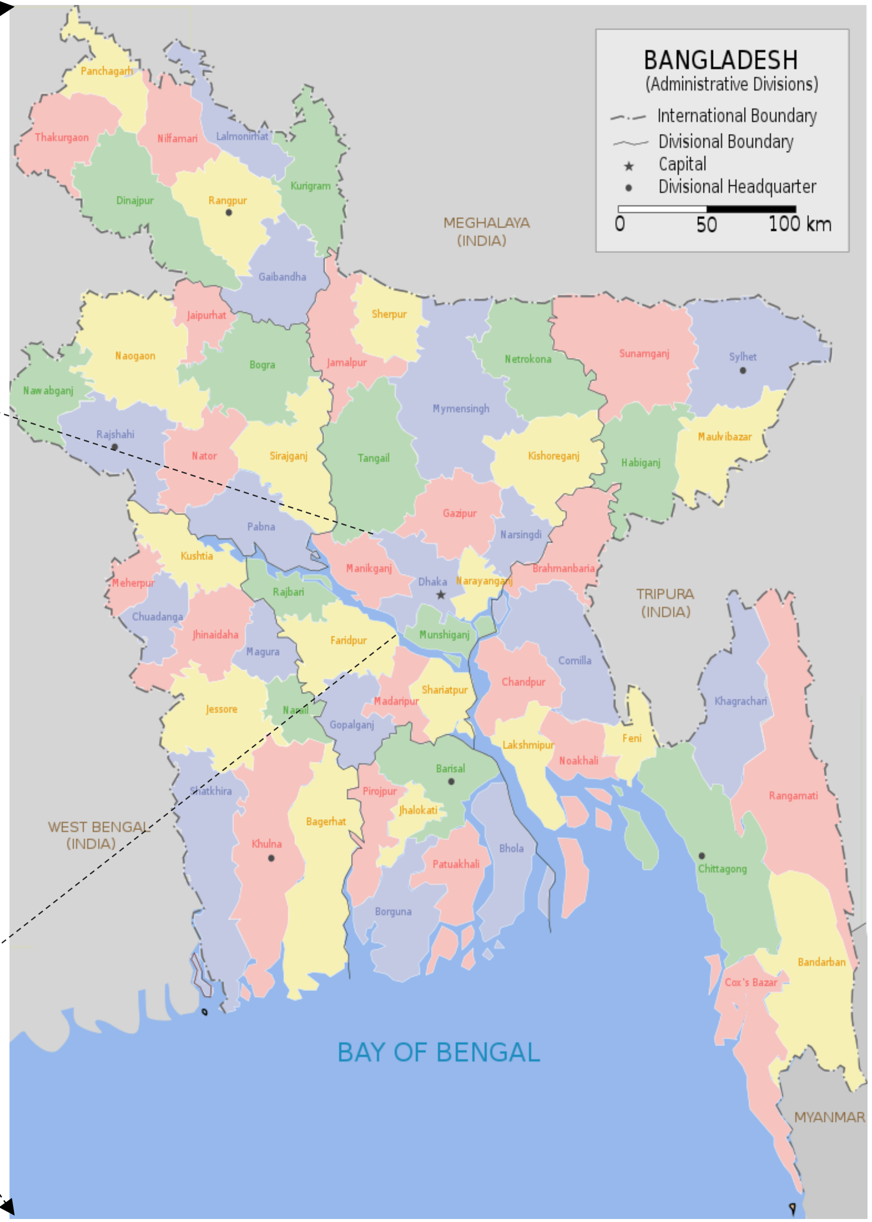
DNCC landfill site, leachate treatment pond (Amin Bazar)

DSCC landfill site, control building with weighbridge and car wash facility (Matuail)

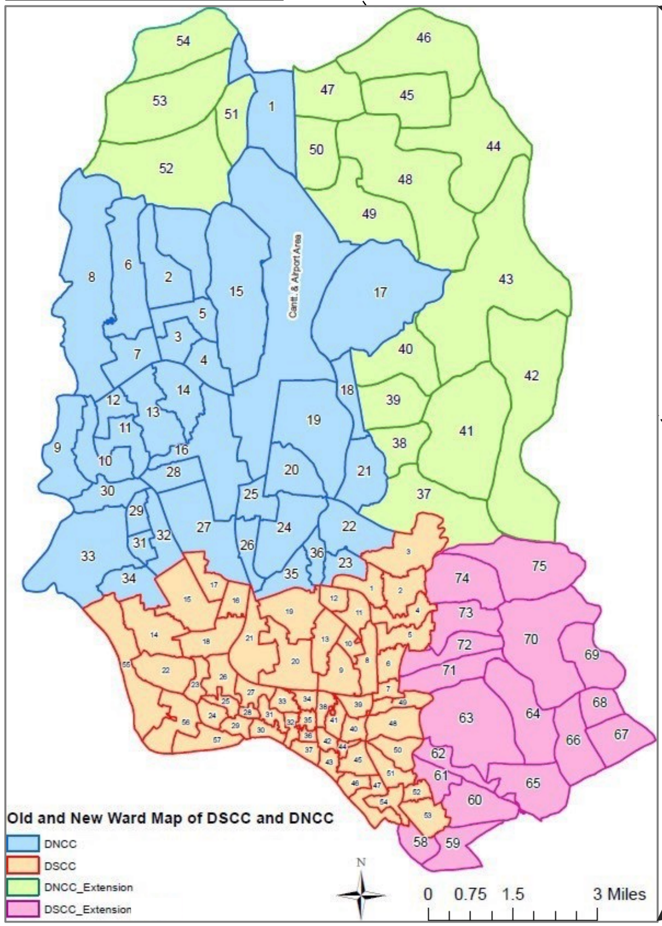
Map of study area

Region: South Asia

Country: Bangladesh



City: Dhaka North & South



CHAPTER 1: INTRODUCTION

1.1 Background

Considering the importance of environmental health and sanitation, Solid Waste Management (SWM) is highlighted in Sustainable Development Goals (SDGs). Municipal Solid Waste Management (MSWM) is one of the most important services to protect urban environment and a precursor for a healthy city. However, most of the cities of developing countries are yet to perform well to ensure proper waste collection, transportation, treatment, and disposal due to various needs.

The Integrated Sustainable Waste Management (ISWM) in long terms needs **physical elements, stakeholders** and **strategic aspects** as mentioned in Global Waste Management Outlook by UNEP, ISWA (David C. Wilson et. al., 2015). **Physical elements** are embodied in the SWM system or infrastructure. It ranges all the elements from waste generation through storage, collection, transport, transfer, recycling, recovery, treatment, and disposal (Wilson, 2015). **Stakeholders** involve all the actors, decision makers, beneficiaries, concerned entities and perceived to be affected or benefited entities. The **strategic aspects** include "the political, health, institutional, social, economic, financial, environmental, and technical facets (Wilson et. al., 2015)." A sound SWM system of a city requires combination of all the elements which can also be broadly perceived in two (2) aspects: **governance** and **physical** (Wilson et al., 2015). **Physical aspects** are assumed as **technical aspects** in this research. Waste collection, resource recovery (i.e., 3Rs), treatment and disposal are included in the **technical aspects**. And organizations with policies, financing and stakeholders' engagement are considered in **governance aspects**. Cities of developing countries are facing difficulties in managing both aspects. For example, one of the most traditional and popular disposal methods for MSW, in developing countries is landfilling (Dong, Jin, and Li 2003). Cities of developing countries face serious environmental problems and public health risks due to non-sanitary conditions of landfills and uncollected mass of municipal solid waste (Cointreau 2006). Dhaka City also has many problems; it is one of the densely populated cities in the world and generate around 7000 tons of waste per day (JICA 2018a; JICA 2018b). Space constrains is an important concern for MSW management in many developing countries where some forms of landfills are practiced (Wilson, et al., 2015). A waste-to-energy plant with incineration is more preferred than landfilling in MSW treatment due to its decomposition and immobilization of hazardous substances, high-degree volume reduction (i.e., about 90%), low space requirement and energy recovery (Eriksson et al. 2007; Huai et al. 2008; Sadef et al. 2016). The European directives also recommend decreasing the bio-degradable fraction of waste to be landfilled and to develop the recycling of materials, energy generation and the waste treatment before landfill disposal (Rada et al. 2007).

Typically, waste generated from the cities of developing countries contains higher moisture content and lower energy content (i.e., calorific value or heating value) than developed economies which is a demerit for incinerator-based waste-to-energy system. Due to high moisture content in the waste mix of developing countries, it is tough to ensure auto combustion and maintaining environmental quality parameter (Durlak, Biswas, and Shi 1997; Kathirvale et al. 2004; Katiyar, Suresh, and Sharma 2013; Kreith and Tchobanoglous 2002; C.-J. Lin et al. 2013; Zhou et al. 2014b). A waste with a moisture content more than 60% may not burn autogenously at 870 ^{0}C (Kreith and Tchobanoglous 2002) and two years later, literature also says that 55% moisture is challenging for incineration (Kathirvale et al. 2004). However, due to its characteristics, incineration is suitable for waste within certain properties, such as moisture content, 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 high heating value (Nzihou et al. 2014; World Bank 1999).

Therefore, the focus of this research is to find ways to enhance the waste-to-energy (WtE) incineration feasibility and thus contribute to the sustainability of municipal SWM. To run the WtE incineration, the desired Lower Heating Value (LHV) or energy content of MSW is one of the most critical needs to assess feasibility and sustainability. The exact range of LHV for auto-thermal combustion depends on the plant technology used and control of the incineration process. However, the LHV is also used in system design of WtE incineration plants. And LHV is considered **equal or greater than 6 MJ/kg** to start WtE incineration in this research as a feasible option in terms of energy recovery. However, only to incinerate waste without energy recovery, LHV less than 6 MJ/kg and about 3.4 MJ/kg may be considered as feasible (JICA, YEC, JESC, 2017). However, this depends on the incineration rate (ton/hour), plant capacity (ton/day), size of the grate and drying zone etc. In case of low energy content or high moisture, drying zone can be enlarged.

Different organizations and scholars have proposed and investigated the feasibility of WtE in different angles. However, the most common approach follows sustainability science (e.g., technical, economic, social, and environmental considerations) with some process simulation. Some have seen specific criteria of WtE such as heating value, energy recovery efficiency and some have seen financial, economic evaluation and with risk analyses. However, a sound SWM system is necessary to ensure efficient waste collection and transportation to the plant and to realize the quality of waste for the WtE plant.

Understanding governance characteristics in terms of SWM plans and policies, stakeholders and their roles in municipal SWM are also important to understand. There are existences of different stakeholders in Dhaka City's SWM. There are central governments (e.g., ministries), local governments (e.g., DNCC, DSCC) for municipal SWM, Primary Collection Service Providers (PCSP) for waste collection, Department of Environment (DOE) for SWM policy formulation and regulation etc. Effort has been made to articulate their roles, issues and how they can contribute towards WtE feasibility. In addition, the decentralized SWM process as modeled by Dhaka City Corporation and JICA Expert Team, known as Ward Based Approach (WBA) has also been investigated to determine how different stakeholders under different approaches (i.e., thematic areas of waste management) can contribute to improve SWM and enhance the feasibility of WtE.

Considering these factors, efforts have been made to develop LHV model based on wet basis physical composition of waste (mass fractions) to determine energy content in the field condition, and model has been applied to check the feasibility whether it can qualify minimum limit or not under *technical aspect*. How management or governance characteristics can influence the technical aspects that is also covered under *governance aspect*. *Technical* aspect is aimed at how to enhance lower heating value (LHV) of waste. On the other hand, the *governance* aspect is aimed at how to support *technical* aspect through decision making or management processes and enhancing waste collection quality and amount.

1.2 Aim and Objectives

The aim of this research is to **improve the sustainability of municipal waste management through enhancing the technical feasibility of waste-to-energy incineration.** Research tries to find the ways to enhance technical feasibility of WtE incineration by enhancing lower heating value (LHV). There are two objectives: objective (1) is considered from the *technical (i.e., physical)* aspect, and objective (2) is considered from the *governance* aspect of the framework of integrated sustainable waste management (ISWM).

(1) to develop an empirical model to determine the lower heating value of waste and investigate WtE incineration feasibility and
(2) to investigate governance characteristics to support WtE incineration feasibility and contribute to sustainability of SWM.

1.3 Hypothesis

"WtE incineration plant would be feasible in Dhaka City if **appropriate measures** are taken in **the near future**." The **near future** is assumed to be by the year of **2030**.

Appropriate measure means improving the lower heating value ($LHV \geq 6\ MJ/kg$) 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 assumed as (a) functional stakeholders are in place with roles and responsibilities, (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., justified by WBA).

1.4 Contents of the Research

This study particularly focuses on improving LHV to contribute to WtE incineration feasibility. That is expected to contribute to enhance the sustainability of SWM. Considering this, **two aspects** (i.e., broader sense) have been considered to understand current state, ways to enhance WtE feasibility (i.e., LHV increase) and SWM sustainability. In these **two aspects**, one is ***technical*** and another one is ***governance***. How the *technical* and *governance* aspects relate, influence each other, and contribute to the achievement of the overall objectives are main contents of the research. They are summarized in **six (6) Scopes**. Scopes (1), (2) and (3) are related to the *technical* aspect and scopes (4), (5) and (6) are related to *governance* aspect as listed below:

(1) analysis of the waste characteristics,
(2) development of empirical model to predict lower heating value of municipal solid waste,
(3) development and analysis of different scenarios to make WtE incineration technically feasible,
(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 through municipal SWM process.

In the ***technical*** aspects, this research has worked on: (1) understanding waste properties (e.g., physical compositions, moisture contents); (2) developing a calorific value model (i.e., multiple regression equation); (3) selection of scenarios (e.g., moisture lose effect, specific area based collection, natural growth trend); and (4) analyses of the selected scenarios using the developed model to improve LHV with aim of achieving feasible WtE incineration. Based on the physical composition analysis, a calorific value model is developed following other reference models. The newly developed model is a tailor-made suit for Dhaka City and is used to evaluate the feasibility of waste incineration with energy recovery. To improve the feasibility, scenarios were selected from the reviews of literature and interviews with professionals in the sector. These include how the calorific value increases with evaporation, the selection of waste from specific areas, the combination of quality and quantity of waste for the plant.

In the **governance** aspects, three characteristics of the current SWM of Dhaka City are examined and recommendations are made. These are as follows: (1) governance potentials, (2) policies and practices of Primary Collection Service Providers (PCSPs), (3) Ward Based Approach (WBA). The idea is to figure out how to harness the potential of governance and improve its contribution to the feasibility of WtE through waste collection and quality improvement. PCSPs are the key stakeholders of SWM in Dhaka City in governance domain. Investigation is done on whether the policies and practices of PCSPs contradict the feasibility of WtE or not, and gaps in the policies are identified. The findings would help in formulating new WtE projects and privatization of SWM services. How the functional elements of WBA contribute to the feasibility of WtE are also explored, and the results are analyzed. The scopes of the research are shown schematically in Figure 1-1.

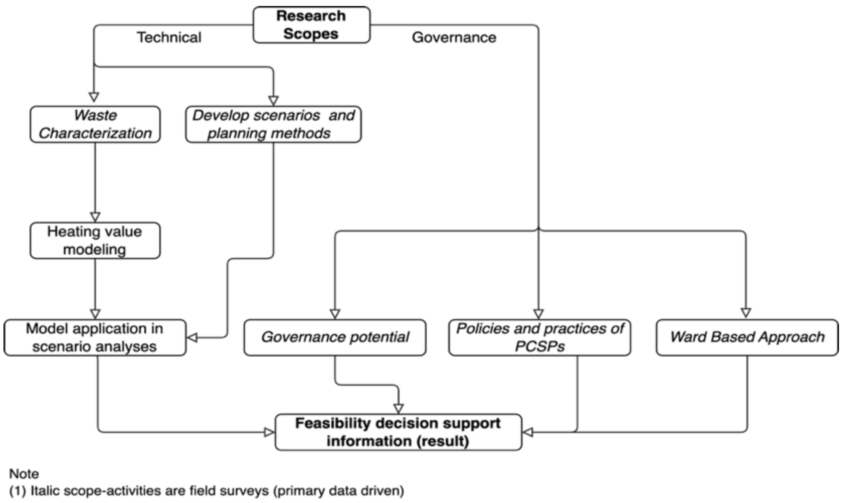


Figure 1-1 Scopes of the research

1.5 Rationale of the Research

This research is undertaken through heating value model development and application on the feasibility of energy recovery from waste with incineration aiming to contribute the sustainability of the SWM. The main focus of this objective was to improve calorific value (i.e., lower heating value, LHV). This research has covered both physical (i.e., technical) and governance (i.e., management) aspects of integrated sustainable waste management (ISWM) concept to improve the feasibility of WtE incineration. The motivation and rationale for this research is presented below.

1.5.1 Overall rationale of the study

Over the past decade, waste generation in Dhaka City has increased dramatically as the population has grown rapidly not only due to urbanization or economic growth, but also due to climate-induced forced migration for livelihood. In 2005, the collection rate was only 45% when the generation was around 3300 t/d (JICA, DCC, 2005). In 2020, DCCs have managed to collect about 80% of the daily generation (i.e., nearly 7000 t/d), but landfills are not fully well prepared for the rapid increase in waste volumes (Waste reports, DNCC, DSCC, JICA, 2021). The reasons are lack of space, complicated leachate collection and treatment procedures, difficulties in securing and developing additional land, etc. In such a situation, WtE incineration may reduce about 90% of the volume and about 80% of the mass, and generate heat or energy as a by-product, where the country is facing a severe energy crisis. This situation has motivated to carry out this research.

However, since the LHV of MSW in developing countries is low due to the higher moisture content, it is necessary to minimize the moisture to maximize the LHV. This provokes the thought for the development of a model to measure LHV that is easy to use and not expensive for the developing countries, particularly for the study area (Dhaka City).

1.5.2 Rationale for LHV model development and scenario analysis

LHV can be determined by several ways as for example proximate analysis, ultimate analysis and bomb calorimetric tests or physical composition based empirical model development etc. However, the sample mass for ultimate analysis is 1-5 mg and for proximate analysis is 1 mg, which is very inadequate to represent the MSW (C.-J. Lin et al. 2013; You et al. 2017), therefore, its precision is poor (Ogwueleka and Ogwueleka 2010). Ibikunle et al., (2020) mentioned, experimental evaluation of solid fuel is labor intensive, costly, and subject to experimental errors. Therefore, it may be arguable unless a large size of the samples is used in the experiments for proximate and ultimate analyses due to high heterogeneity in complex mix of MSW (Kathiravale et al. 2003; J.-I. Liu, Paode, and Holsen 1996). On the other hand, empirical models based on food waste, paper and cardboard, plastics, textiles, wood, rubber proportions from *physical composition analysis* on thermal characteristics (Zhou et al. 2014a) are proposed by many (Japan National Solid Waste Foundation 1991; X. Lin et al., 2014). Drudi et al., (2019), Y. F. Chang et al., (2007); Liu et al., (1996) had found them to be quicker and cheaper, and simpler with higher accuracy to ultimate analysis (C.-J. Lin et al. 2013). Details of similar explanations are also provided in Chapter 2 (Literature Reviews).

From the theoretical point of view, it is true that in the past there have been similar works to some extent in different parts of the world; however, the adaptation of the model and the development of planning methods to improve its feasibility is the first of its kind, considering the process methods used in this research. There is no similar work for the megacity of Dhaka in which a model based on physical composition has been developed and similar feasibility scenarios have been analyzed and considered in the planning methods. A simple model with planning methods to capture the idea of feasibility in practice are urgently needed by municipalities and industries in developing countries. This is a research gap, especially for the cities of Bangladesh.

1.5.3 Rationale for studying governance characteristics

Improving the sustainability of waste management through WtE incineration requires harmonious and well-coordinated efforts on both physical or **technical aspects** (e.g., collection, quality performance, etc.) and **governance aspects** (e.g., management, policy, finance, organizations, stakeholder participation, etc.). They are interrelated and interdependent. Chapter 2 outlines the position of this study within the concept of the integrated SWM framework. The importance of and criteria for examining **governance capacity or potential** are found in the previous literatures and they are also cited in Chapter 2 and Chapter 6. It is important to recognize who the stakeholders are, how they make decisions, and what role they may play in the various phases of WtE decision-making or planning, construction, commissioning, operation as well as waste collection and quality assurance. Some stakeholders are responsible for SWM routine works such as DCCs, PCSPs, and some others are for administrative decisions such as ministries, departments, etc. Also, it is important to understand whether WtE is a priority in planning or not. And if it is in the higher- level plans, how are the stakeholders working to make it happen.

1.5.4 Rationale for studying PCSPs policies and practices

A viable WtE incinerator requires a consistent, regular waste feed in terms of quality, LHV (MJ/kg) and quantity (t/d). A sizable portion, more than half, of the municipal waste in Dhaka City is household waste. And primary collection (i.e., door-to-door or house-to-house collection) is common. This collection must be stable and ensure the quality of waste. Considering this point, it is necessary to understand the working practices of primary waste collection service providers (PCSPs) and their problems, capacity building needs, etc. Their practices or work habits may affect the **overall average calorific value** (MJ/kg). If a PCSP is volatile in such a situation, due to the fragility of its organization, it cannot contribute well to sustainable SWM by keeping the city clean. Moreover, PCSPs cannot contribute well to WtE feasibility by providing quality waste, or they can hinder WtE feasibility by mixing unexpected waste (e.g., construction waste, ceramics, etc.).

1.5.5 Rationale for studying WBA

The WBA encompasses some of both aspects (viz. technical or physical and governance) of the integrated SWM framework. It includes decentralization, waste workers safety, pride and productivity, inclusivity, collection improvement etc. To have desired waste quality (MJ/kg) and sufficient quantity (t/d), it needs stakeholders' education and capacity building and active participation. Such functional elements are embodied in WBA. WBA components are assumed to improve the WtE incineration feasibility and thus contribute to sustainability of SWM. Therefore, it is attempted to try to review the existing conditions and determine whether WBA can play a role in WtE feasibility. If it can play a role, it is rationale to understand the issues and seek for solution options.

1.6 Global Implication of the Research

A simple, inexpensive, fast, and user-friendly calorific value prediction and application model is tailored to local conditions in developing countries, especially where numerous laboratory tests at various times of the year are difficult. The developed calorific value model can be applied in different areas; in particular, it could provide better results where waste characteristics are comparable to those of Dhaka City. The prediction accuracy will be high in cities of developing countries.

1.7 Structure of the Dissertation

This dissertation consists of nine (9) Chapters. However, the individual chapters contain specific objectives connecting to the overall objectives, and the scope of the study. And in conjunction with them, each chapter draws sub-methods, results, discussion, and conclusions so that it stands alone.

The arrangement of the Chapters as the structure of the dissertation is shown in Figure 1-2. The chapters have contributed to the publication of various conference and journal papers, which are listed in Table 1-1.

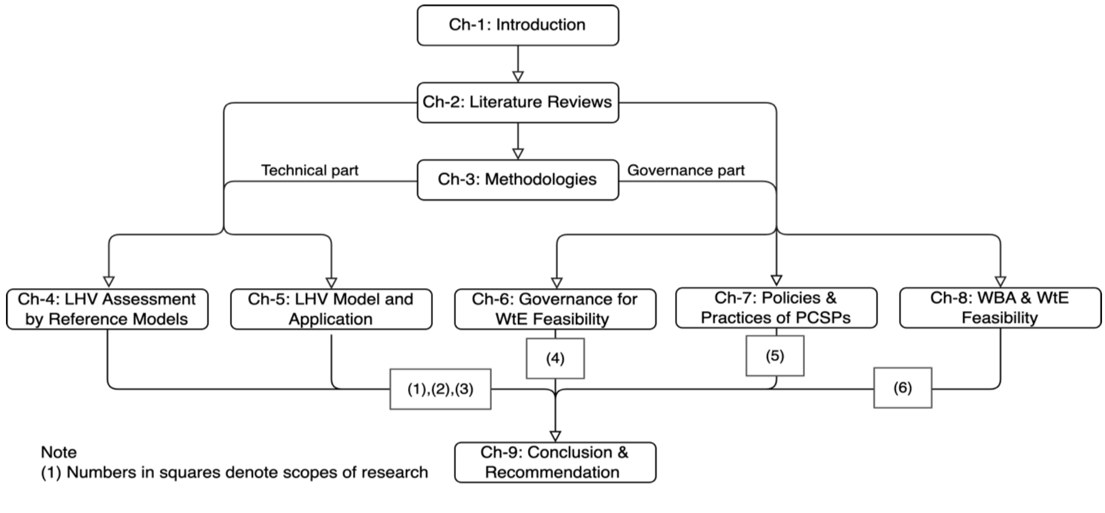


Figure 1-2 Dissertation structure

Table 1-1 List of publications and chapters' arrangement

Sl.	Paper type	Conference & Journals Information	Paper Title	Dissertation Chapter
1	Peer reviewed Journal	Springer Journal of Material Cycles and Waste Management	Developing empirical model for heating value of MSW to assess Waste-to-Energy incineration feasibility: study in Dhaka City	Chapter 5
2	Conference[a]	The 8th 3RINCs, Japan	Developing an empirical model for heating value of MSW: Study in Dhaka City	Chapter 5
3	Conference proceedings	The 32nd Annual Conference of JSMCWM, Japan	Waste-to-Energy Feasibility Assessment in the Purview of Governance Potential: Points to be Considered in Dhaka City	Chapter 6
4	Conference proceedings	The 33rd Annual Conference of JSMCWM, Japan	Policies and Practices of Primary Collection Service Providers of Dhaka City	Chapter 7
5	Conference proceedings	The 31st Annual Conference of JSMCWM, Japan	Assessing heating value of MSW of Dhaka City to support WtE Technology	Chapter 4
6	Conference proceedings[b]	8th International Conference on Integrated Solid Waste & Faecal Sludge Management	Assessing the Roles of Ward Based Approach (WBA) on the Feasibility of Waste-to-Energy in Dhaka City	Chapter 8

[a]This paper (Sl. 6) is a part of refereed paper (SL. 1) and presented in the 8th 3RINCs.
[b]Conference is scheduled to be held on in February 25-26, 2023, in Khulna University of Engineering and Technology (KUET), Bangladesh.

Chapter 1 serves as a general introduction with a background of the study. The total of six (6) scopes (i.e., areas) of the study, hypotheses, rationale, etc. are stated in the introductory chapter.

Chapter 2 provides a literature review citing previous studies on the feasibility of WtE with an overview of various indicators, parameters, etc. However, several authors or organizations have studied the feasibility of WtE, which are discussed in this chapter. Chapter 3 is a summary of the methods used in this study. However, an attempt is also made to make each chapter independent in terms of its different objectives, methods, and conclusions. Chapter 4 and Chapter 5 are the technical aspect of the thesis, which deals with the application of the mathematical models (Figure 1-2). Chapter 4 shows the application of the reference model and gives an overview of the status of the lower heating value of the different waste sources. On the other hand, Chapter 5 details the waste characteristics, the profile of waste management in the study areas, and the development of the model to estimate the lower heating value. Chapter 5 also describes the application of the model in different scenarios where the developed model is used to predict the feasibility of MSW incineration in Dhaka City. Chapters

4 and 5 have helped to achieve Objective 1 from technical aspects covering the three (3) scopes of the study.

Chapter 6, Chapter 7, and Chapter 8 address the governance aspect of the study (Figure 1-2), which checks the feasibility of waste incineration from a management perspective by understanding governance characteristics. Chapter 6 describes the overarching aspects of governance potential, stakeholders, plans, priorities, etc. Chapter 7 describes the role of primary collection service providers (PCSPs) as key players in waste management that can help sufficient and high-quality waste supply to the WtE facility. This chapter describes the current state of service delivery in terms of strengths, weaknesses, opportunities, and threats (SWOT) of PCSPs. Chapter 8 is based on the Ward Based Approach (WBA), which was developed and implemented as part of a JICA technical assistance project. This chapter shows how the WBA can contribute to the feasibility of WtE or how the roles of the WBA can influence WtE. However, there are several aspects that influence the sustainability of the WBA itself. These are also examined, and viable solutions are identified and documented.

Finally, Chapter 9 presents the conclusions. The conclusions are formulated based on the two (2) objectives as well as the six (6) scopes (i.e., areas) of the study. The limitations of the research are briefly outlined in this chapter. An indication of how this research can be continued in the future is provided as a guide in this chapter.

We have made an effort to organize the individual chapters so that they stand on their own or are self-contained to improve readability. Therefore, the numbers of the tables and figures are numbered sequentially, with the chapter number followed by the sequential numbers. Equations are also numbered from 1 for each chapter but are not linked to the chapter number. To avoid flipping back and forth, some information is intentionally repeated in different chapters.

CHAPTER 2: LITERATURE REVIEWS

2.1 Concept of Sustainable SWM and Research Perspectives

This study focuses on improving the sustainability of municipal waste management (SWM) in the spectrum of solid waste treatment considering waste-to-energy (WtE) incineration feasibility enhancement. The recent simplified concept of integrated sustainable waste management (ISWM) framework combines **physical** and **governance** aspects derived from the older original concept of ISWM (Wilson et al., 2015). Physical components include waste collection that is driven by the urgency of public health; 3Rs (reduce, reuse, and recycle) is driven by notion of resource recovery, and waste treatment and disposal are driven by necessity of environmental protection. Physical component is assumed as **technical aspects** of this research. Governance aspect includes financial sustainability, stakeholders' engagement in the form of service providers and service recipients as inclusiveness. Governance aspect also considers sound institutions and proactive policies. However, literature also suggests specific governance characteristics (potential) in different parameters and indicators to check the feasibility of WtE incineration as mentioned by IGES, IETC, and UNEP (C. Liu et al., 2020). Bhuiyan (2010) in the paper published by Habitat International, "A crisis in governance: Urban solid waste management in Bangladesh," outlined various definitions and situation of SWM governance of Bangladesh. Author analyzed the roles of governance in SWM and tried to point out operational problems impeding SWM services toward city dwellers.

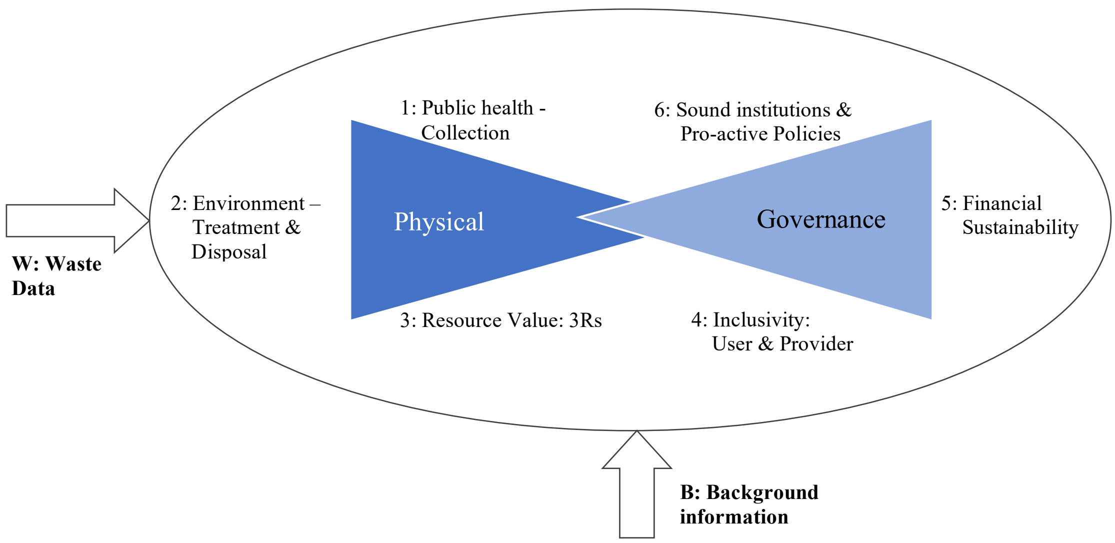


Figure 2-1 The Integrated Sustainable Waste Management (ISWM) framework

Source: This figure is taken from 'Wasteaware' benchmark indicators… (Wilson et al., 2015)

In the context of the ISWM framework, this study covers both technical (i.e., designated as physical) aspect and governance aspect. Waste treatment is considered under the technical aspect, which is determined by the need to protect the environment, and thermal waste incineration is considered in this study as a contribution to sustainable waste management. Moreover, in order to make WtE incineration feasible, waste collection is inevitable, which is considered as a public health protection in the framework of ISWM.

And to ensure efficient and high-quality collection, governance with stakeholder participation is needed, e.g., those who provide the services and those who receive the services. This fact is referred to as inclusivity in the ISWM framework. This study examined primary collection service providers (PCSPs) in terms of their policies and practices. PCSPs are important key players in SWM of Dhaka City and effectively contribute to increasing the collection rate and bringing waste into the municipal collection flow. The governance aspect also focuses on the Ward Based Approach (WBA), a combination of novel approaches developed by Dhaka city corporations and JICA expert team to ensure waste management through decentralization and stakeholder participation in waste management. The WBA can also be considered as a systematic planning, organizing and implementation framework for community or grassroots or decentralized waste management. In addition to Dhaka, WBA has also been applied in Africa, and comparative studies have been carried out (Kodani et al., 2020; Oseko, 2020; Oseko & Ishii, 2012, 2016; Sato & Okamoto, 2007). And latest status of WBA is mentioned in *New Clean Dhaka Master Plan 2018-2032,* DNCC & JICA (2019), DSCC & JICA (2019). The components and processes of the WBA are described in detail in Chapter 8, showing the functional link to the Sustainable Development Goals (SDGs) and WtE incineration feasibility.

2.2 Higher and Lower Heating Value Concepts

To understand the efficiency of a fuel (i.e., MSW), the energy content is measured as the heating value or calorific value. Knowing the calorific value is one of the most important requirements for designing waste-to-energy (WtE) plants. The calorific value is needed to design the calculations or numerical simulations of waste thermal conversion systems. The calorific value is measured by different experimental or analytical methods, e.g. the bomb calorimetric test (Drudi et al., 2019; Nwoke et al., 2020; Rominiyi & Adaramola, 2020), and by applying empirical mathematical models (e.g., regression equations) and unit is expressed as kJ/kg, kcal/kg, Btu/lb (Chang et al., 2007; Falconi et al., 2020; Kathiravale et al., 2003; Korai et al., 2016;Shi et al., 2016b).

Heating value can be expressed as Higher Heating Value (HHV) or Gross Calorific Value (GCV) and Lower Heating Value (LHV). The Higher Heating Value (HHV) is defined as the quantity of heat generated by complete combustion of a mass unit of sample at constant volume in an oxygen atmosphere assuming that both the water contained in the sample and that generated from the combined hydrogen, remains in liquid form (Franjo et al. 1992). HHV is the amount of heat produced during the complete combustion of unit mass of MSW (called HHV-1 in ASTM standard) in laboratory when the total products of combustion are cooled in the standard condition (Finet 1985; Nzihou et al. 2014). In HHV, moisture of waste and water formed from combined hydrogen content of waste stays in the form of total steam or liquid form (Finet, 1985; Franjo et al., 1992). In LHV, it is assumed that water as steam allowed to escape and net energy of combustion is used as energy content of MSW as fuel (Magrinho & Semiao, 2008). The LHV is defined as the energy content released from the combustion of the organic component of MSW in an incinerator (Ogwueleka and Ogwueleka 2010). LHV is typically used in system design of WtE plants and widely used to determine the energy content of MSW. The relation between LHV and HHV is shown in Table 2-1; however, LHV is mostly used in WtE study.

Table 2-1 Relation between higher heating value and lower heating value

Relation	Eq.	Unit	Reference
$LHV = HHV(1 - H_2O) - 2240(H_2O + 9H)$	(1)	KJ/kg	(Franjo et al., 1992)
$LHV_i = HHV_i(1 - H_2O_i) - 2240(H_2O_i + 9H_i)$	(2)	KJ/kg	(Finet 1985)
$LHV = HHV - 24.40(\%W + 9\%H)$	(3)	KJ/kg	(Lorenzo Llanes & Kalogirou, 2019)
$LHV = HHV - 6(9H - W)$	(4)	kcal/kg	(C.-J. Lin et al. 2013)
$LHV = HHV - \left[\left(\frac{18.015 + H\%}{2}\right) + moisture(\%)\right]\frac{5.85}{100}$	(5)	MJ/kg	(Salman, Thorin, and Yan 2020)
$LHV_c = HHV - 0.0244(Moisture + 9H)$	(6)	MJ/kg	Chang & Davila, (2008); Rhyner et al., (1995)
$LHV = HHV - 44.03N$	(7)	KJ/kg	(Nzihou et al. 2014)
$LHV = \frac{HHV(100 - W)}{W} - rW$	(8)	KJ/kg	(X. Lin et al. 2015a)
$LHV_d = HHV_d - (9 \times 2.442 \times H_d)$	(9)	MJ/kg	(Basu 2018)
$LHV_w = \left[\left(HHV_d - 2.442 \times (W_d + 9H_d)\right) - (1 - W_w)\right]$	(10)	MJ/kg	(Drudi et al. 2019)
$LHV = \frac{HHV \times (100 - W)}{100} - W \times 0.244$	(11)	MJ/kg	(Sokólski et al. 2020)

Note. 2240 KJ/Kg is heat of vaporization or water at 25°C, 9H means the final mass of water formed by hydrogen content H in the dry sample. H_2O is the corresponding value of moisture of various combustible components, LHV_i of i component with moisture content H_2O_i and Hydrogen content H_i; r is latent heat of vaporization of water at normal pressure.

Various empirical models have been developed to determine heating value typically based on three analyses: *proximate, ultimate, and physical composition analysis* (Azam et al., 2019; Chang and Davila, 2008; Chang et al., 2007; Dong et al., 2003; Drudi et al., 2019; Katiyar et al., 2013; Khuriati et al., 2017; Lin et al., 2013; Liu et al., 1996; Lorenzo Llanes and Kalogirou, 2019; Rana et al., 2018; You et al., 2017; Zhou et al., 2014).

Proximate analysis requires measurement of moisture (H_2O), volatile matter (V), fixed carbon, (C) and ash content (X. Lin et al. 2015a) to generate heating value. Measurement of *LHV* from *ultimate analysis* is better than others but it also needs experimental analysis to measure C, H, O, N, S, Cl, and moisture content (H_2O), which is costly and time-consuming procedures (Y. F. Chang et al., 2007; C.-J. Lin et al., 2013).

The sample mass for ultimate analysis is 1-5 mg and for proximate analysis is 1 mg, which is very inadequate to represent the characteristics of waste with vast variances or heterogeneity (C.-J. Lin et al. 2013; You et al. 2017; Zhou et al. 2014b), therefore, its precision is poor (Ogwueleka and Ogwueleka 2010). Ibikunle et al., (2020) mentioned, experimental evaluation of solid fuel is labor intensive, costly, and subject to experimental errors. Therefore, it may be arguable unless generous size of the samples is used in the experiments for proximate and ultimate analyses due to high heterogeneity in complex mix of MSW (Kathiravale et al. 2003; J.-I. Liu, Paode, and Holsen 1996).

On the other hand, empirical models based on food waste, paper and cardboard, plastics, textiles, wood, rubber proportions from *physical composition analysis* on thermal characteristics (Zhou et al. 2014a) are proposed by many (Japan National Solid Waste Foundation, 1991; X. Lin et al., (2014). Drudi et al., (2019), Y. F. Chang et al., (2007); Liu et al., (1996) had found them to be quicker and cheaper, and simple with higher accuracy to ultimate analysis (C.-J. Lin et al. 2013). Kathiravale et al., (2003) found empirical model based on physical composition exhibit better performance than other models. In the empirical model development, two methods are widely used by the scholars: one is artificial neural network (AAN)(X. Lin et al., 2014; Ogwueleka & Ogwueleka, 2010; Ozcan et al., 2016); and the other one is multiple regression analysis (MRA) (Ebru Akkaya and Demir 2009; Boumanchar et al. 2019; Y. F. Chang et al. 2007; C.-J. Lin et al. 2013; X. Lin et al. 2015a; J.-I. Liu, Paode, and Holsen 1996). Dulong's formula is the prominent model to derive energy content from elemental data. Nzihou et al., (2014) found Dulong's equation gives the smallest relative errors when compared to experimental calorific values and Kathiravale et al., (2003) also found its precision is closest to the bomb calorimetric test when compared with other models. However, considering precision of samples, costs, and lab availability in cities of developing countries etc. factors, this research has tried to develop empirical model based on multiple regression to be the first of its kind in the study area, Dhaka City. Summary of previously developed models are shown in Table 5-1 in Chapter 5.

2.3 Waste-to-Energy Feasibility Criteria

Problems with waste quality and quantity (e.g., lower calorific value), poor plant management, and inadequate institutional arrangements are seen as reasons for hindering feasibility of WtE incineration. Different organizations have seen WtE feasibility studies from various angles to enhance sustainability. Some of the chronological findings that have appeared in scholarly publications are briefly outlined here as relevant body of knowledge.

IGES, IETC, and UNEP derived twenty-four (24) critical feasibility criteria based on six (6) sustainability components, as follows: (1) Social condition; (2) Public awareness & residents' cooperation; (3) Institutional; (4) ***Governance potential (i.e., governance capability);*** (5) Financial; (6) Technological (e.g., ***Waste composition and LHV***; bottom and fly ash treatment) (C. Liu et al. 2020). In this research survey and analysis are done on the Governance potential.

Lorenzo Llanes & Kalogirou, (2019) in Havana, Cuba, used *Aspen plus & excel based model for process simulation* to study feasibility on techno-economic aspects, which describes that for a feasible WtE project following barriers need to overcome in underdeveloped countries: (1) Higher investment and maintenance cost; (2) No business opportunities ; (3) Lack of knowledge of the technology; (4***) informal sector***; (5) ***legislation framework***; (6) ***waste characteristics***. This study on Manila, Philippines, proposes an investment model to analyze the economic feasibility of WtE projects in the Philippines. They applied the *real options approach* (ROA) under uncertainty and compared the option values of investing in WtE technologies (Agaton et al. 2019).

JICA, YEC, JESC (2017) delineated to some almost similar twenty-four (24) items under six (6) sustainability components, including *Governance capability* as cited in the work of IGES, IETC, and UNEP in 2020. ISWA, (2013) recommended for Low- & middle-income countries, seven (7) conditions to be met to make WtE project: (1) A mature and well operated waste management system already exists; (2) MSW is already being disposed in controlled and well-operated landfills; (3) Supply of combustible MSW should at least amount to 100,000 t / year; (4) ***LHV* must be, on average, *at least 7 MJ/kg and never fall below 6 MJ/kg*;** (5) Community is able and willing to pay for the increased treatment cost for example via management charges, tipping fees, tax-based subsidies, or high electricity feed-in tariffs; (6) Skilled staff can be hired and maintained; (7) Community planning system is stable and able to make long term appropriate planning.

According to World Bank (1999), 7 parameters in technical assessment which includes (1) Plant location; (2) Incineration technology; (3) **Energy recovery (i.e., related to *LHV*)**; (4) Air pollution control; (5) Incineration residues; (6) Operation and maintenance; (7) Environmental impact and occupation health. These are further segmented into 32 key criteria for assessment as for example: the technology must be based on mass burn technology with a moveable grate, the annual amount of waste for incineration should be no less than 50,000 metric tons with average $LHV \geq 7\ MJ/kg$; furnace is to in stable and continuous operation and complete burnout of the waste and flue gases (CO<50 mg/Nm3, TOC<10 mg/Nm3), The flue gases from the furnace must be cooled to 200 °C or lower in boiler before flue gas treatment.

Song et al., (2017) carried out PESTEL analysis for systematic analysis of macro-environment in China citing several others from different regions of the world. PESTEL framework guides a comprehensive analysis considering six (6) domains such as *Political* (e.g., legislation, policies), *Economic* (e.g., major sources of income, investment intensity, investment mode, subsidies from government, energy price, scale of investment etc.), *Social* (e.g., public concern, culture, solutions to opposition), *Technical* (e.g., waste composition, heating value, grate or fluidized type, technique with or without axillary fuel like coal), *Environmental* (e.g., pollution and environmental risk control, environmental protection expenses,) and *Legal aspects* (e.g., industrial, economic, technological, and environmental protection legislation and policies).

For developing & emerging countries, GIZ (Mutz et al. 2017) developed a *decision matrix* with twelve (12) essential parameters subdividing into forty-eight (48) criteria for feasibility: (1) Waste management level; (2) Composition of waste; (3*) **Heating value of MSW for thermal processes**, organic content ;* (4) Suitable quantities of waste for WtE; (5) Efficient operation of waste facilities; (6) Additional transportation time and distance to WtE plant; (7) Marketing and/or final disposal of process residues; (8) Legal framework & environmental requirements for WtE; (9) Financing the management of MSW; (10) Access to foreign currency; (11) Access to energy end-users from WtE; (12) Incentives for low carbon energy generation.

The exact range of LHV for a WtE incineration feasibility depends on the plant technology (e.g., grate firing or fluidized bed etc.,) and control of incineration process. International guidelines show that value of LHV is to be ≥ 6 as shown in Table 5-2 (Chapter 5) with a viable plant capacity. In this research $\boldsymbol{LHV \geq 6\ (MJ/kg)}$ is considered as feasibility threshold.

Risk management to maximize WtE feasibility has been seen as credit risk, market risk, legal risk, volume risk, operational risk, and liquidity risk. Various techniques are available for risk management: change analysis; decision tree analysis; fault tree analysis; hazard review; risk and probability matrix etc. (Cagliano, Grimaldi, and Rafele 2015); those can be tailored to WtE study in Dhaka City. Liu et al., (2018) pointed out thirteen (13) *risk categories* while considering feasibility of WtE incineration in public-private-partnership (PPP) mode they are as follows: Macrolevel risks (viz. political, legal, macroeconomic, social and natural); Mesolevel risks (viz. project selection, project finance, design, construction, technical, operational) and Microlevel risks (viz. relationship and third party). Under these *risk categories,* authors have also identified fifty-four (54) *risk factors* based on their case studies.

2.4 Waste to Energy Feasibility Challenges in Developing Economies

For the smooth operation of a WtE plant, a solid SWM system is required to confirm the quality and efficiency of the collection. High quality waste collection is a prerequisite for a viable WtE incineration plant. Aliu et al., (2014) cited many documents on the massive issues related to the waste generation, collection, disposal, and management in urban cities of developing countries. Managing the functional elements (e.g., generation to treatment and disposal) of SWM and hierarchy management of MSW are common prevalent issues. Guerrero et al., (2013) mentioned "Solid waste management is a challenge for the cities' authorities in developing countries mainly due to the increasing generation of waste, the burden posed on the municipal budget as a result of the high costs associated to its management, the lack of understanding over a diversity of factors that affect the different stages of waste management and linkages necessary to enable the entire handling system functioning."

Mastellone, Maria Laura (2015) in her book 'Waste Management and Clean Energy Production From Municipal Solid Waste' mentioned one to six factors as reasons for the failure of waste incinerators, citing the United States Environment Protection Agency, US EPA (2012). They are as follows: (1) inability or unwillingness to pay the full treatment fee, resulting in insufficient revenue to cover loan installments and operation and maintenance costs; (2) lack of convertible currencies to purchase spare parts; (3) operation and maintenance failures (e.g., due to lack of skilled labor); (4) **problems with waste characteristics and quantity**; (5) poor plant management; and (6) inadequate institutional arrangements. The percentage of combustible waste and moisture content are important waste characteristics those can significantly affect the waste heating value (LHV) and thus the feasibility of WtE incineration. This research investigates how to improve LHV by examining different scenarios and embracing governance.

2.5 Literature of Primary Collection Service Providers (PCSPs)

Both the public and private sectors are working together with informal service providers to improve of SWM in developing countries. Dhaka South and North City Corporation (DSCC & DNCC) are entrusted with domestic waste management in the capital city. In DNCC and DSCC, waste collection consists of two parts: primary collection and secondary collection. DNCC and DSCC are responsible for secondary waste collection. The informal private sector, called Primary Waste Collection Service Providers (PWCSPs) or PCSPs, is responsible for primary waste collection (Bangladesh Post, 2021). PCSPs also operate as an informal recycling sector. The informal sector is characterized by small-scale, labor-intensive, largely unregulated, and unregistered production or provision of services with little technical input (Wilson et al., 2006). PCSPs collect waste from buildings, households, and commercial businesses and transport it to municipal collection points (i.e., secondary collection points). Now both municipalities have decided to outsource the PWCSP service as part of the formalization of this sector. DSCC has started to appoint a primary waste collection service provider (PWCSP) in each ward through a competitive bidding process, and DSCC has appointed PCSPs in 69 of its 75 wards (Chandan & Mollah, 2020). The service provider of each ward will generate Tk 0.1 million in revenue annually for the DSCC (Daily Sun, 2020). DNCC is also following to some extent similar process with some contractual improvements. For waste collection, PCSPs perform informal recycling, but under the new outsourcing reform, the municipality plans to stop separation unsystematically to prevent pollution (Daily Sun, 2020). Through information and education, these informal collectors could maximize the proportion of combustible waste, which would improve the feasibility of WtE incineration. Therefore, understanding primary waste collection systems is especially important in finding ways to improve the quality and sustainability of municipal waste management, and they are important stakeholders.

2.6 Literature on Ward Based Approach

The concept of WBA emerged from a development study during the formulation of the first Clean Dhaka Master Plan (JICA, DCC, 2005) and matured with the technical assistance (i.e., cooperation) projects supported by the Japanese government from 2007 to 2013 and from 2017 to 2022. There are several works published on WBA by different authors in different languages. WBA has also been applied in Africa, and comparative studies have been conducted (Kodani et al., 2020; Oseko, 2020; Oseko & Ishii, 2012, 2016; Sato & Okamoto, 2007). And the latest status of WBA is mentioned in New Clean Dhaka Master Plans 2018-2032, DNCC & JICA (2019), DSCC & JICA (2019). The WBA is a framework for planning and implementing field operations for MSW management. There are mechanisms for voluntarism, citizen engagement, flexibility, and resource mobilization. There are four (4) approaches with different themes and functional elements. These include organization building, improving occupational health and safety and labor productivity, promoting participatory waste management through community involvement, and improving the collection system. The WBA framework refers to improving the sustainability of waste management and improving the quality and quantity of waste collection. Finally, these are related to the feasibility of WtE incineration and the sustainability of municipal waste management. Chapter 8 discusses in more detail the role of WBA and its influence on the feasibility of WtE, as well as its own sustainability aspects.

2.7 Summary of Literature Review

Waste quality and quantity issues are an important focus of this research, and Chapter 5 describes how they can be technically improved to achieve a **LHV of at least 6 MJ/kg.** This value is considered a critical value for the start or feasibility of WtE combustion (with energy recovery). A number of references from developing countries are used to develop the LHV model. Considering the ease of use in developing economies, a simple and user-friendly empirical model was developed, which is assumed to have high replication potential in the cities with similar waste characteristics. The unit of energy content has two attributes: MJ and kg. The mixture or total collected waste must achieve this in combination like a weighted average. Therefore, we need to focus on the quality of waste and the collection quantity. To achieve a stable quality of waste collection as part of integrated SWM framework, appropriate governance must be in place. As the quantity and quality of waste collection is largely influenced by plans and policies, stakeholder involvement and participation, institutional arrangements, etc. These aspects are studied and presented in Chapter 6, Chapter 7, and Chapter 8 under the term "*governance*." Governance characteristics are described in Chapters 6, 7, and 8 as governance potential (i.e., capability), PCSPs (i.e., key actors for waste collection), and WBAs (SWM processes or systems).

CHAPTER 3: METHODOLOGY

3.1 Theoretical Framework of the Research

This study focuses on improving the sustainability of municipal waste management through the treatment of municipal waste, considering the improvement of the feasibility of waste-to-energy (WtE) incineration. Based on literature review, subjective experiences and observations, different research or study scopes were selected under *technical* and *governance* aspects of integrated sustainable waste management (see Figure 3.1). Within both aspects, the different research *scopes* were selected for investigation based on the rationality considerations explained in Chapter 1 (1.5).

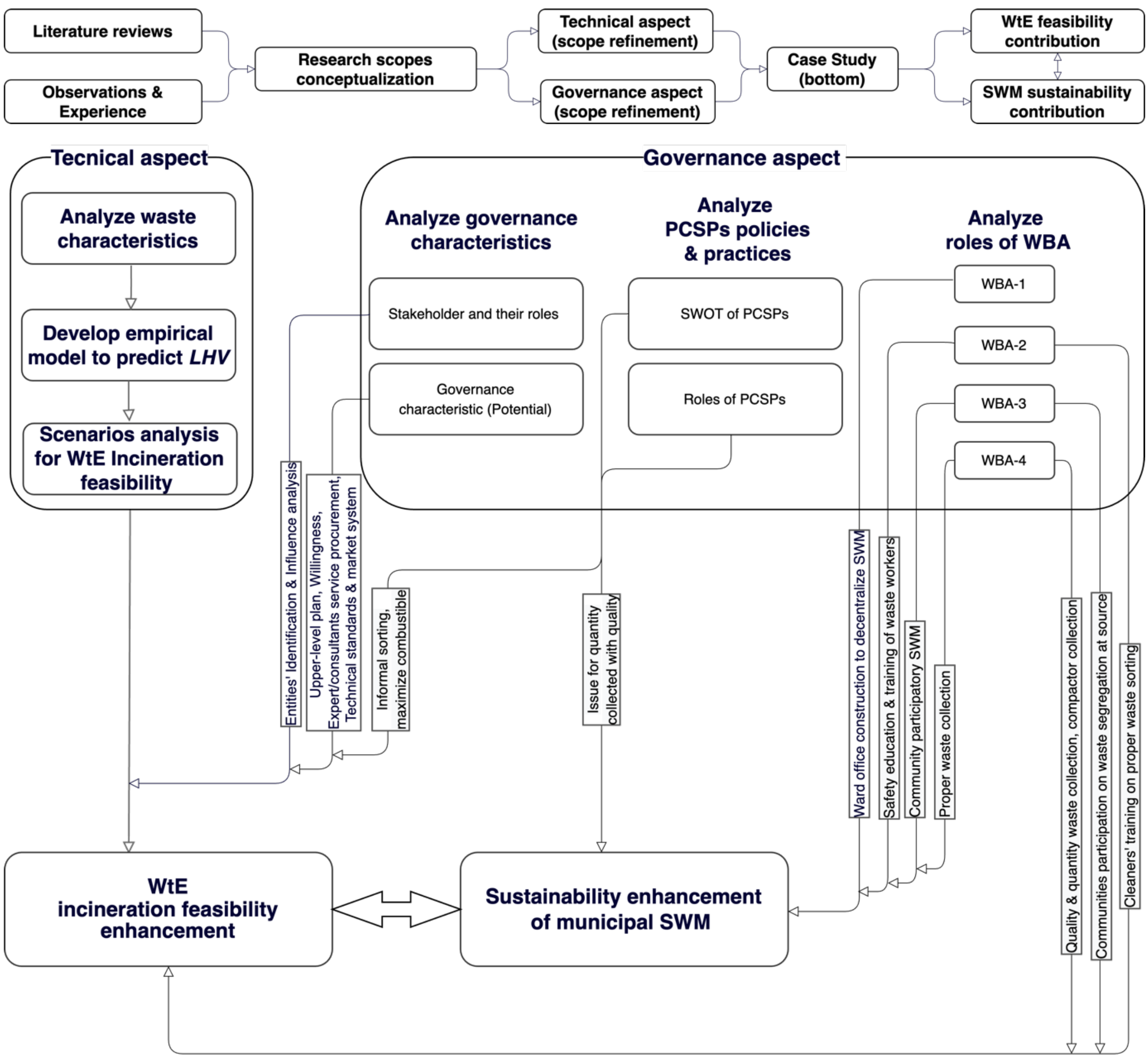


Figure 3-1 Conceptual framework of the study

For the technical aspects, waste characterization analysis, LHV model development, and feasibility scenario analysis were considered. For the governance aspects, three scopes were selected (e.g., governance characteristics, policies and practices of PCSPs as important key actors, and WBA as a SWM process or system) against which case studies were conducted to understand the issues and how to improve the feasibility of WtE to contribute to the sustainability of waste management.

3.2 Analysis of Waste Characteristics

Survey was carried out in two different seasons between 2017 and 2018. Author oversaw the survey undertaken with the help of DNCC and DSCC and JICA team. Each time eight (8) days survey were done for households, restaurants, markets, office, and road wastes. Landfill waste characterization was done on time avoiding monsoon season. Waste was characterized into 16 categories as shown in the Table 3-1. Moisture contents both on wet and dry basis were measured for some components.

Table 3-1 Sampled waste sources with composition categories

Sample Waste Sources	Composition Category Targeted
1. Household 2. Office 3. Market 4. Restaurant 5. Landfill	1. Food Waste 2. Bones/Shells 3. Paper 4. Other Paper 5. Grass/Wood 6. Textiles 7. Rubber/Leathers 8. PET Bottle 9. Other Plastics 10. Cans (Aluminium/Steel) 11. Other Metals 12 Bottle/Jar 13. Ceramic/Glasses 14. Sand/Stones 15. Medical/Hazardous 16. Electrical/Electronic

Source: Dhaka North and South City Corporation, JICA Project Office

3.3 Heating Value Model Development

Multiple regression model is developed following statistical process where waste compositions are considered as independent (i.e., explanatory) variables and LHV is considered as the dependent variable. Preliminary models’ selection and applications are shown in Chapter 4. However, the detailed of model development with error analyses and application with scenario analyses are described in the Chapter 5.

3.4 Scenario Selection for Planning Methodology Development

Initially nine (9) different scenarios have been thought which are as follows:

(1) natural growth of LHV over time using developed model (LHV_{y_i})

(2) locational waste sources preferences ($LHV_{\mathrm{N}_i or\ \mathrm{S}_i, J_i}$)

(3) improving LHV by evaporative moisture loss (LHV_{e})

(4) methane (CH_4) cofiring with MSW

(5) RDF co-combustion ($LHV_{\mathrm{rdf.}}$)

(6) pretreatment for compost co-combustion ($LHV_{\mathrm{com.}}$)

(7) improving LHV using plastic bag collection (LHV_{p})

(8) augmenting LHV by additives (e.g., rick husk, coconut husk, waste engine oil, bagasse) (LHV_{ij})

(9) improving LHV by moisture reduction having compactor truck collection (LHV_{C})

The scenarios have been applied in the developed model and details are discussed in the Chapter 5. However, three different scenarios have been selected based on the practicality, time constraint and easy to use, which are as follows:

(1) Natural growth of LHV over time using developed model (LHV_{y_i})

Here, y_i : $2020, 2021, \ldots\ldots 2030$, year

(2) Locational waste sources preferences ($LHV_{\mathrm{WN}_i or\ \mathrm{WS}_i, J_i}$)

Here, $\mathrm{N}_i(DNCC) = 1,2,3, \ldots\ldots 54$; $\mathrm{S}_i(DSCC) = 1,2,3, \ldots\ldots 75$

$J_i = Sources\ of\ waste: MKT, HH, OFS$,

$MKT: Market, HH: HH: Household, OFS: Office$

(3) Improving LHV by evaporative moisture loss (LHV_{e})

Here,

$LHV_{\mathrm{ei}}\ for\ example\ \ evaporation\ or\ moisture\ loss\ by\ i\ (e.g., 10\%, 15\%, 20\%\ etc)$

3.5 Assessing Governance Characteristics for WtE

Governance characteristics as governance potential were examined based on the previous framework of the governance capability study. Along with literature review, expert interviews were made and analyzed. There are several dimensions and indicators used to assess governance potential. The institutional and organizational dimensions were highlighted in the assessment of potential. They are described in the Chapter 6.

3.6 Assessing Policies and Practices of Primary Collection Service Providers

Through observational survey and SWOT (strength, weakness, opportunity, threat) analysis, the policies, and practices of PCSPs are conceptualized. Important findings and brief methodologies are described in the Chapter 7. How they can contribute to WtE feasibility and sustainable SWM investigated.

3.7 Assessing Ward Based Approach for WtE

The existing status of Ward Based Approach and its influence on the WtE feasibility has been assessed. Non-randomized respondents have been selected after careful consideration from the experienced, knowledgeable, and skilled officials in the sector. Data were collected and analyzed using MS Forms and MaxQDA. The detailed survey methods and analysis patterns are described in the Chapter 8. In this chapter, a mind map is shown that connects the roles of the WBA and the targets of the SDGs.

CHAPTER 4: LOWER HEATING VALUE ASSESSMENT BY REFERENCE MODELS

4.1 Introduction and Objectives of LHV Assessment Using Reference Models

Though there is shift from landfill to resource recovery including waste-to-energy (WtE) in municipal solid waste (MSW) management, problem with waste quantity and quality is seen as a reason of the failure of incineration plants (EPA, 2012). This chapter is aimed at depicting the characteristics of MSW of Dhaka City comprising moisture content, combustible proportions, and lower heating value (LHV) aiming to support the feasibility study of WtE incineration. A verbal conference paper was presented, and published in the 31st conference proceedings of the Japan Society of Material Cycles and Waste Management (Mondal & Kitawaki, 2021) based on this chapter.

This chapter shows the properties of MSW of Dhaka City for moisture content, combustible proportion, and lower heating value (LHV) to support the feasibility study of WtE incineration technology. These properties are calculated for different waste sources: household, market, office, hotel & restaurant, and disposal site. LHVs are determined using three different models and descriptive statistics are shown. Two models are based on wet basis physical composition, another model is on the relationship with country's GDP. Result shows, waste from offices can be incinerated as it exhibits suitable LHV (7.86 MJ/kg) for power generation. The weighted average LHV of mixed waste is 5.01 MJ/kg which falls below the minimum limit for power generation. Historical characterized data are projected to understand change-trend of combustibles and moisture content over time. Projection shows, in 2025, combustible fraction will be > 32% and moisture content will be reduced to 55% from the current level of 61.74%. Evaporation by drying is suggested with reference rate of moisture loss to maximize the LHV of MSW. However, values are updated in Chapter 5 where newly developed models have been used for the study area and applied in different feasibility scenario analysis.

4.2 Methodology to Use Reference Models

Characterized data are projected and liner regression equation is shown based on published and unpublished data. Moisture, physical composition, and LHV are calculated for different waste sources. LHV is calculated using three different models: Eq. 1 (Y. F. Chang et al. 2007), Eq. 2 (Drudi et al. 2019) and Eq. 3 (JICA, DCC 2005). The average LHV of two models (Eq. 1 & Eq.2) is calculated and compared with references of JICA (2017).

$$LHV_{wet\,(Chang)} = (35.19P_{pa} + 71.17P_{pl} + 36.24P_{te} + 48.06P_{wo} + 42.21P_{fo} + 44P_{mi})(\frac{100-W}{100}) - 6W \quad (1)$$

$$LHV_{wet\,(Drudi)} = [(15.42O_r + 19.14S + 32.68P_l + 8.33P_a + 21.51T) \times (1 - W_w)] - (2.442 \times W_w) \quad (2)$$

$$LHV_{(JICA)} = 344\,ln(x) - 1{,}222 \quad (3)$$

Here,

$LHV_{Wet\,(chang)}$: *wet basis lower heating value* ($kcal/kg$)

$LHV_{wet\,(drudi)}$: *wet basis lower heating value* (MJ/kg)

$LHV_{(JICA)}$: *GDP based Lower heating value* ($kcal/kg$)

P_{pa}, P_a : *Paper waste* (wt %)

P_{pl}, P_l : *Plastic waste*, (wt %)

P_{te}, T : *Textile waste* (wt%)

P_{wo} : *Wood waste*(wt%)

P_{fo}: *Food waste* (wt %)

P_{mi}: *Miscellaneous* (wt %)

W, W_w: *Moisture*(wt %)

O_r : *Food/yard waste* (wt %)

S : *Sanitary waste* (wt %) (*we considered other papers*)

x : *GDP/capita* ($US\$/yr$) (*year* 2019 *is considered*)

4.3 Results and Discussion on Application of Reference Models

Historical data is shown in Figure 4-1 to understand change-trend. It shows positive slope for recyclable and combustible proportions, while moisture content shows negative. Considering the slope steepness, liner regression trends are assumed to be more realistic than exponential and power functions and considered for projection. In 2025, combustible fraction will be > 32% and moisture content will be reduced to 55% from 61.74% (current level). JICA reference material (2017) mentions, LHV 6.3 MJ/kg is the lower limit for power generation while World Bank (1999) mentions the annual average is to be 7 MJ/kg. Our calculated weighted average LHV of mixed waste is 5.01 MJ/kg (excluding street waste). LHVs with different waste sources are shown in Figure 4-2, office waste meets the required limit though it has around 43% moisture. Drying as pretreatment may help to maximize the LHV. In room condition, waste with several manual turning per day shows about 10% evaporative loss in 4 days (Ishii et al., 2019) which can be sustained by mechanized system, sunlight facility or enlarging the grate area before combustion zone of incinerator.

In the year of 2018-19, nearly 7000 tons of waste was generated per day in Dhaka City Corporations (North & South) with combustible fraction nearly 30% as shown in Table 4-1. However, authority has slightly revised and adjusted this figure of generation data in 2019-20 compared with 2018-19 data. And such latest data are shown in Chapter-5, where generation rate is considered as 6,689 ton/day. However, descriptive statistics of calculated LHVs based on reference models are shown in Table 4-2 which shows that restaurants and households exhibit low LHV compared with office, and market waste.

Table 4-1 Waste quality information based on sources in Dhaka City (2018-2019) *

Waste Sources	Generation (100%)						Disposal (71%)	
	HH	OFS	STREET	MKT	RST	Total	LFS-M	LFS-A
Generation, t/d	4366	274.4	913.0	924.7	760.9	7239	2372	2774
Moisture, %	62.16	43.19	37.75	55.10	74.10	61.74**	56.77	56.90
Recyclable, %	24.20	39.28	20.44	42.50	23.32	26.54	31.09	25.31
Combustible %	26.14	49.14	43.46	43.69	23.40	29.37**	38.17	33.17

Note. *Analysis is made based on the data taken from JICA (2018). t/d: ton/day, HH: household, OFS: Office, Street: Street sweeting and construction, MKT: Market, RST: Hotel & restaurant, LFS-M: Matuail Landfill, LFS-A: Amin Bazar Landfill, ** without street waste as it contains high sand proportion (>25%). In Chapter 5, the figures are slightly revised.

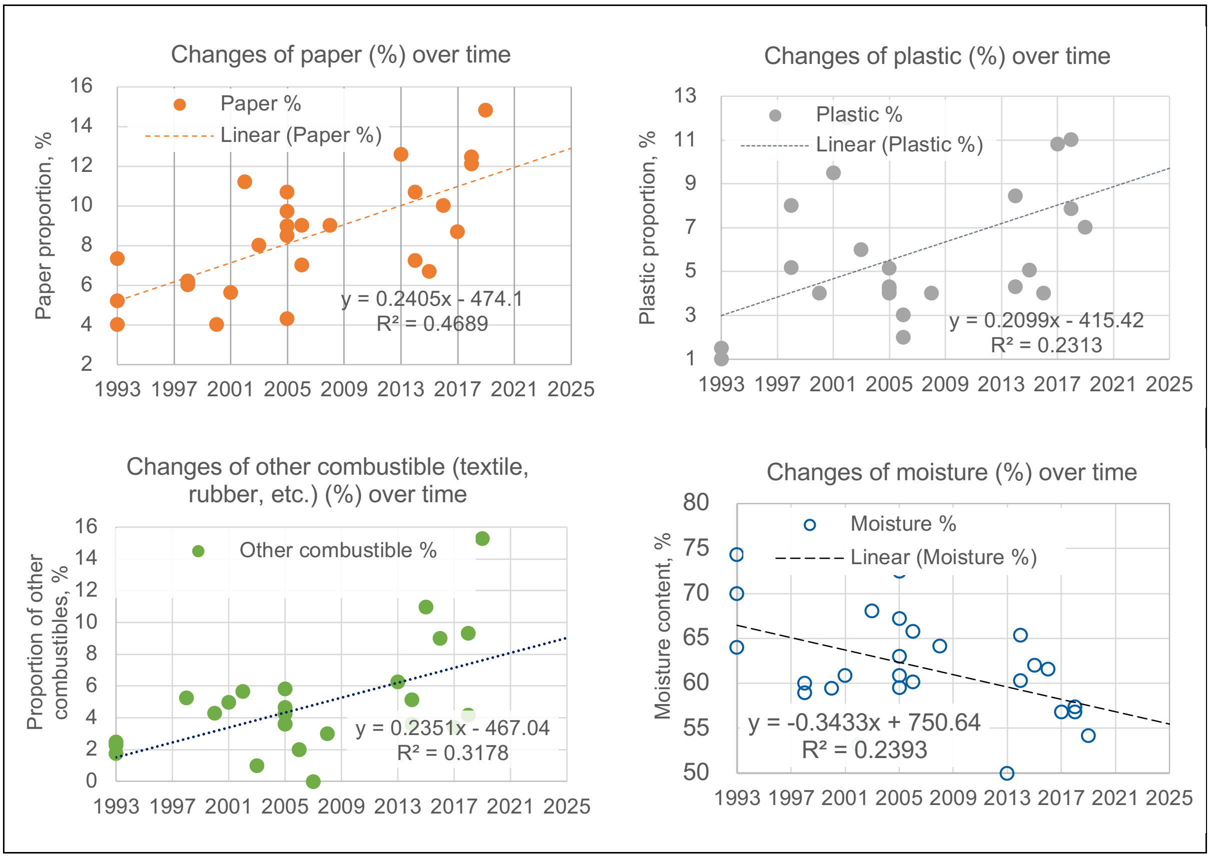


Figure 4-1 Paper, plastics, other combustibles, and moisture content change trends in Dhaka City

Table 4-2 Descriptive statistics of calculated *LHV*s based on reference model

Statistics	HH	RST	OFS	MKT	LFS
Mean, *LHV* ($\bar{x}$), MJ/kg	4.91	2.69	7.86	6.56	6.27
Median, *LHV* (Md), MJ/kg	4.91	2.67	7.88	6.44	6.26
Standard Error ($\sigma_{\bar{p}}$)	0.14	0.13	0.24	0.16	0.12
Standard Deviation(σ_X)	0.61	0.56	1.01	0.70	0.49
Sample size (n)	18	18	18	18	18
Margin of error (coef. 1.96)	0.28	0.26	0.49	0.32	0.23
Upper bound (M_u), MJ/kg	5.19	2.95	8.32	6.88	6.49
Lower bound (M_l), MJ/kg	4.63	2.43	7.39	6.24	6.04

Note. HH: household, OFS: Office, MKT: Market, RST. Res: Hotel & Restaurant, LFS: Landfill Site

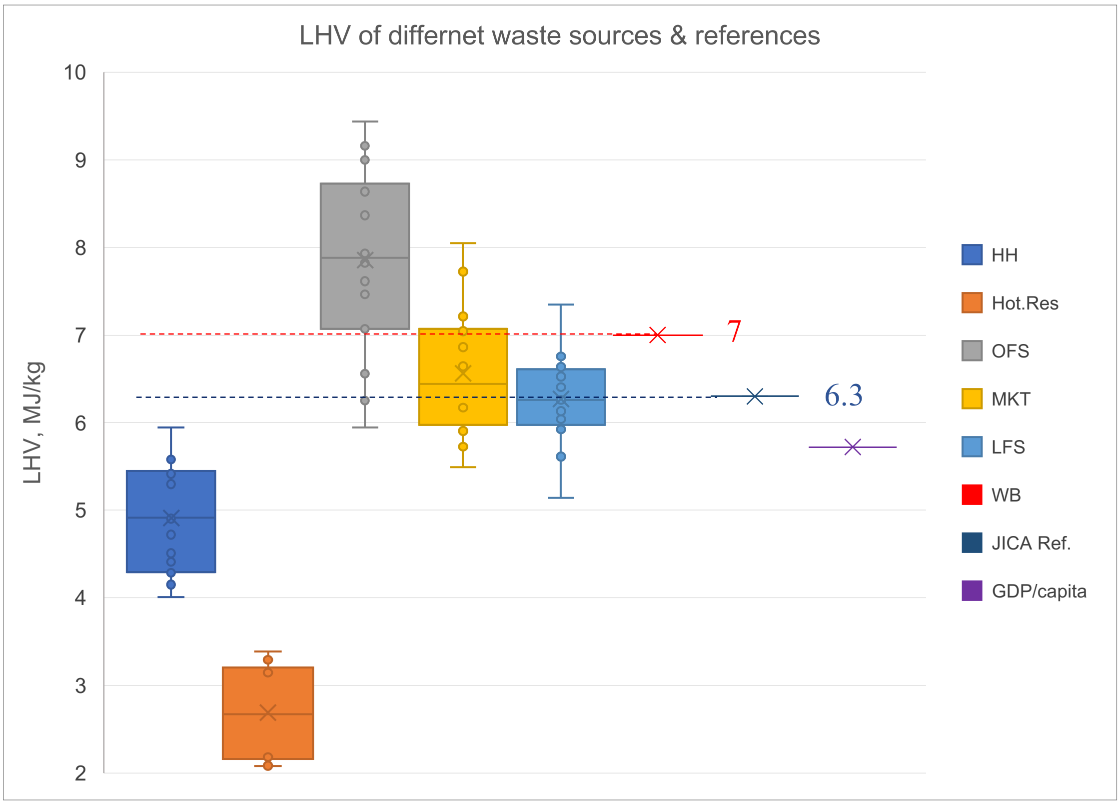


Figure 4-2 *LHV* of different waste sources and reference levels

4.4 Conclusion on Application of Reference Models

Waste from offices can be incinerated as it exhibits suitable *LHV* (7.86 MJ/kg) for power generation. Market, office, and household waste may be targeted for incineration with appropriate pre-treatment for combustibility. Hotel & restaurant wastes are suggestive for anaerobic digestion for high moisture content. Projection analysis may be improved more with historical data refinement to support future WtE technology in Dhaka City. Based on this idea of using a reference model, research has developed a new model that uses references from developing countries and is applied in the Dhaka City (Chapter 5, details).

CHAPTER 5: LOWER HEATING VALUE MODEL DEVELOPMENT AND APPLICATION TO ASSESS WASTE-TO-ENERGY FEASIBILITY

5.1 Background Information

Cities in developing countries mostly face serious environmental problems and public health risks due to the non-sanitary conditions of landfills, uncollected mass of Municipal Solid Waste (MSW) and space constraints where some forms of landfills are practiced (Cointreau, 2006; Wilson et al., 2015). Dhaka City is no more an exception; it is a megacity of 400-year-old and one of the densely populated metropolises in the world (Population density by city, 2014). Dhaka City does not have official resource recovery or waste-to-energy (WtE) facility yet, almost all waste are disposed to the landfills. Solid Waste Management (SWM) is administered by two city corporations namely: 'Dhaka North City Corporation (DNCC)' and 'Dhaka South City Corporation (DSCC)' and both corporations hereinafter jointly referred as 'DCCs.' The lives of existing landfills will finish very soon. Currently, drainage congestion, waterlogging, mosquito breeding, and river pollution are frequent news in medias (Chandan, 2021; Dhaka Tribune, 2021a; The Daily Star, 2020). Recently, a climatic watchdog has identified a landfill site as a significant contributor to global warming, tracing methane emission rate 4 ton/hour (Aaron Clark, 2021; Dhaka Tribune, 2021b). In such a situation, WtE can be considered as an essential solution to diminish the current crisis in Dhaka City. WtE incineration system is more preferred than landfilling in many cities and its popularity is also increasing due to its immobilization of hazardous substances, high-degree volume reduction, and low space requirement (Eriksson et al., 2007; Huai et al., 2008; Mian et al., 2017; Sadef et al., 2016).

In China, from 2004 to 2014, the number of incineration plants was increased 3.5-folds (i.e., 54 to 188), which later contributed nearly 30% of total wastes and Japan exhibited this figure around 80% in 2010 (Mian et al. 2017; Trentinella 2021). Over 430 WtE plants were under operation in China by the end of 2019 having capacity to incinerate 450,000 tons per day (t/d), that is >70% of generation (Yan, P, and Waluyo 2020). Japan directly incinerates 80.3% of household waste; 18.7% sends to other intermediate treatments (Trentinella 2021). There is widespread network of incinerators, where 1,103 and 306 facilities are owned by municipalities and private entities respectively in 2019, according to ministry of environment Japan

(Trentinella 2021). According to UNEP & IGES, Japan has the largest number of incineration plants in the world (C. Liu et al. 2020).

Incineration is a process of controlled combustion with the presence of oxygen (i.e., thermal decomposition via oxidation), at the temperature on or above 850 ^{O}C with the benefit of volume reduction, disease control and energy recovery (C. Liu et al., 2020). European Parliament and Council (2000) terms incineration is thermal treatment by oxidation of waste with or without recovery of heat (European Parliament and the Council 2000). WtE incineration can be classified as the most common thermal treatment where the mass and volume can be reduced by around 70% and 90%, respectively (Lorenzo Llanes and Kalogirou 2019). It can achieve nearly 100% destruction of pathogens, toxic or hazardous organic substances contained in waste and may take only a few seconds to destroy, whereas landfill may take for years to decompose (C.C. Lee, G.L. Huffman 2007).

Typically, waste generated from the cities of developing countries contains higher moisture contents than developed economies which is a hindrance for WtE incineration, and tough to ensure auto-combustion and energy recovery by maintaining environmental quality (Durlak, Biswas, and Shi 1997; Kathirvale et al. 2004; Katiyar, Suresh, and Sharma 2013; Kreith and Tchobanoglous 2002; C.-J. Lin et al. 2013; Zhou et al. 2014b). A waste with a moisture content more than 60% may not burn autogenously at 870 ^{0}C (Kreith and Tchobanoglous 2002), literature also says 55% moisture is challenging for incineration (Kathirvale et al. 2004). Autothermic combustion and energy production depend on the composition of MSW, particularly paper and plastics which enhance heating value (Zhou et al. 2014b) but moisture contributes to reduce heating value. However, incineration is suitable for waste within certain properties, such as moisture content < 50%, the inert rate or ash content (ignition residuals) < 60 %, the rate of combustible fraction (i.e., fuel fraction: ignition loss of dry sample) > 25 % and a sufficiently high heating value (Nzihou et al. 2014; World Bank 1999). Though there is global tendency of gradual shifting from landfill to resource recovery including WtE in MSW management, problem with waste quantity and quality has been seen as a reason of the failure of incineration plants (EPA 2012; Mastellone 2015).

This chapter seeks to evaluate the lower heating value (LHV) with the development of a simple and easy to use empirical model based on wet basis physical composition (weight %). Model is applied in justifying the hypothesis that different scenarios can maximize LHV making the WtE incineration feasible. Scenarios are moisture reduction, selection of waste from specific areas and natural growth of heating value over time due to increase of combustible fractions. This chapter supported the preparation and publication of a peer-reviewed article in the Springer Journal of Material Cycles and Waste Management (Mondal & Kitawaki 2022).

5.2 Reviewing Heating Value Measurement Processes

To understand efficiency of MSW as fuel, the energy content as heating value (i.e., calorific value) is measured. Heating value is a critical need for design-calculations or numerical simulations of thermal treatment of waste. It is measured by different experimental or analytical methods such as by bomb calorimetric test (Drudi et al., 2019; Nwoke et al., 2020; Rominiyi & Adaramola, 2020) and by applying empirical mathematical models (e.g., regression equations), and unit is expressed as $MJ/kg, kJ/kg, kcal/kg, Btu/lb$ (Y. F. Chang et al. 2007; Falconi et al. 2020; Kathiravale et al. 2003; Korai, Mahar, and Uqaili 2016; Shi et al. 2016).

Heating value is typically expressed as Higher Heating Value (HHV) and Lower Heating Value (LHV) with wet and dry basis. HHV is the amount of heat produced during the complete combustion of unit mass of MSW (called HHV-1 in ASTM standard) in laboratory when the total products of combustion are cooled in the standard condition (Nzihou et al. 2014). In HHV, moisture of waste and water formed from combined hydrogen content of waste stays in the form of total steam or liquid form (Franjo et al. 1992). In LHV, it is assumed that water as steam allowed to escape and net energy of combustion is used as energy content of MSW as fuel (Magrinho and Semiao 2008). The LHV is defined as the energy content released from the combustion of the organic component of MSW in an incinerator (Ogwueleka and Ogwueleka 2010). LHV is typically used in system design of WtE plants and widely used to determine the energy content of MSW. Various empirical models have been developed to determine heating value typically based on three analyses: *proximate, ultimate, and physical composition analysis* (Azam et al. 2019; Y. F. Chang et al. 2007; Drudi et al. 2019; Katiyar, Suresh, and Sharma 2013; C.-J. Lin et al. 2013; Rana, Ganguly, and Gupta 2018; You et al. 2017; Zhou et al. 2014b).

Proximate analysis requires measurement of moisture (H_2O), volatile matter (V), fixed carbon, (C) and ash content (A) (X. Lin et al. 2015a) to generate heating value. Measurement of LHV from *ultimate analysis* is better than others but it also needs experimental analysis to measure C, H, O, N, S, Cl, and moisture content (H_2O), which is costly and time-consuming procedures (Y. F. Chang et al. 2007), (C.-J. Lin et al. 2013). The sample mass for ultimate analysis is 1-5 mg and for proximate analysis is 1 mg, which is very inadequate to represent the characteristics of waste with vast variances or heterogeneity (C.-J. Lin et al. 2013; You et al. 2017; Zhou et al. 2014b), therefore, their precision becomes poor (Ogwueleka and Ogwueleka 2010). Ibikunle et al., (2020) mentioned, experimental evaluation of solid fuel is labor intensive, costly, and subject to experimental errors (Ibikunle et al. 2020). Therefore, it may be arguable unless exceptionally large size of the samples is used with repetitive experimentations for proximate and ultimate analyses (Kathiravale et al. 2003; J.-I. Liu, Paode, and Holsen 1996). Dulong's formula is the prominent model to derive energy content from elemental data. Dulong's equation gives the smallest relative errors when compared to experimental calorific values and its precision is closest to the bomb calorimetric test when compared with other models (Nzihou et al. 2014; Kathiravale et al. 2003). On the other hand, empirical models based on food waste, paper and cardboard, plastics, textiles, wood, rubber proportions from *physical composition analysis* on thermal characteristics (Zhou et al. 2014a) are proposed by many e.g., (Drudi et al. 2019a), (Y. F. Chang et al. 2007), (X. Lin et al. 2015a), (J.-I. Liu, Paode, and Holsen 1996), (Japan National Solid Waste Foundation 1991), as to be quicker and cheaper, and simpler with higher accuracy nearly to ultimate analysis (C.-J. Lin et al. 2013). S. Kathiravale et al., (Kathiravale et al. 2003) shared that empirical model on physical composition exhibited better performance than other models. In the empirical model development, two methods are widely used: one is artificial neural network (ANN) (E. Akkaya and Demir 2010; Ibikunle et al. 2020; Khuriati et al. 2017; Ogwueleka and Ogwueleka 2010; Ozcan et al. 2016); and the other one is multiple regression analysis (MRA) (Ebru Akkaya and Demir 2009; Boumanchar et al. 2019; Y. F. Chang et al. 2007; C.-J. Lin et al. 2013; X. Lin et al. 2015a; J.-I. Liu, Paode, and Holsen 1996). Summary of models are shown in Table 5-1.

Table 5-1 Summary of models predicting lower heating value from physical compositions, changed after Wang et al., (2021); Drudi et al., (2019)

Model	**Eq.**	**Unit**	**Region & remarks**	**Reference**
$LHV_w = -68.06F_o + 91.44P_a + 52.65P_l + 30.73T_x + 34.91W_d + 7342.79$	(1)	kJ/kg	ANN-RM, 250 data set globally, 67 cities, 40 countries	(Wang et al. 2021)
$LHV_w = \left[\left(15.42O_r + 19.14S_a + 32.68P_l + 8.33P_a + 21.51T_x\right) \times (1 - W)\right] - (2.442 \times W)$	(2)	MJ/kg	SM, Saopalo, Brazil, $n = 36$, $R^2 = .995$; 108 data: 36 × 3 experiment	(Drudi et al. 2019)
$LHV_w = (35.19P_a + 71.17P_l + 36.24T_x + 48.06W_d + 42.21F_o + 44\,M_i) \times \left(\frac{100 - W}{100}\right) - 6W$	(3)	$kcal/kg$	OPM, in Taiwan, $n = 180$, $R^2 = 0.983$	(Y. F. Chang et al. 2007)
$LHV_w = [(16.55O_r + 20.42S + 36.17P_l + 9.06P_a + 22.81T_x) \times (1 - W)] - [(2.442 \times (9H + W_w - (9H \times W))]$	(4)	MJ/kg	FM, Saopalo, Brazil, $n = 36, R^2 = 0.996$; 108 data, 36 × 3 experimnets	(Drudi et al. 2019)
$HHV_d = 112.157F_o + 183.386P_a + 288.737P_l + 5064.701$	(5)	kJ/kg	Kuala Lumpur, Malaysia, $n = 30, R^2 = 0.779$;	(Kathiravale et al. 2003)
$HHV_d = 81.209F_o + 285.035P_a + 288.737P_l + 8724.209$	(6)	kJ/kg	Kuala Lumpur, Malaysia, $n = 30$, $R^2 = 0.645$	(Kathiravale et al. 2003)
$HHV_d = 112.815F_o + 184.366P_a + 298.343P_l - 1.920W + 5130.380$	(7)	kJ/kg	Kuala Lumpur, Malaysia, $n = 30$, $R^2 = 0.779$	(Kathiravale et al. 2003)
$LHV_w = (38.47F_o + 39.04P_a + 101.47P_l) \times \left(\frac{100 - W}{100}\right) - 6W$	(8)	$kcal/kg$	SM, Taiwan $n = 180, R^2 = 0.975$	(Y. F. Chang et al. 2007)
$LHV_w = 2229.91 + 28.16P_l + 7.90P_a + 4.87P_{ga} - 37.28W$	(9)	$kcal/kg$	Taiwan (Liu J.I.1996), $n = 34$ $R^2 = 0.967$	(Drudi et al. 2019)
$LHV_d = [88.2P_l + 40.5(F_o + P_a)] \times (\frac{100 - W}{100}) - 6W$	(10)	$kcal/kg$	Japan National MSW foundation, 1991	(Y. F. Chang et al. 2007; Japan National Solid Waste Foundation 1991)
$LHV_d = (38.52P_a + 92.09P_l + 49.24T_x + 38.34W_d + 37.55F + 64.07\,M_i)\left(\frac{100 - W}{W}\right) - 6W$	(11)	$kcal/kg$	Developed in Taiwan Lin, 2000 Model	(Y. F. Chang et al. 2007; Drudi et al. 2019)
$LHV_w = 141 + 23P_a + 8P_l + 40R_u + 49W_d + 2.5F_o + 22P_{mi}$	(12)	$kcal/kg$	Semarang City, Indonesia' $R^2 = 0.491$	(Khuriati et al. 2015)
$LHV_w = 219P_l + 112P_a + 108W_d + 115T_x$	(13)	kJ/kg	SM, 31 cities in China' $n = 103$	(X. Lin et al. 2015)
$LHV_d = (47.3P_a + 58.6P_l + 38.6T_x + 32.4W_d + 45.2F_o + 62.3R_u + 50.1\,M_i)\left(\frac{100 - W}{W}\right) - 6W$	(14)	$kcal/kg$	Taiwan, $n = 497$ $R^2 = 0.987$	(C.-J. Lin et al. 2013)
$LHV_w = 22.1P_a + 28.1P_l + 24.6T_x + 12.7W_d + 6.0F_o + 57.4R_u + 17.2\,M_i$	(15)	$kcal/kg$	Taiwan, $n = 497$ $R^2 = 0.954$	(C.-J. Lin et al. 2013)
$LHV_d = \left[\frac{100W}{100}\right]\left\{38.8\left(P_a + P_{ga} + W_d + M_i\right) + 50.9(T_x + R_u) + 73.7P_l\right\} - 6W$	(16)	$kcal/kg$	Tokyo	(Kathiravale et al. 2003)
$LHV_w = \left(23(F_o + 3.6P_a) + 160(P_l + R_u)\right) \times 2.326$	(17)	kJ/kg	Studies from 35 countries	(X. Lin et al. 2015)

Note. F_o: food waste (wt %); P_a: paper, cardboard (wt %); S_a: sanitary waste (wt %) assumed as paper, P_l: plastics (wt %); R_u: rubber (wt %); T_x: textiles (wt %); W_d: wood (wt %); M_i: miscellaneous/other combustibles (wt %); W: moisture (wt %); O_r: organic fraction (wt %); P_{ga}= Garbage (wt%; textiles, wood, food waste, miscellaneous also included); P_{mi}= Miscellaneous component (wt%); OPM: original proposed model; FM: Full Model; SM: simple or simplified model.

The exact range of LHV for a WtE incineration feasibility depends on the plant technology (e.g., grate firing or fluidized bed etc.,) and control of incineration process. International guidelines show that value of LHV is to be ≥ 6 (MJ/kg) as shown in Table 5-2 with a viable plant capacity. In this paper $\boldsymbol{LHV \geq 6\ (MJ/kg)}$ is considered as feasibility threshold.

Table 5-2 Required LHV (MJ/kg) for WtE project (taken from literature)

UNEP (Chen Liu et al., 2020)	Lorenzo Llanes & Kalogirou, (2019)	JICA, YEC, JESC, (2017)	India SWM Rules, (2016)	Constantinos S P. Themelis, (2014)	World Bank, (1999), ISWA (2013)
≥ 6	$5-7$	6.28 (power generation) 3.4 (auto combustion)	≥ 6.28	> 6	≥ 6 (all seasons) ≥ 7 (annual average)

5.3 Methodology for Model Development and Application

5.3.1 Study area information

Dhaka City is the capital of Bangladesh with an area of 305.23 km^2. It is a megacity of about 12.4 million people generating waste about 6,689 t/d (Table 5-3). SWM activities are mostly decentralized through 20 zones and 129 wards of DCCs as shown in Figure 5-1. Where, the shaded areas are under the jurisdictions of DCCs, and color densities show generation rate as ton per day. The blank areas are out of coverage of DCCs. The basic SWM profiles of DCCs are shown in Table 5-3.

Table 5-3 Study area (DCCs) information in 2019-2020, if not specified differently

Brief SWM profile	DNCC	DSCC
Total jurisdiction area, km^2	196.23	109.00
Population in million	6.10	6.30
Average population density, people/km^2	31,488	57,798
SWM Budget (Million BDT)	3,467	5,888*
Number of zones	10	10
Total wards (old/new**)	54(36/18)	75(57/18)
Estimated waste generation, t/d	3,433	3,256
Household waste, t/d	2,094	1,947
Business waste (office, market, hotel, restaurant etc.), t/d	755	1,081
Street, construction waste, t/d	584	228
Number of landfill site (name of landfill site)	1 (Amin bazar)	1 (Matuail)
Average collection rate	80%	78%
Number of waste collection vehicle (heavy equipment)	163(16)	307 (41)
Secondary collection modes	CT, OT, CC	CT, OT, CC
Average landfill disposal, t/d	2,750	2,540
Landfill operation cost, BDT/t	244	426
Number of cleaners (average workers/day) ***	3,914 (self, 2,479; outsourced, 1,435)	5,168

Note. 1 US$ = 84.78 BDT, CT: Compactor Truck, OT: Open Truck, CC: Container Carrier, *information is fiscal year 2017-2018, ** Coverage areas added in 2016, where regular waste collection and management are yet to start fully, ***all paid by DCCs.

Source: Adapted from Waste Reports (2021) and New Clean Dhaka Master Plans (2019) of DNCC, DSCC, and JICA (DNCC and JICA 2021; DSCC and JICA 2021; DNCC and JICA 2019; DSCC and JICA 2019).

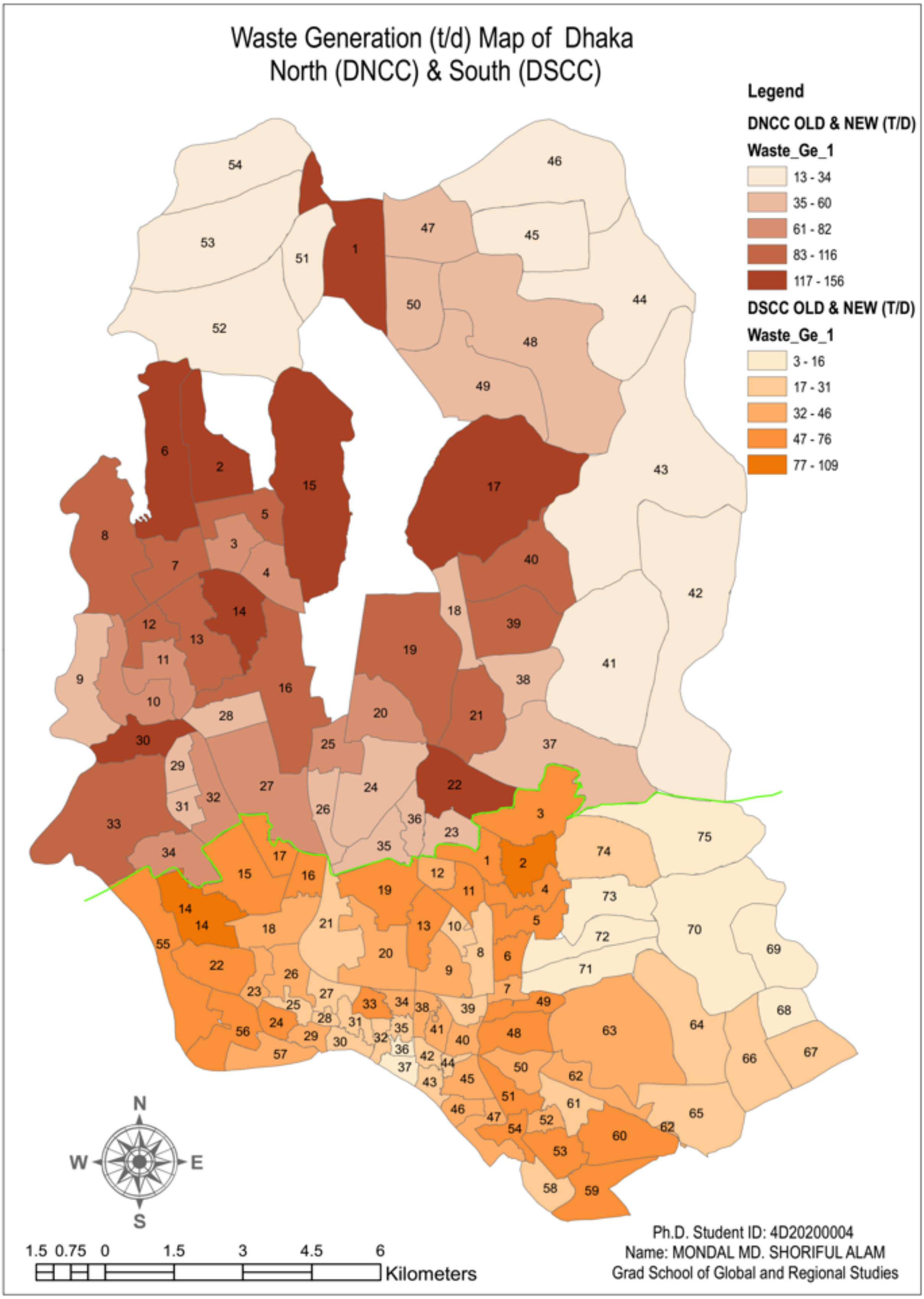


Figure 5-1 Map of Dhaka City Corporations (study area, DCCs)

5.3.2 Data acquisition

Waste characterization data has been collected from DCCs (JICA SWM Project). Standard field and laboratory protocols have been adopted following ASTM D5231-92, EC SWA-tool mostly in sample sizing, sample clustering, field characterization, laboratory works, and duration of survey. Sample sources are classified in 5 categories: household, restaurant, market, office, and landfill (samples taken from landfill sites). 90 composite datasets were prepared (i.e., 5×18) from characterization in generation phase and disposal phase (i.e., mixed waste in landfills taken from random trucks). Datasets were developed based on extensive characterization surveys in 2 seasons (8 days/season) in 2017-2018. Each of datasets was prepared from mixing of several similar waste sources, quartering, separating, and measuring mass fractions and moisture. As for example, 1 household dataset was prepared from characterizing of randomly selected 9 households' generated waste-mix in a same day. Moisture content was measured by fan-assisted oven drying of different components at 100 °C for 24 hours at the laboratory of Military Institute of Technology (MIST). Historical data of physical components are also taken from publicly available literature and official reports to understand trend change of LHV.

5.3.3 Empirical model for lower heating value and waste collection planning

Multiple regression models have been developed based on the average values of LHV of every data set using Eq. (1), Eq. (2) and Eq. (3) considering as dependent variables. These models are selected considering wet basis LHV, recent publications, and wider regional coverages.

Table 5-4 Parameters and units

Parameter	Description	Unit	Parameter	Description	Unit
LHV_w	Lower heating value wet basis	MJ/kg	P_a	Paper, cardboard portion	%
LHV_d	Lower heating value dry basis	MJ/kg	M_i	Miscellaneous/other combustibles portion	%
HHV_d	Higher heating value dry basis	MJ/kg	R_u	Rubber portion	%
$MAPE$	Mean absolute percentage error	%	W_d	Wood portion	%
SEE	Standard error of estimate	MJ/kg	W	Moisture portion	%
R^2	Coefficient of determination	-	S_a	Sanitary waste (assumed in paper category)	%
P_l	Plastics portion	%	η	Gross power generation efficiency	%
T_x	Textile portion	%	P_g	Generator output	MW
O_r	Organic portion	%	B	Waste (ton) treated (inflow) in furnace per hour	t/h
F_o	Food waste portion	%			

Note. Composition proportions are mass fractions, expressed as discarded wet basis weight parentage (wt%)

The conceptual flow of model development is shown in the Figure 5-2 (left) and application to have desired waste feed for feasible WtE is shown in Figure 5-2 (right). Different parameters used for model development which are summarized in Table 5-4.

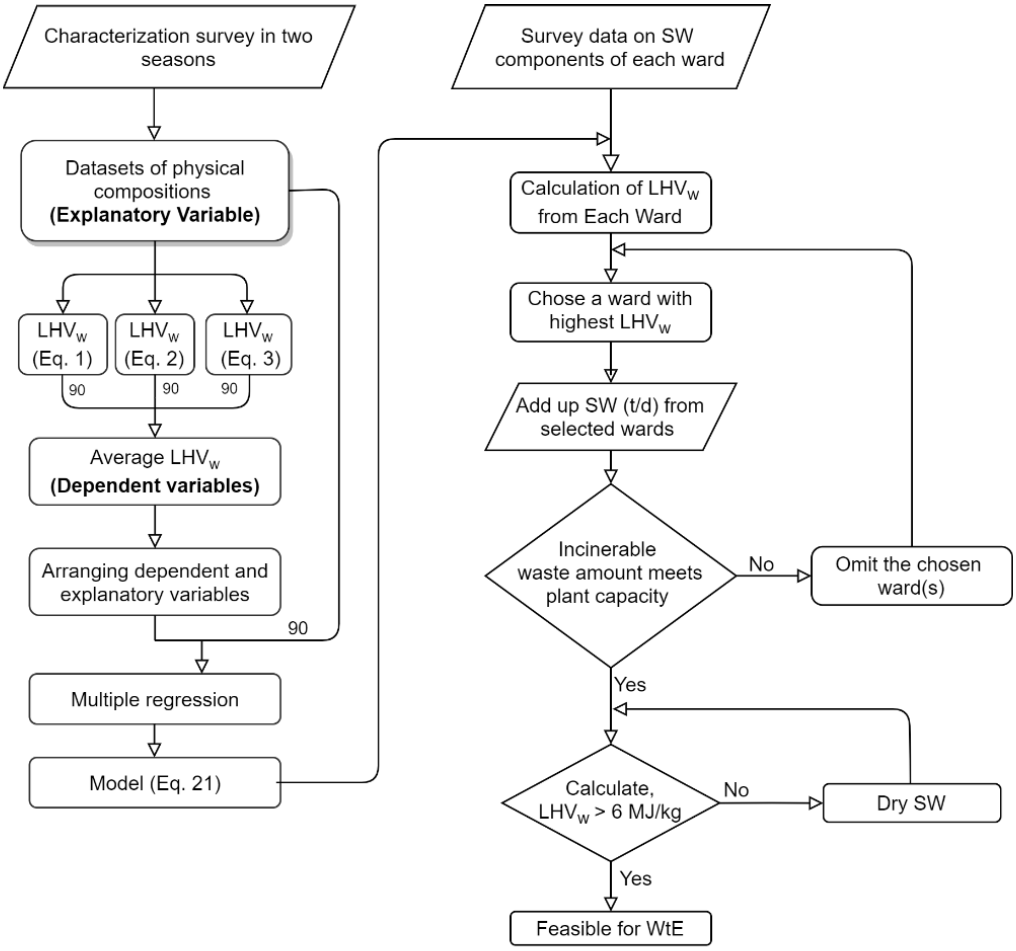


Figure 5-2 Flow diagram of model development (left) and application to have quality waste feed in desired amount for a feasible WtE plant (right)

Regression coefficients are determined for seven (7) explanatory variables (wet basis, weight %): food (F_o), paper (P_a), textiles (T_x), wood, grass, and trimmings (W_d), plastics (P_l), rubber and leather (R_l) and moisture (W_w). Bones and shells are considered as 'food,' all types of papers are considered as 'paper' in model development. Regression models are developed after looking into analysis of variance (ANOVA); coefficient of determination (R^2); P-values to justify existence of non-zero correlation; normal probability plot and residual plots using *data analysis* tool of MS Excel. Mean Absolute Percentage Error (MAPE) and Standard Error of Estimate (SEE) are calculated by Eq. (18) and Eq. (19) respectively to understand consistency and errors of equations; where x_{pi} is *predicted* LHV_w; x_{oi} is *observed* LHV_w and n

is the number of datasets (i.e., 90) (X. Lin et al. 2015; Wang et al. 2021). Considering these factors model equation is developed and applied for LHV prediction.

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\frac{|x_{pi}-x_{oi}|}{x_{oi}} \times 100 \qquad \text{Eq. (18)}$$

$$SEE = \sqrt{\frac{\sum_{i=1}^{n}(x_{pi}-x_{oi})^2}{n-1}} \qquad \text{Eq. (19)}$$

5.3.4 Application of model in different scenarios

Heating value increasing hypothetical scenario information have been gathered from literature, characterization survey and interview of municipal officials who have long-years of experience (i.e., more than 15 years), took local and international trainings and have solid understanding of current SWM. In addition to this, discussion meetings were held with several waste collection vehicle drivers, several primary collectors with in-person inspections. Scenario-information includes, which wards have more combustible fraction, waste collection rate, waste compositions, moisture content, and historical changes in waste quality.

5.3.5 Electricity generation estimation

Electricity generation is estimated using Eq. (20) following UNEP and IGES, considering the gross power generation efficiency (η) is 16.6% and 20% with turbine bypass factor (C. Liu et al. 2020). According to Tokyo Metropolitan Government (2020), latest facilities have achieved > 20% gross power generation efficiency, η (C. Liu et al. 2020).

$$\eta = (P_g \times 3600)/(B \times LHV_w \times 1000) \qquad \text{Eq. (20)}$$

Here,

η: gross power generation efficiency (%);

P_g: generator output (MW);

B: amount of waste treated (inflow) in a furnace (t/h)

5.4 Result and Discussion

5.4.1 Physical composition of Municipal Solid Waste of Dhaka City

The typical characteristics of MSW of DCCs of various sources are shown in Table 5-5. Market samples represent shops, shopping malls, megamalls, super-shops but not grocery or vegetable markets. Restaurant means mostly restaurants with kitchen facilities. Office means government and private offices, institutions, or organizations. Food waste takes a significant share in the composition, which is a reason for high moisture content of mixed waste; it is 61.74% (Mondal & Kitawaki 2020). Due to mixed waste generation combustible fractions also contain high moisture, and samples from landfill also show significant amount of moisture in the papers, textiles, and woods than the point of collection or generation. However, in predicting LHV bone fraction is assumed as food.

Average moisture content of all the sample sources is shown Table 5-6. Food contains more than 80% moisture and paper and wood and textile contain above 41%, 49% and 36% moisture respectively (wet basis).

Table 5-5 Mean value of wet basis typical physical composition (weight %) of MSW of DCCs

Composition	Household		Office		Street		Market		Restaurant		Landfill (DNCC)		Landfill (DSCC)	
	P	M	P	M	P	M	P	M	P	M	P	M	P	M
1. Food (F_o)	68.7	80.4	41.0	81.6	26.1	72.3	52.0	90.5	72.4	89.4	52.2	74.0	63.9	72.3
2. Bones (F_o)	3.0	21.3	1.6	30.9	0.5	29.3	3.0	23.9	3.3	46.1	3.8	28.8	0.9	31.1
3. Paper (P_a)	8.3	29.6	22.1	14.0	4.6	38.4	18.4	18.0	6.7	45.6	8.1	58.4	2.1	52.5
4. Other Paper (P_a)	2.7	54.7	2.9	35.3	1.3	33.2	2.3	36.1	5.2	65.0	3.6	58.4	2.4	52.5
5. Grass/Wood (W_d)	2.8	53.9	11.5	33.6	23.2	43.2	1.8	42.4	0.8	53.6	8.4	69.5	8.3	67.1
6. Textiles (T_x)	3.6	18.9	2.0	28.0	5.6	25.3	6.6	36.8	1.4	52.8	5.9	58.0	4.8	51.6
7. Rubber/Leathers (R_l))	0.0	-	0.3	-	0.4	-	0.7	-	0.1	-	1.7	-	0.4	-
8. PET Bottle (P_p)	0.7	-	1.2	-	0.0	-	0.7	-	1.1	-	0.5	-	-	-
9. Other Plastics (P_p)	8.0	-	9.1	-	8.3	-	13.2	-	8.1	-	10.0	-	15.3	-
10. Aluminum/Steel, can	0.1	-	0.0	-	0.0	-	0.1	-	0.1	-	0.3	-	0.0	-
11. Other Metals	0.2	-	0.7	-	0.1	-	0.1	-	0.3	-	0.2	-	0.1	-
12 Bottle/Jar	0.3	-	0.1	-	.03	0.3	0.3	-	0.4	-	0.4	-	0.1	-
13. Ceramic/Glasses	0.7	0.2	0.6	21.1	0.9	1.2	0.1	0.1	0.1	-	1.0	6.3	0.8	1.2
14. Sand/Stones	0.3	1.3	5.8	1.4	28.7	18.8	0.6	8.7	0.0	-	3.2	27.1	0.7	9.0
15. Medical/Hazardous	0.4	-	0.2	-	0.1	-	0.1	-	0.0	-	0.3	0.0	0.2	-
16. Electrical/Electronic	0.2	-	0.8	-	0.1	-	0.0	-	0.0	-	0.5	0.0	0.1	-
Moisture content (W_w)		62.2		43.2		37.8		55.1		74.1		56.8		56.9
Recyclable (R)	24.2		39.3		20.4		42.5		-		31.1		25.3	

Note. P: Physical component's proportion (%); M: Mean moisture proportion in individual component (%).
Source: Analyzed from data taken from JICA SWM project office in DNCC, DSCC (JICA 2018).

Table 5-6 Statistics of moisture content of individual component in DCCs (weighted average of sample sources)

Component	Food	Bone	Paper	Wood	Textile
Mean moisture (M), %	80.72	29.93	41.83	49.58	36.94
Sample (n)	26	22	46	20	25
Minimum (M_l), %	41.90	15.50	5.50	9.04	2.34
Maximum (M_h)%	94.33	54.94	70.37	86.97	66.02
Sample median (Md), %	81.63	26.10	44.98	53.51	39.95
Standard error, %	2.34	2.37	4.05	5.43	4.01

Source: Analyzed from data taken from JICA SWM project office in DNCC, DSCC (JICA 2018).

5.4.2 Physical composition-based model development

To develop the model correlation analysis was done as shown in Table 5-7. Summary output of regression statistics, ANOVA with coefficients of regression model is shown in Table 5-8, Table 5-9 respectively.

Table 5-7 Correlation analysis

	F_o	P_a	W_d	T_x	R_l	P_l	W_w	*LHV*
F_o	1							
P_a	-0.74	1						
W_d	-0.54	0.08	1					
T_x	-0.30	-0.05	-0.01	1				
R_l	-0.23	0.11	0.01	0.09	1			
P_l	-0.31	0.15	-0.15	0.19	0.26	1		
W_w	0.93	-0.70	-0.33	-0.35	-0.31	-0.46	1	
LHV	-0.93	0.71	0.34	0.37	0.32	0.56	-0.97	1

Table 5-8 Summary output

Regression Statistics	
Multiple R	0.9994
R Square	0.9987
Adjusted R Square	0.9986
Standard Error	**0.0672**
Observations	90

Table 5-9 ANOVA and coefficients of regression

	df	*SS*	*MS*	*F*	*Significance F*
Regression	7	291.121	41.59	9220.07	0.00
Residual	82	0.370	0.00		
Total	89	291.491			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	7.721	0.18	43.48	2.09E-58	7.37	8.07	7.37	8.07
F_o	0.034	0.00	12.03	8.67E-20	0.03	0.04	0.03	0.04
P_a	0.074	0.00	32.77	7.00E-49	0.07	0.08	0.07	0.08
W_d	0.071	0.00	26.76	2.84E-42	0.07	0.08	0.07	0.08
T_x	0.077	0.00	30.97	5.11E-47	0.07	0.08	0.07	0.08
R_l	0.104	0.01	10.62	4.48E-17	0.08	0.12	0.08	0.12
P_l	0.121	0.00	51.63	2.61E-64	0.12	0.13	0.12	0.13
W_w	-0.126	0.00	-42.56	1.13E-57	-0.13	-0.12	-0.13	-0.12

The developed models for Dhaka City are shown in equation Eq. (21) - Eq. (24), where the values of coefficient against each explanatory variable are checked for P-value (i.e., non-zero correlation).

$$\boldsymbol{LHV_w\left(\frac{MJ}{kg}\right) = 7.721 + 0.034F_o + 0.074P_a + 0.071W_d + 0.077T_x + 0.104R_l + 0.121P_l - 0.126W_w} \quad \text{Eq. (21)}$$

$$LHV_w\left(\frac{MJ}{kg}\right) = 7.660 + 0.038F_o + 0.075(P_a + W_d + T_x) + 0.112(R_l + P_l) - 0.130W_w \quad \text{Eq. (22)}$$

$$LHV_w\left(\frac{MJ}{kg}\right) = 7.695 + 0.034F_o + 0.074P_a + 0.071\,W_d + 0.077T_x + 0.121(R_l + P_l) - 0.126W_w \quad \text{Eq. (23)}$$

$$LHV_w\left(\frac{MJ}{kg}\right) = 8.220 + 0.032F_o + 0.070P_a + 0.068\,W_d + 0.073T_x + 0.121P_l - 0.130W_w \quad \text{Eq. (24)}$$

The Eq. (21) is suggested as proposed model (PM), which shows better precision and less errors compared to other three simplified models (SM) (Table 5-10). Proposed model, Eq. (21) is applied to find the energy contents of different waste sources and descriptive statistics of LHV_w are shown in Table 5-11, where the market and office waste meet the threshold of $LHV_w(\geq 6MJ/kg)$, and hotels/restaurants are suggestive to be avoided for WtE facility. On the other hand, household waste in combination with market and office waste can be incinerated, where it meets the critical $LHV_w(\geq 6MJ/kg)$. However, Eq. (23-24) are simplified models can also be applied for LHV_w approximation with a lesser precision. They are simplified based on unification of components where the values of coefficients are same, and some trial and errors are made to get reasonable result with statistical checks (e.g., P value, error estimations, adjusted R^2) as shown in Table 5-7. As for example, in Eq. (22), paper, wood and textiles are combined, and plastics, rubber and leather are combined due to the closeness of coefficients' value. Similarly, in Eq. 23, Rubber, leather, and plastics are combined, in Eq. (24) Rubber, leather is excluded to get rational LHV with the values of coefficients corresponding to the variables.

Table 5-10 Statistical results and coefficients of empirical model with errors' estimation

Eq.	Estimated coefficients								R^2	Adjusted R^2	MAPE (%)	SEE $\left(\frac{MJ}{kg}\right)$	Datasets	Model
	Intercept	$\boldsymbol{F_o}$	$\boldsymbol{P_a}$	$\boldsymbol{W_d}$	$\boldsymbol{T_x}$	$\boldsymbol{R_l}$	$\boldsymbol{P_l}$	$\boldsymbol{W_w}$						
(21)	7.721	0.034	0.074	0.071	0.077	0.104	0.121	-0.126	0.9987	0.9986	0.959	0.065	90	PM
(22)	7.660	0.038	0.075*			0.122**		-0.130	0.9986	0.9985	0.978	0.069	90	SM
(23)	7.695	0.034	0.074	0.071	0.077	0.121**		-0.126	0.9987	0.9986	1.024	0.9987	90	SM
(24)	8.220	0.032	0.070	0.068	0.073	-	0.121	-0.130	0.9970	0.9968	1.370	0.100	90	SM

Note. PM: Proposed model, SM: Simplified model, * combined coefficient for $\boldsymbol{P_a}$, $\boldsymbol{W_d}$, $\boldsymbol{T_x}$, ** combined coefficient for $\boldsymbol{R_l}$, $\boldsymbol{P_l}$, (-) excluded from regression.

Table 5-11 Descriptive statistics of predicted LHV_w of different sources

Statistics	Restaurants	Household	Market	Office	Landfill
Mean, LHV_w $(\bar{x})$, MJ/kg	4.34	4.71	7.05	7.23	6.05
Standard Error	0.26	0.31	0.46	0.37	0.20
Median, LHV_w (MJ/kg)	4.59	4.65	7.13	7.39	5.90
Standard Deviation	1.09	1.31	1.94	1.55	0.85
Sample Variance	1.19	1.71	3.77	2.42	0.73
Kurtosis	0.60	1.71	-0.82	-1.21	-0.23
Skewness	-0.19	0.34	-0.19	-0.15	0.29
Range	4.54	5.80	6.88	5.13	3.22
Minimum (MJ/kg)	2.16	2.19	3.48	4.41	4.47
Maximum (MJ/kg)	6.71	7.99	10.37	9.53	7.69
Sum $(\sum)$	78.11	84.82	126.83	130.06	108.88
Count, data sets (n)	18	18	18	18	18
Confidence Level (95.0%)	0.54	0.65	0.97	0.77	0.42

Comparisons between the lower heating values of the proposed model (PM) and the reference models are shown in Figure 5-3 for household waste samples, Figure 5-4 for restaurant waste samples, Figure 5-5 for market waste samples, Figure 5-6 for office waste samples, and Figure 5-7 for landfill waste samples. The landfill waste samples are from two landfills in Dhaka City (namely Amin Bazar Landfill of DNCC and Matuail Landfill of DSCC).

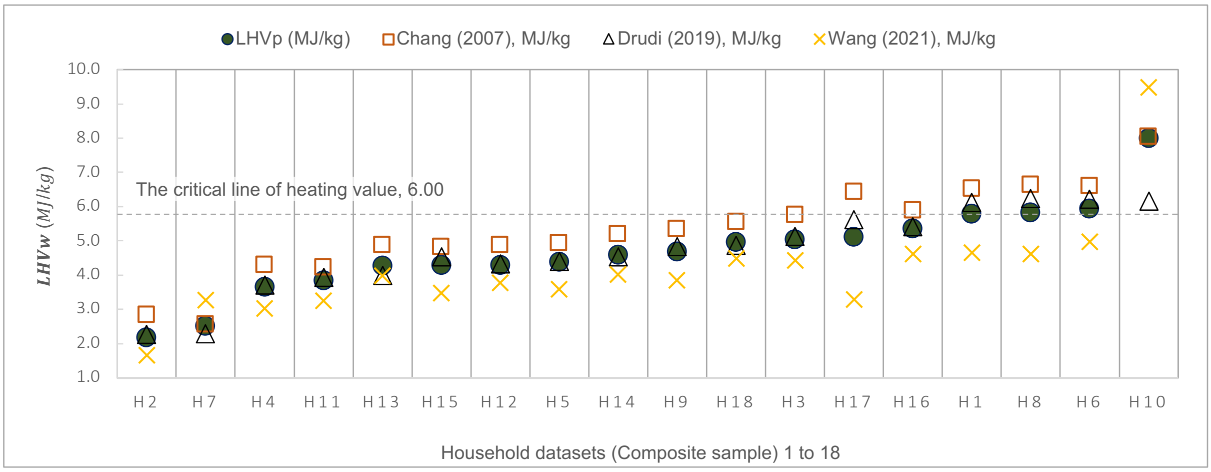


Figure 5-3 Comparisons of LHV for proposed model (LHV_p) and reference models for **(Household waste)**

Figure 5-3, Figure, 5-4, Figure 5-5, Figure 5-6, and Figure 5-7 show that all the proposed model values waste fall within the ranges of the various reference model values. The proposed model values are closest to the values of Drudi (2019) and Change (2007) models. However, the model values of Wang (2021) are found to be extreme and extremely sensitive to paper. For example, household, restaurant, and landfill waste contain a smaller amount of paper, and the values of Wang's (2021) model are minimal compared to the other models. In contrast, office waste contains maximum paper content and Wang's (2021) model has maximum values compared to other models.

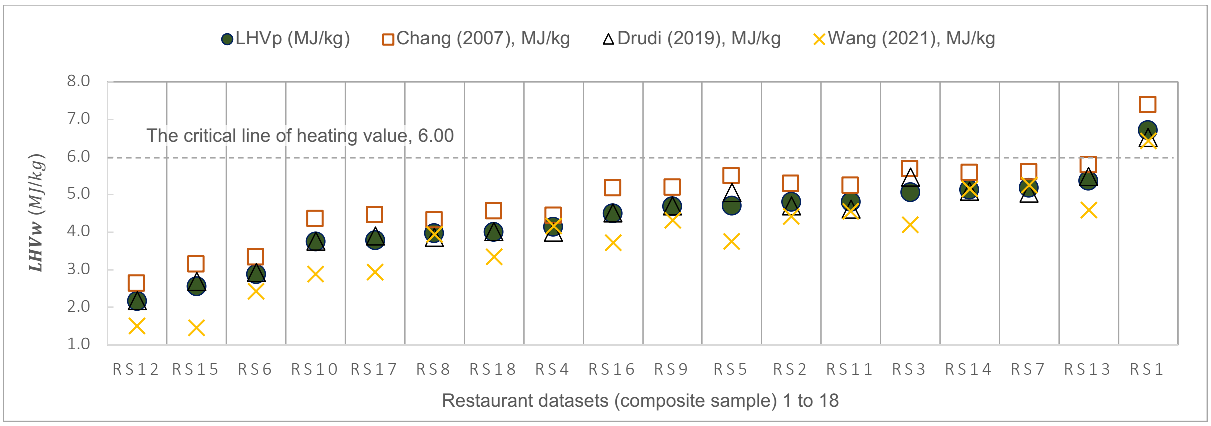


Figure 5-4 Comparisons of LHV for proposed (LHV_p) and reference models **(Restaurant waste)**

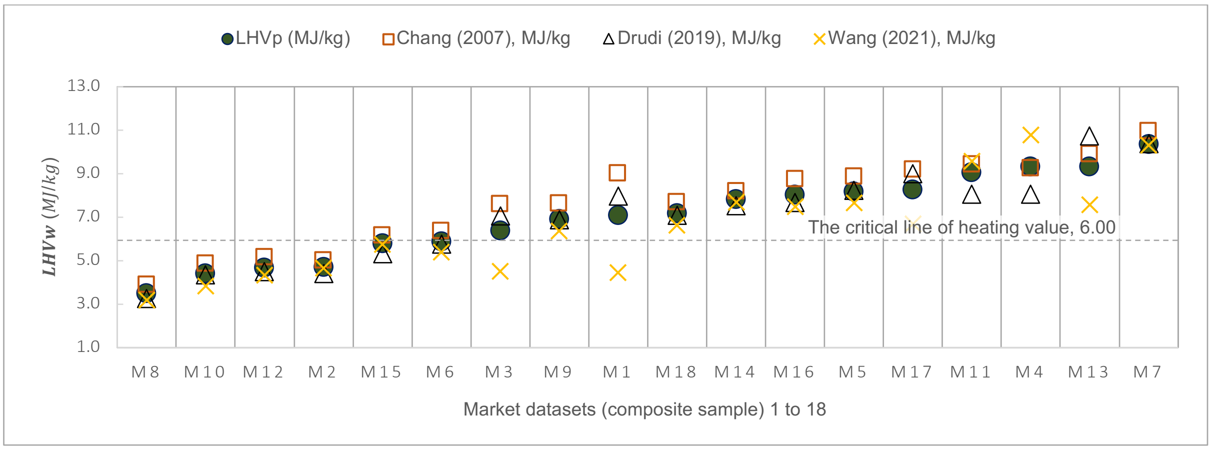


Figure 5-5 Comparisons of LHV for proposed (LHV_p) and reference models (**Market waste)**

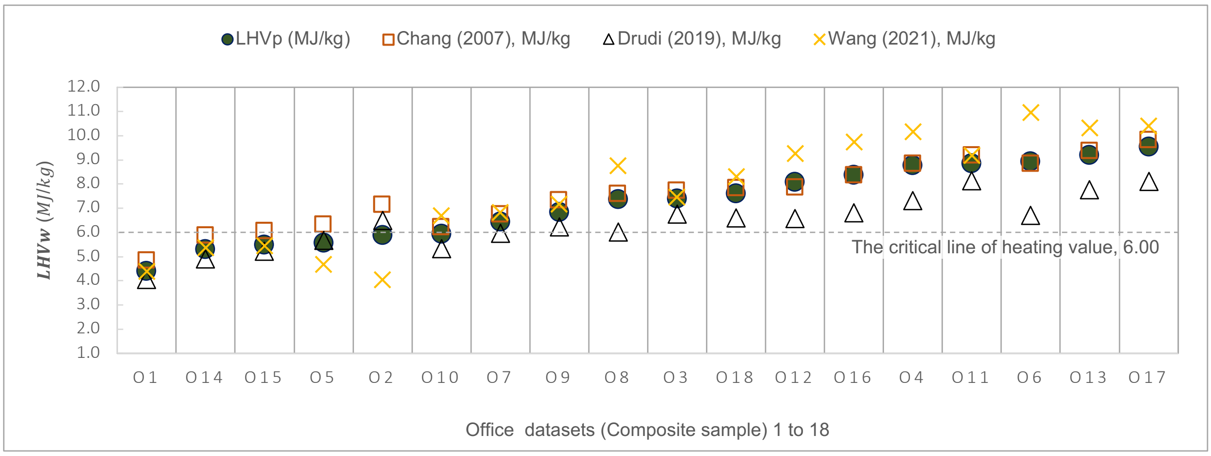


Figure 5-6 Comparisons of LHV for proposed (LHV_p) and reference models (**Office waste)**

Average lower heating value of landfill mix waste is 6.05 MJ/kg as shown in Table 5-11 and Figure 5-7. Landfill mix waste for DSCC exhibits slightly higher values than DNCC landfill waste due to its high plastic contents though food is less in DNCC landfill than DSCC.

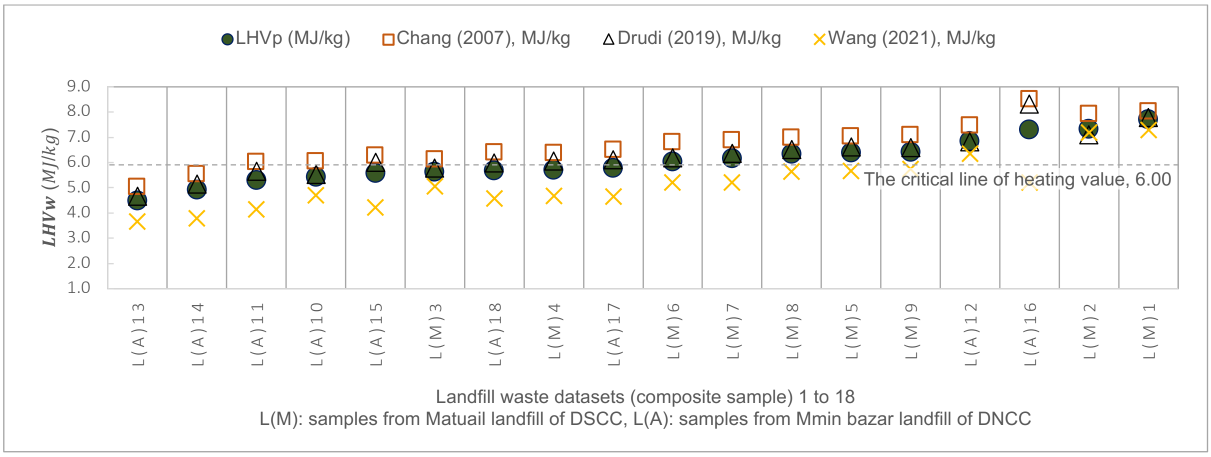


Figure 5-7 Comparisons of LHV for proposed (LHV_p) and reference models (**Landfill waste)**

It is possible to enhance the LHV_w by different augmenting scenarios, which are portrayed as follows as scenario analyses.

5.4.3 Raise in lower heating value by evaporation & selection of areas

Evaporative moisture loss (i.e.,10%) can be achieved within 1-2 days as found by Ishii et al., (2019), where ambient temperature 32-33 °C; relative humidity 70-90% under mix of sunny and cloudy conditions (Akio Ishii et al. 2019). It can be triggered more by the provision of sunlight; enlarging storage bunker; increasing storage time; mechanical turning and increasing the drying zone in the grate with appropriate retention time, which can contribute to improve the LHV as mentioned by different entities (C. Liu et al. 2020; JICA, YEC, JESC 2017; Yang et al. 2012). Chang et al., (Y.-H. Chang, Chen, and Chang 1998) found a great evaporation effect at air classification and trommel screening along with increase of combustible proportion and decrease moisture.

Collection of household and commercial waste from market and office dominant areas with some moisture loss provision can also be simulated to minimize moisture and maximize LHV. If household waste is planned to be fed with equal proportion of office and market waste, the LHV_w becomes 6.33 MJ/kg, that supports the starting limit of WtE incineration ensuring auto thermal combustion with some heat and power generation (World Bank 1999). However, with the moisture loss of 10%, 15% and 20%; the mean $LHV_w(MJ/kg)$ can be increased to a great level as shown in Table 5-12. These scenarios exhibit LHV_w meeting the required starting limits (6 MJ/kg) of UNEP (C. Liu et al. 2020) and JICA (JICA, YEC, JESC 2017). It is suggestive to use restaurants in anaerobic digestion for methane production as it has low LHV_w and remarkably high moisture content (i.e., 74.1%).

Table 5-12 LHV_w approximation for household, market, office waste with different drying efforts

Waste nature	LHV_w(No effort for evaporation) (MJ/kg)	LHV_w (10% evaporative loss) (MJ/kg)	LHV_w(15% evaporative loss) (MJ/kg)	LHV_w (20% evaporative loss) (MJ/kg)
Household (HH) 100%	4.71	5.24	5.50	5.76
Market (MKT) 100%	7.05	7.44	7.64	7.84
Office (OFS) 100%	7.23	7.58	7.76	7.94
MKT: OFS: HH (1:1:1)	6.33	6.75	6.97	7.18
MKT: OFS:2HH (1:1:2)	5.93	6.38	6.60	6.83

Using Eq. (21), sensitivity analysis was carried out to obtain minimum critical values of each component (i.e., wet basis) to have $LHV_w, > 6$ (MJ/kg) for a feasible WtE from incineration and estimated as for example, $F_o \leq 50\%$, $P_a \geq 6\%$, $P_l \geq 12\%$, $W_d \geq 4\%$, $T_x \geq 4\%$ and $W_w \leq 47\%$. Figure 5-2 portrays how to achieve minimum critical value by means of moisture loss (e.g., evaporative loss in bunker, leachate drain out) and selecting special wards where office and markets are high in number and municipal staff are well known about them. As a strategy to achieve maximum power generation waste should be selected from the wards with high LHV_w . Authorities can decide specific areas with special tariff for WtE incineration waste collection such as market areas, office areas, large hotels, commercial hubs etc.

In addition to food waste, combustible components also contain a significant amount of moisture as shown in Table 5-5, it is possible to reduce by drying. The existing relation of moisture sensitivity with LHV is shown in Figure 5-8, where $Y = LHV\ (MJ/kg)$, $X = moisture\ content\ (\%\ )$, considering components are in field condition (n = 90).

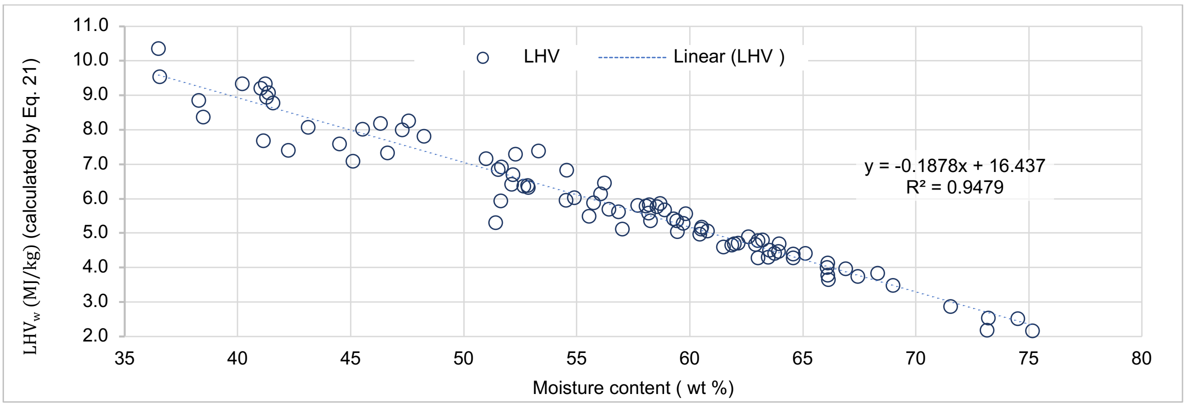


Figure 5-8 Existing relationship with moisture content (wt %) and $LHVw\ (MJ/kg)$ in DCCs

Feasibility of WtE plant depends on the income from sale of energy; energy production depends on the LHV of the waste; however, the income is reduced with lowering the LHV which causes the increase of net treatment cost (World Bank 1999). Assuming 500 t/d WtE plant in economies of scale (Constantinos S Psomopoulos and Themelis 2014), wards could be targeted, where LHV exceeds critical value ($6\ MJ/kg$). As shown in Table 5-13, there are Wards of DNCC (e.g., 1, 19, 20 and 32) have food waste less than 50% and combustible and other fractions are higher than 50% with estimated LHV more than 6 MJ/kg. In those wards' waste do not require drying and can be fed directly to waste-to-energy incineration plant (if objectionable matters are excluded).

Table 5-13 Waste composition and LHV_w of wards having higher fractions of combustible

Ward No. (DNCC)	Collection rate (t/d)	$F_o(\%)$	P_a (%)	$P_l(\%)$	$R_l(\%)$	$W_d(\%)$	$T_x(\%)$	$W_w(\%)$	$LHV_w(MJ/kg)$
1	≥ 190	$45(around)$	$15 \leq P_a \leq 20$	$11 \leq P_l \leq 15$	$1 \leq R_l \leq 2$	$7 \leq W_d \leq 8$	$4 \leq T_x \leq 5$	48 ~ 51	6.5 ~ 7.2
19	≥ 110	$40 \leq F \leq 45$	$18 \leq P_a \leq 25$	$11 \leq P_l \leq 13$	$1 \leq R_l \leq 2$	$10 \leq W_d \leq 15$	$3 \leq T_x \leq 4$	50 ~ 52	6.6 ~ 7.5
20	≥ 75	$45(around)$	$15 \leq P_a \leq 20$	$12 \leq P_l \leq 15$	$1 \leq R_l \leq 2$	$3 \leq W_d \leq 5$	$5 \leq T_x \leq 6$	46 ~ 50	6.7 ~ 7.2
32	≥ 50	$45(around)$	$15 \leq P_a \leq 20$	$11 \leq P_l \leq 15$	$1 \leq R_l \leq 2$	$10 \leq W_d \leq 15$	$3 \leq T_x \leq 5$	49 ~ 55	6.5 ~ 7.3
*O**	*≥75*	*50*	*6*	*12*	-	*4*	*4*	*47*	*6.0*

Note. composition values are wet basis weight %, *O**: other wards (selective areas) with hypothetical *critical value* to have feasible LHV_w for 500 (t/d) WtE incineration in each city corporation

5.4.4 Changing lower heating value over times

Existing range of LHV of household waste is from 2.19 MJ/kg (i.e., low-income household, slum) to 7.99 MJ/kg (i.e., high-income household, Uttara residential areas), it dictates a portion of high-income communities have obtained suitable waste quality (*viz*. Table 5-5, Table 5-11). If no efforts are made, as shown in Figure 5-5, typical household waste will gain the quality of required LHV_w around 2030 but evaporation of moisture can make this earlier; however, market and office waste have already attained the threshold (Table 5-11).

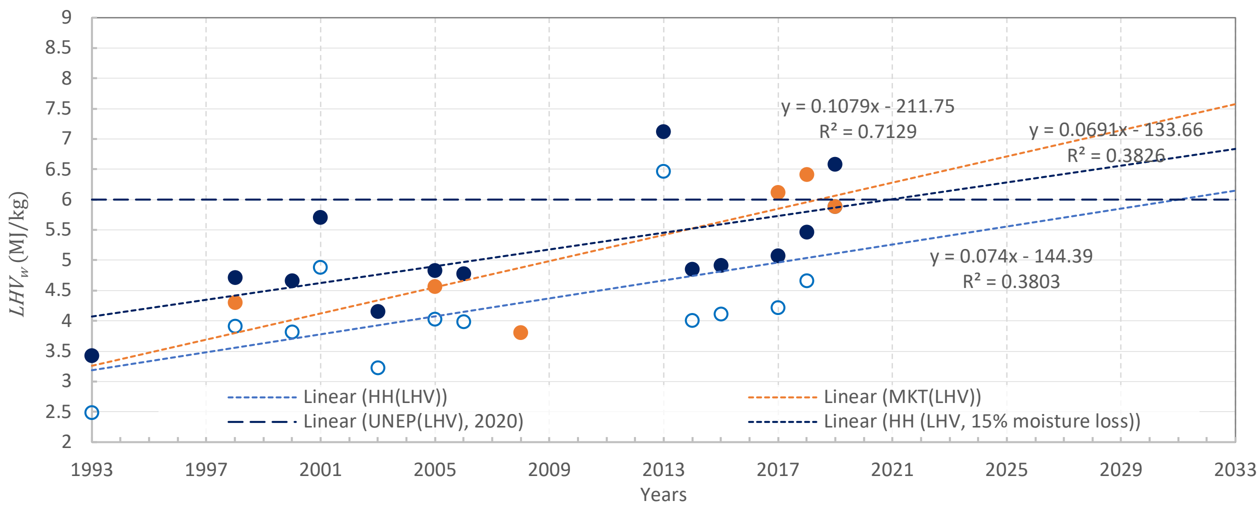


Figure 5-9 Changing trends of LHV_w over time for household and market waste

Old characterization data are reviewed from the literatures of (JICA 2018; Yousuf and Rahman 2007; JICA, DCC 2005; Abdus Salam 2001; Alamgir and Ahsan 2007; Asad and Khandaker 2015; BCAS 1998; F.A.Samiul Islam 2016; Hai and Ali 2005; HHECL 2017; Hoque and Rahman 2020; Iftekhar Enayetullah, A.H.Md.Maqsood Sinha, and Ilari Lehtonen 2014; Iftekhar Enayetullah and Q.S.I. Hashmi 2006; Kabir 2015; K.M.N., Huda 2002; Sujauddin, Huda, and Hoque 2008), where, not all the data are used to plot the Figure 5-9, only clearly mentioned sources of waste as household or market are used. And characterization data of dumpsites, mixed waste and unclear sources are not used to plot. According to Figure 5-9, 15% moisture loss of household waste can reduce around 10 years gap to attain the minimum feasible LHV. And market waste has already attained that limit around 2018.

5.4.5 Waste collection and integrated SWM to improve lower heating value

Waste collection by special trucks (i.e., currently there are 104 compactor trucks in DCCs) helps against rainwater intrusion into the waste. However, plastic bag collection may boost the LHV, due its high energy content. A sensitivity analysis is done considering minimum critical value of other fractions as constant and changing the plastic proportions shown in Eq. (25), were, $Y = LHV\ (MJ/kg),\ X = plastics\ content$ (%).

$$Y = 0.113X + 4.644 \qquad \text{Eq. (25)}$$

The uncollected, indiscriminately disposed, or non-recycled plastic waste on streets, drains and rivers banks are common in DCCs which can contribute to enhance the feasibility, if they are brought to collection stream though community participation. Strong community participation is inevitable with frequent environmental education and monitoring in terms of quality waste discharge and not mix with hazardous substances. Another important approach can be integration of other waste treatment like composting, anaerobic digestions etc. from where left-over plastics, reject, methane gas etc. can be added to incineration as indicated by JICA team in the New Clean Dhaka Master Plan (i.e., the Eco-town concept) (DNCC and JICA 2019; DSCC and JICA 2019). That concept depicts that waste treatment options would be established based on the type of waste encompassing incineration, composting, anaerobic methanation, construction waste recycling, recycling center, medical waste treatment, e-waste treatment etc. along with landfill. And there will be internal material flow among these systems too. However, may be at the beginning not all the waste could be treated and a significant amount of waste without treating to be landfilled as it is happening currently. Such answers will come from detailed feasibility and new project information.

5.4.6 Electricity generation estimation

The Renewable Energy Policy of Bangladesh mentions 10% of electricity should come from renewable energy sources (RES) by 2020, accordingly, in absolute terms, at least 2000 MW must be generated from RES; however, around 600 MW electricity had been generated so far from RES (*Bangladesh Post* 2020). The electricity generation from MSW of DCCs can be estimated 5.76 MW and 6.96 MW having the critical composition of LHV, 6 (MJ/kg) with

16.6% and 20% efficiencies respectively, for a 500-ton plant. Yachiyo Eng. Co., Ltd., found 6.5 MW was achievable for a 500-ton capacity incineration facility (Yachiyo Engineering Co., Ltd. 2021) for MSW. Recently, JFE Corporation has predicted (11.6 MW) for the same capacity of plant in Vietnam by having a mix of municipal and industrial waste (JFE Engineering Corporation 2021). The estimated power generation with different assumed conditions is shown in Table 5-14.

Table 5-14 Estimated power generation rate, P_g (MW) in different plant capacities and efficiencies

LHV_w (MJ/kg)	Assumed plant capacity, 500 t/d		Assumed plant capacity, 750 t/d	
	Power generation with efficiency, 16.6%, P_g (MW)	Power generation with efficiency, 20%, P_g (MW)	Power generation with efficiency, 16.6%, P_g (MW)	Power generation with efficiency, 20%, P_g (MW)
6.00	5.76	6.94	8.65	10.42
6.38	6.13	7.38	9.19	11.08
6.60	6.34	7.64	9.51	11.46
6.83	6.56	7.91	9.84	11.86
7.00	6.72	8.10	10.09	12.15

Source: calculated following IGES, UNEP (C. Liu et al. 2020).

Energy contents as predicted by previous studies as shown in Table 5-15 are in gradual increase due to economic improvement and waste compositional changes (e.g., reducing of moisture content, food waste, and increase paper and plastics etc.)

Table 5-15 LHV of MSW predicted by different previous studies

Year	Heating value (MJ/kg)	City	Reference
2005	2.3-3.6	Dhaka	(2007)
2005	3.22-6.05	Dhaka	(Hai and Ali 2005)
2016	0.71	Dhaka	(Islam 2016)
2016	1.06	Chittagong (Chattogram)	(Islam 2016)
2020	5.8	Bangladesh	Estimated by model on LHV of JICA (JICA, DCC 2005), using GDP of WB (World Bank 2020)
2021	4.2-5.0	Dhaka (North)	(Yachiyo Engineering Co., Ltd. 2021)

Note. GDP: Gross Domestic Product in United States Dollars ($) based on World Bank data.

5.5 Conclusion on Lower Heating Value Model Development and Application

Following statistical processes for multiple liner regression, models are developed to predict LHV_w with the proposition of simplified models. 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 survey.

The proposed model is used for future LHV prediction, and it may also be used in other areas where waste characteristics are similar. In general, around 60% of MSW of DCCs is household fraction which contains around 70% food waste with a moisture content $> 80\%$. Currently, LHV of household waste falls below the required limit of starting WtE (i.e., $6\ MJ/kg$), but it 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 enough to adopt WtE incineration in terms of feasible LHV of waste from selected areas.

CHAPTER 6: GOVERNANCE FOR WASTE-TO-ENERGY FEASIBILITY

6.1 Context of Governance Study

Problems with waste quality and quantity (e.g., lower calorific value), poor plant management, and inadequate institutional arrangements were seen as reasons for waste-to-energy (WtE) incineration failure. This study contributed to clarify some critical feasibility issues on the *institutional and organizational arrangement* in the lens of *governance capability* (C. Liu et al. 2020) in Dhaka City by exploring key stakeholders with their expected roles to maximize WtE feasibility and minimize the impediments. However, governance capability is checked using four (4) different criteria (Mondal & Kitawaki, 2021) status is shown.

6.2 Methodology to Assess Governance Potential

Online (i.e., zoom) interview meetings were held in July 2021 with three (3) local government officials, one (1) JICA Expert considering their more than twenty (20) years of experience in SWM, environmental and energy regulation, and postgraduate education (e.g., M.Sc., Ph.D., and Postdoc). Interviews were done on the questions which were emailed before the separate meetings: (1) who the key stakeholders are, (2) roles of stakeholders, (3) types of coordination among them, (4) challenges to start WtE incineration, (5) ways to overcome them, (6) feasibility enhancement option considering *Governance* capability on four (4) criteria taken from literature of IGES (C. Liu et al. 2020). Meetings were recorded with permission and scripted, and then narrations are coded. After compiling all the narrations, the contextual summary is made. The framework of the survey is shown in Figure 6-1.

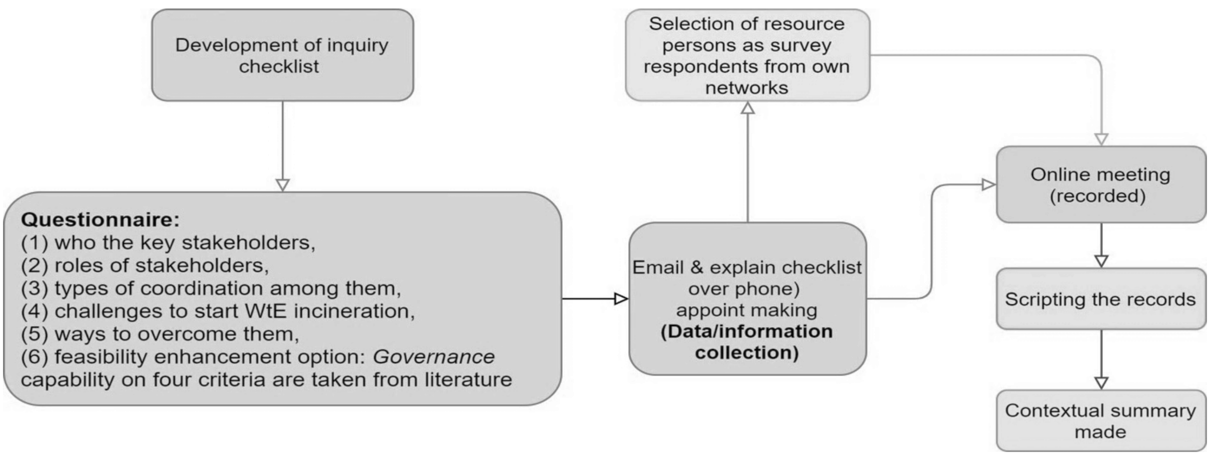


Figure 6-1 WtE feasibility assessment framework on governance aspect

6.3 Feasibility on Governance Aspects

There are many stakeholders for WtE incineration in Dhaka City who are directly and indirectly connected. Key stakeholders and their roles in the project planning, approval, implementation, and operation level might differ; however, they are summarized in Table 6-1. The functions of stakeholders might change based on the mode of operation of the project, such as DBO, BOOT etc., of PPP. It has been found that power authority (i.e., BPDB) and local governments (e.g., city corporations) both may take responsibility. However, unless city corporations take the responsibility of waste management including quality-waste feed (e.g., certain energy content, physical compositions etc.) in plants, the feasibility is deemed to be risky. PCSPs are important stakeholders to support waste collection. It is necessary to mobilize them through by proper training, registration and monitoring. PCSPs can help to improve waste quality. Due to the high moisture content and low calorific value, it has suggested in upper level plan to make the decision to design and operate various facilities together (i.e., the eco-town concept) that include composting, recycling centers, anaerobic digestion, WtE incineration etc. It will ultimately facilitate the feed of higher energy content waste to WtE incineration facility and thus maximize the feasibility.

Apart from the mentioned stakeholders, special entities (e.g., IPP, SPC, bilateral or multilateral organizations) may help to expedite the decision-making process of the stakeholders through technology promotion, investment support, facilitation, and advocacies. Though so many companies came to Dhaka City in the last decade for WtE, no one could show a functional infrastructure yet. No one even has carried out comprehensive feasibility or pre-feasibility analysis for Dhaka City except JICA Expert Team. However, detailed feasibility is yet to be studied.

Table 6-1 Important stakeholders and expected roles in WtE planning, approval, and establishment

LGD, MoLGRD&C	City Corporation (DNCC/DSCC)	PC, NBR, BB	BPDB, MPEMR, SREDA	DOE	Civil Society and others
Administrative support, Project ownership arrangement, Collaboration with other stakeholders	SWM system development, Land preparation, Supply of quality waste, Project Preparation, Waste supply, and land contract	PC: DPP Approval, Fiscal support, NBR: Monetary support, Customs structure, Tax incentives, BB: Low-interest loan	SREDA: Feed-in tariff fixation BPDB/MPEMR: Energy purchase, Forming framework for energy purchase, PPA	EIA approval, NOC, Environmental quality parameters set and auditing, waste quality standardization, try for CDM, JCM collaboration etc.	Environmental NGOs, Associations (market committees, organization of citizens, plant-site communities etc.), PCSPs

Note. LGD: Local Government Division; MoLGRD&C: Ministry of Local Government Rural Development and Cooperatives, DNCC: Dhaka North City Corporation; DSCC: Dhaka South City Corporation; PC: Planning Commission; NBR: National Board of Revenue; BB:

Bangladesh Bank; DPP: Development Project Proposal; BPDB: Bangladesh Power Development Board; MPEMR: Ministry of Power Energy and Mineral Resources; SREDA: Sustainable & Renewable Energy Development Authority; DPE: Department of Environment; PPA: Power Purchase Agreement, CDM: Clean Development Mechanism, JCM: Joint Crediting Mechanism, Source: authors' survey, PCSPs: Primary Collection Service Providers

The promoters of WtE (e.g., local governments, companies, manufacturers, investors) may collaboratively minimize these issues. The status of the *Governance capability* is shown in Table 6-2. The main challenges are lack of sufficient guiding documents in terms of regulations and specifications for WtE, no local private investors, stakeholders do not have a prior similar experience, no established similar bureaucratic process, lack of mutual understanding among the decision or policymakers etc. (Source: authors' survey).

Table 6-2 Governance characteristics (potential) on WtE incineration in Dhaka City

Governance capability indicators for WtE (C. Liu et al. 2020)	Status in Dhaka City
(1) WtE incineration is positioned in an upper-level plan	8th Five-year Plan of Bangladesh government has targeted 48 MW waste-to-energy within 2025 (GOB 2020). JICA expert team with DNCC and DSCC have formulated Master plans for SWM including WtE and Eco-Town concept.
(2) Local government leaders have willingness to consider WtE incineration	City authorities and senior officials are positive towards WtE. LGD formulated a working group and circulated priority instructions to DNCC, DSCC, CCC.
(3) Local government can obtain support from expert committees and consultants to implement projects	DNCC/DSCC are used to procure contractors' works and consulting services; however, they do not have prior experience in managing works or services on WtE but have taken training on WtE from JICA and MOEJ.
(4) Energy departments and electric power companies have developed technical standards and operations to sell and set the sales price of electricity	No Feed-in-Tariff (FIT) is fixed yet for WtE, and no mature market system established yet for WtE with technical standards and prices, but there is a mature market system for fossil fuel-based power that may help.

Note. GOB: Government of Bangladesh; CCC: Chattogram City Corporation; JICA: Japan International Cooperation Agency; MOEJ: Ministry of Environment Japan
Source: authors' survey meetings and literature reviews

Various possibilities can be explored and utilized to enhance feasibility and minimize the risks. For example, consideration of priority project with DBO, BOOT or through the Project Evaluation Committee (PEC) and the Executive Committee of National Economic Council (ECNEC) in the form of DPP approval may enable to avail various tax incentives, subsidies, inter-organizational coordination strengthening (e.g., environmental clearance, PPA, land acquisition, rationalizing project ownership etc.), which may contribute to the feasibility of WtE incineration in Dhaka City.

6.4 Conclusion on WtE Feasibility of Governance Aspect

There are issues of sufficient guiding documents in terms of regulations and specifications for WtE, no local private investors, stakeholders do not have a prior similar experience, no established similar bureaucratic process practiced, lack of mutual understanding among the decision or policymakers etc. Existing literature on WtE incineration feasibility mostly tries to justify the feasibility, but there is room to improve in maximizing the feasibility of G*overnance capability*.

It is possible to enhance the feasibility by trying to untap the hidden potential of *Governance capabilities* and get benefit from it. However, it is heavily driven by the local policies and practices but materializing the incentives as fiscal and monetary supports, policy supports, supports in PPA, FIT etc. will contribute attractively towards the feasibility of WtE incineration. It can be difficult for externals unless a government entity is actively involved in the study and conducts it itself. These incentive factors are likely to materialize through facilitation and discussion. Those can enhance the feasibility of WtE and contribute to sustainability of SWM.

CHAPTER 7: POLICIES AND PRACTICES OF PRIMARY COLLECTION SERVICE PROVIDERS

7.1 Overview of Policies and Practices of Primary Collection Service Providers

Primary Collection Service Providers (PCSPs) are the entities providing door-to-door waste collection service in Dhaka North City Corporation (DNCC) and Dhaka South City Corporation (DSCC) both hereinafter referred as “DCCs.” PCSPs are critically examined from different views: the policy instrument, ownership in Primary Collection Service (PCS) and their strength, weakness, opportunity, and threat (i.e., SWOT analysis).

The current waste collection rate in DCCs is about 80%. This is contributed by the primary collection service providers who collect waste from households, buildings, stores, and offices on a regular basis. To ensure the quality of collection so that the waste is suitable for incineration, PCSPs can play a significant role in many ways, especially where municipal vehicles do not have access or cannot collect directly. Therefore, the study of policies and practices related to their services is of particular interest for research.

The purpose of this chapter is to present PCSPs' issues assuming that it will be helpful in formulating future Solid Waste Management (SWM) projects, privatization in the SWM and thereby contribute to sustainability of SWM and the feasibility of waste-to-energy incineration (Mondal & Kitawaki, 2022).

7.2 Approach and Methodology to Study Primary Collection Service Providers

JICA Project Team surveyed PCSPs between December 2018 and April 2019. Data were collected by direct counting (e.g., head counts) methods in all 54 wards of DNCC and 75 wards of DSCC with a simple questionnaire comprising the information of number of rickshaw vans, hand trolleys, staff working etc., and data were validated with telephone interviews and meetings with PCSPs as well as municipal staff at ward, zone, and headquarters. Amount of waste in the primary collection rickshaw van was sampled and measured in weighbridge located in the landfill site. Summary data were published in New SWM Master Plans (DNCC and JICA 2019; DSCC and JICA 2019) and uploaded in Dhaka North and South City Corporation websites.

In addition, SWOT analysis was carried out. SWOT is an acronym for *strengths, weaknesses, opportunities, and threats* (Aich and Ghosh 2016). SWOT analysis is a commonly used methods to assess internal and external factors affecting a system or service positively and negatively (Eheliyagoda 2016). The elements of SWOT analysis include: (1) *strength* as resources or capacity of the entity that can use to achieve its objectives; (2) *weakness* as limitation, fault or defect in the entity or system that will keep it from achieving objectives; (3) opportunity as any favorable situation in the entity's environment and (4) *threat* as any unfavorable situation in the entity's environment that is potentially damaging to its strategy or service (Karppi, Kokkonen, and Lähteenmäki-Smith 2001; Ding et al. 2015).

Effort has been made to understand how PCSP capacities and roles can influence the feasibility of WtE incineration through SWOT analysis along with telephone and in person interviews.

7.3 Primary Collection Service Provider Status

The political hegemony as well as socio-political coercions have been commonplace events to own the PCSPs in many areas for the last two decades. Grass-roots political leaders, ward councilors or their allies directly or indirectly intervened to own or get a share of ownership or control the coverage areas using social power (Stangor, Jhangiani, and Tarry 2022) and political power (Parsons 1963). Initially community-based organizations, NGOs, typically involved in PCS; however, changes of different political regimes in the past have influenced a lot in changing PCSPs status. Efforts to shift the PCSPs from informal to formal sector were made by a JICA's technical cooperation project through inclusive and participatory permission and registration system.

Permitting and registration was introduced, monitored, and adapted between 2007 and 2013 as part of a technical assistance project. It was working well; however, authoritarian domination catalyzed by political power hampered its comprehensive approach. Currently many private companies are involved, many of old PCSPs took registration from different authorities as shown in Table 7-1. Hidden conflicts to get controls over PCSPs or the coverage areas are still observed. Many of the PCSPs are unregistered and there are cases of local political leaders have taken control of the PCS.

The actual number of working staff or workforce are not officially disclosed. Survey found, as shown in Table 7-1 is around 6,500 in 2018, however, national newspaper published the number is about 19,000 in 2021 when it was outsourced by private entities in DSCC covering expansion areas as newly added wards (Bangladesh Post, February 13, 2021). These non-municipal workforce number is almost double of municipal workforce which need massive support for capacity building to ensure quality service as responded mentioned.

Table 7-1 PCSPs status in numbers until 2018 (DNCC, DSCC and JICA, 2019)

Particulars	DNCC	DSCC	Particulars	DNCC	DSCC
Total PCSPs	454	246	Total workers	3,687	2,450
PWCSP enlisted	55%	40%	Supervisory staff	352	177
Total registered	382 (84%)	206 (84%)	Total Rickshaw vans	1,785	1,228
DCCs registered	340 (75%)	146 (59%)	Total hand trolleys	151	45
MoSW registered	16 (4%)	9 (4%)	Total trips of vans / day	3,570	2,456
UP registered	6 (1%)	12 (5%)	HH coverage / day	516,552	396,402
Other registered	20 (4%)	39 (16%)	Business coverage /day	14,501	8,951
No registration	72 (16%)	40 (16%)	HH coverage /day/van	298	330

Note. MoSW: Ministry of Social Welfare, UP: Union Parishad (Council), HH: Households, PWCSP: Primary Waste Collection Service Provider, Association of PCSPs in DCCs

7.4 Policies, Practices and Dilemma in Primary Collection Systems

The waste collection system in DCCs is two-sequenced, one is primary collection, and the other is secondary collection. According to the *Local Government* (*City Corporation) Act 2009 (amended-2011),* primary collection is the responsibility of waste generators, while secondary collection is the responsibility of DCCs (Figure 7-1).

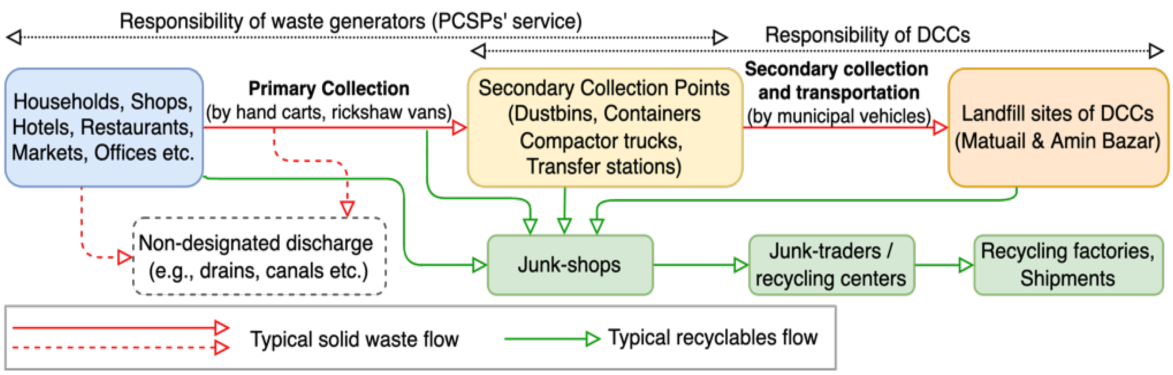


Figure 7-1 Two-sequenced waste collection in Dhaka City

Waste generators purchase the service from PCSPs, and this has become common. *SWM Rules (2021)* emphasizes segregated collection by the municipalities (i.e., DCCs), which has not been adopted yet. Thus, if PCSPs do not work on separate collection, it would be difficult to establish such a collection flow. Currently, generators mostly discharge mixed waste and PCSPs collect accordingly, and segregate it by themselves. PCSPs help to minimize the amount of waste that ends up in landfills by separating it and incorporating it into the recycling chain. They can also help to ensure the quality of waste destined for the WtE facility by minimizing objectionable waste, maximizing combustible fractions, and avoiding their mixing.

DNCC has made waste supply agreement to install incinerator with a company where mixed discharge is supposed to boost calorific value. On the other hand, officials are in dilemma to maintain the contract and follow the *SWM Rules (2021)*. Rules stipulate "non-recyclable waste of 1000 kcal or more should be used for conversion to energy …." And it also mentions "High calorific quality waste can be used directly for energy production." However, there is no clear categories of waste in the rules, and which may put the field work in confusion. Recently, in 2021, DSCC commenced allocating PCSPs on an open-bid basis. For the first time, each PCSP has begun a monthly contribution to DSCC, which is 0.1 million Tk (1US$ = 84.78 Tk, 2021). This allows PCSPs to collect a service fee from each household or business entities < = 100 TK /month. However, there are cases where the collection fee is > 100 Tk /month, the wages of workers are poor, there are no bidders, the allies of the local political leaders have won the contracts. Charging equal amount to each household or PCSPs' deposit (i.e., fee) are important controversies as households' number, living standards and revenues from different wards are not same.

Aiming to overcome such bottlenecks, DNCC is planning to float improved tender specifications very shortly considering more clear selection criteria, area-based service fee, more than one PCSP per ward, prioritizing who are already working with a set of performance benchmarks (e.g., regular and timely collection, no scattering of waste on streets, segregated collection, rickshaw vans should not be aesthetically objectionable, good attitude towards citizens etc.). However, this process is taking time as many of the public representatives (ward councilors) could not agree upon or approve it. Ward councilors are part of decision-making body within DCCs. JICA modeled the coexistence of PCSPs and FTFP (fixed-time-fixed-place) collection in areas where trash-compactor-trucks are accessible. The FTFP system does not require rickshaws, dustbins, containers etc. and has proven to be the cleanest and most efficient (Mondal, 2011). However, DCCs could not expand it because of the lack of a coordinating role among PCSPs, community, and DCCs. The self-interests of drivers and PCSPs were also the reason of the problem.

7.5 SWOT Analysis to Assess the Sustainability of Primary Collection Service

Though the roles of PCSPs are vital to keep the city clean and enhance collection rate but they are facing different issues like Organizational, Financial, Work Health Safety, Political / local power, Legislation, Technical / Logistics. And their power structures are also different to provide the services. Some cases they are immensely powerful and some cases very weak to exist. According to survey, to sustain the PCS system, ten (10) different strengths (internal factors) were identified, and the most important of which are recognized as *political power, social power, and business leadership.* In contrast, eighteen (18) weaknesses (internal factors) were discovered that are likely to affect the sustainability, where the most crucial factors are *lack of power factors (socio-political), limited workforce and operational logistics* (Table 7-2).

Table 7-2 Internal factors (strength and weakness) to be dealt with for PCSPs service improvement

Strength		Weakness	
(1)	Political power, social power, and business leadership power etc.,	(1)	Almost no safety gears (PPE), lack of working safety and health care facilities and such education,
(2)	Experience in discharging waste to the municipal system,	(2)	Lack of policy documents to govern itself and to be governed by DCCs (i.e., permission system needs improvement),
(3)	Availability of workforce	(3)	Almost no standard / benchmark / performance indicator,
(4)	Familiar to key officials and affiliated by grass-roots leaders (ward councilors, political unit leader, housing society, mosque management committee etc.),	(4)	Equipment is not standardized and certified,
		(5)	Small or individual PCSP are in very weak financial condition in terms of cashflow,
(5)	Have registration from city corporation,	(6)	Many rickshaw vans are old,
(6)	Belongingness of PWCSP foundation/association,	(7)	Sometimes weak harmonization between PCSPs and secondary waste collectors which affects working efficiency and time management,
(7)	Have adequacy operational logistics,		
(8)	High level community engagement and citizens participation track records	(8)	Difficult to manage time with manual rickshaw pulling,
(9)	Some PCSPs have operational reliability in terms of regularity, attitude, and complete coverage of assigned areas	(9)	Some PCSPs have limited number of workforce and operational logistics compared to the requirement,
		(10)	Some PCSPs have poor official or book-keeping knowledge so they have no documents or database,
(10)	Play key roles festival waste management	(11)	Insufficient payment to the driver or labor,
		(12)	Poor cooperation and communication between waste generator and collectors,
		(13)	Improper waste separation practices,
		(14)	Many of them are less interested in registration,
		(15)	Heterogeneity in service charge,
		(16)	Irregularity and insufficient coverage and lack of operational logistics,
		(17)	Not environment friendly waste collection equipment
		(18)	Difficult to travel to STS when the STS location is far

Note. PPE: Personal Protective Equipment, STS: Secondary Transfer Station typically known as Transfer Station

In terms of external positivity, eleven (11) opportunities (external factors) were classified, the most significant of which are the *great demand of services and people's willingness to pay.* And officials and PCSPs helped to identify eight (8) threats (external factors) that could hinder the sustainability of PCS, with the most serious factor considered to be *pressure from political leadership with intend to influence on organizational decision making.* Ideally, many of the internal and external dominating factors may not be consistent to comply the notion of good governance. They are listed in Table 7-3.

Table 7-3 External factors (opportunity and threat) to be dealt with for PCSPs service improvement

Opportunity	Threat
(1) Increasing demand due to huge population and its growth, willing ness to pay	(1) Lack of robust policy instruments to govern PCSP
(2) Service charge can be increased with the passage of time as economy grows	(2) Huge power pressure from local political leaders
(3) Still service is less than demand	(3) PCSPS may lose ownership or coverage areas with the change of political regime with the passage of time as history says
(4) Rapid and unplanned urbanization intensify waste generation	(4) Institutional malpractice by representative body
(5) Improvement of living standard	(5) PCSPs must manage local leaders and musclemen
(6) Economic development of the country	(6) Municipal staff and elected bodies like local councilor sometime disturb in form of taking control of service
(7) Concern of Prime Minister on SWM makes it National priority	(7) If formal and private companies work along with primary and secondary collection together existing PCSPs may lose business
(8) Recognition and introducing PCSP monitoring system from Dhaka City Corporation	(8) Existing SWM rules does not mention PCSP service clearly
(9) 3R concept are facilitating new opportunity for stakeholder	
(10) Economic prospect for SWM (resource recovery)	
(11) Employment opportunity to the marginals and others in need.	

7.6 Conclusion on Policies and Practices of Primary Collection Service Providers

PCSPs are the key players in municipal SWM in Dhaka City in terms solid waste collection amount and collection quality. To improve the sustainability of waste management in Dhaka City, there is an urgent need to pay special attention to the formalization of PCSPs through policy reformation or creations of bylaws, and performance benchmarking on how to govern.

The absence of regulations or policy documents leads to poor governance. This research identified the need for three (3) different improved regulatory documents: *(1) approval and management documents of PCSPs as an institutional document of DCCs, (2) monitoring and reporting management of PCSPs, (3) standard operating procedures of PCSPs with clear benchmark indicators that ensure waste quality, efficient collection, and customer satisfaction*.

The existing licensing/registration system addresses corrections related to transparent inclusivity options that ensure a level playing field for PCSPs. On the other hand, PCSP monitoring, and reporting are very outdated and poorly practiced. There is no user-friendly information technology that would allow for better and faster monitoring and reporting, problem identification, and problem resolution. PCSP operating procedures are limited to a simple list of activities that should be updated in terms of area (i.e., location) and charges (i.e., how much to charge the generator and how much to deposit at the DCCs). There are mobile banking users in almost every household, and many are using for utility bills and various other purposes; however, those can be practiced in the payment of waste fees. This could be a good step to formalize and improve the quality of service with transparency. Using IT to manage the work of PCSPs can improve transparency, ease of use, and accountability, contributing to better governance.

PCSPs are facing wide varieties of issues. Sociopolitical power plays key role in governing primary collection service. City authorities could not efficiently govern 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 absence of complaints. The mindset of some political leaders to be changed by sacrificing greed in some cases. It is inevitable to rationalize the performance indicators, service fees, and PCSP deposit fee, and try to continue the practice of good governance that can lead to efficient and high-quality collection that benefits waste incineration.

It has been shown that if PCSPs do not function sustainably and actively, it will be difficult to ensure the quality of the waste supply while ensuring the quantity. In this case, the feasibility of waste incineration and the sustainability of waste management will be at risk.

CHAPTER 8: WARD BASED APPROACH AND WASTE-TO-ENERGY FEASIBILITY IN DHAKA CITY

8.1 Background of WBA and WtE

DNCC & JICA (2019), DSCC & JICA (2019) have proposed Eco-town concepts for intermediate waste treatment in the New Clean Dhaka Master Plans for Dhaka North and South City. Waste-to-energy and other forms of waste treatment have been prioritized and outlined in this concept (Table 8-1).

Table 8-1 Proposed intermediate waste treatment options in Eco-town for Dhaka City

Treatment option	Incineration	Composting	Biogas	Material recovery	Recycling / Conversion
Waste types	High heating value (e.g., high combustible)	Vegetable, (e.g., green market)	High moisture, (e.g., restaurant)	Recyclable materials (e.g., dry recyclable)	Construction & demolishing waste

Source: Adapted from New Clean Dhaka Master Plans 2018-2032, DNCC & JICA (2019), DSCC & JICA (2019)

The 8th Five-Year Plan of the Government of Bangladesh (2020) calls for 48 MW renewable energy to be developed from WtE projects by 2023. The Bangladesh Power Development Board (BPDB), along with various municipal corporations, has begun to rollout of WtE projects. However, no WtE project has yet been fully realized in terms of construction or commissioning. Meanwhile, agreements were signed with two municipal corporations and two companies, as shown in Table 8-2. A sound SWM system is required as a precursor to the implementation of WtE. In this context, an attempt is made to investigate how the existing SWM can contribute to feasibility. Under the name of Ward Based Approach (WBA), a combination of approaches has been proposed and tested within the existing waste management system to improve the quality and efficiency of waste management in Dhaka City. This prompted the study to explore how WBA can support the feasibility and sustainability of waste incineration. Assessing the feasibility of waste-to-energy incineration plants involves a variety of criteria, parameters, and indicators. However, this chapter investigates how WBA play roles or likely to play roles for the feasibility of WtE through the functional elements of WBA (Mondal & Kitawaki, February 2023).

Table 8-2 Planned waste-to-energy projects in Dhaka North City and Narayangonj City

City	Agreement date	Land (acre)	Waste (t/d)	Electricity (MW/d)	Purchase rate per unit $(kW \cdot h)$		Purchase (years)	Company	Reference
					US cents	BD Tk			
DNCC	Dec 1, 2021	30	3000	42.5	21.78	18.295	25	CMEC	Daily Star (2021)
NCC	Sept1, 2022	10	600	6.0	20.91	20.00	25	U&D	New Age (2022)

Note. DNCC: Dhaka North City Corporation; NCC: Narayangonj City Corporation, t/d: Metric ton per day; MW/d : Megawatt per day, $kW \cdot h$: Kilowatt-hour.

8.2 Study Context of WBA for WtE

Research questions for studying WBA towards WtE

This chapter has solidified understanding on WBA contribution towards WtE feasibility by examining several questions. Such as what is WBA? What are the roles of WBA and how do they contribute to the feasibility of WtE? How does WBA work? Can WBA play a role in the feasibility of WtE? What are the sustainability issues of WBA? What conclusions can be drawn to support WBA in terms of WtE feasibility?

Hypothesis to study WBA toward WtE

An attempt was made to justify the hypothesis that WBA can positively influence the feasibility of WtE if WBA is properly implemented as part of the DCCs' waste management system. Proper implementation means that WBA is integrated with delegation of authority, budget allocation, capacity building, knowledge management, human resource support, etc. as routine tasks of the waste management departments of the DCCs and is concurrently functioning.

Objective of the study of WBA

The objective of this study is to understand the role of WBA in WtE feasibility. It aims to understand how the various components of WBA function and can influence the feasibility of WtE. WtE refers to the waste-to-energy options proposed in the SWM Master Plans, which primarily include incineration and biogas (DNCC & JICA, 2019; DSCC & JICA, 2019).

8.3 Conceptualizing Ward Based Approach

Dhaka City Corporations (DCC) have developed, tested, improved, and expanded several novel decentralized solid waste management practices. These concepts are referred to as the Ward Based Approach (WBA). The concept of WBA emerged from a development study during the formulation of the first Clean Dhaka Master Plan (JICA, DCC, 2005) and matured with the technical assistance (i.e., collaboration) projects supported by the Government of Japan from 2007 to 2013 and from 2017 to 2022.

WBA is a systematic framework of planning, organizing, and executing field works of MSW management in collection phase (i.e., grass-roots level, community level or ward level). WBA works through the strengthening horizonal (i.e., parallel) and vertical (i.e., hierarchical) management tiers where most of the activity initiatives are expected to be bottom up and budgetary and human resources support are mostly top-down but demand-driven. Mechanisms of voluntarism, citizens' engagement, flexibility, and resources mobilizations scopes are there. There are several works published by different authors in different languages about WBA. WBA has also been applied in Africa, and comparative studies have been carried out (Kodani et al., 2020; Oseko, 2020; Oseko & Ishii, 2012, 2016; Sato & Okamoto, 2007). And latest status of WBA is mentioned in *New Clean Dhaka Master Plan 2018-2032, Waste Reports,* DNCC & JICA (2019), DSCC & JICA (2019).

The WBA has four (4) approaches with various scopes of work in the two-sequenced collection system of Dhaka City as shown in Figure 8-1. WBA-1 is concerned with building a decentralized organization for SWM officially through the construction and operation of ward offices. WBA-2 serves to improve the working environment of waste workers by promoting occupational health and safety and work pride. WBA-3 advocates for participatory, community-based waste management. This is a community-centered approach to local waste management planning in consultation with three (3) stakeholders (namely DNCC/DSCC, PCSP, and community). WBA-4 allows for the modernization of the waste collection system through the implementation of a new compactor truck coupled with fixed time, fixed place (FTFP) system and the improvement of the existing system. Fixed time and fixed place systems are described in literature such as DSCC & JICA (2021), Mondal (2011) a clean system that does not require municipal bins/containers or secondary collection points in the system but can transport waste by vehicle from the nearby point of generation to the landfill. There are synergistic effects of WBA in improving local sanitation, job creation, governance, etc.

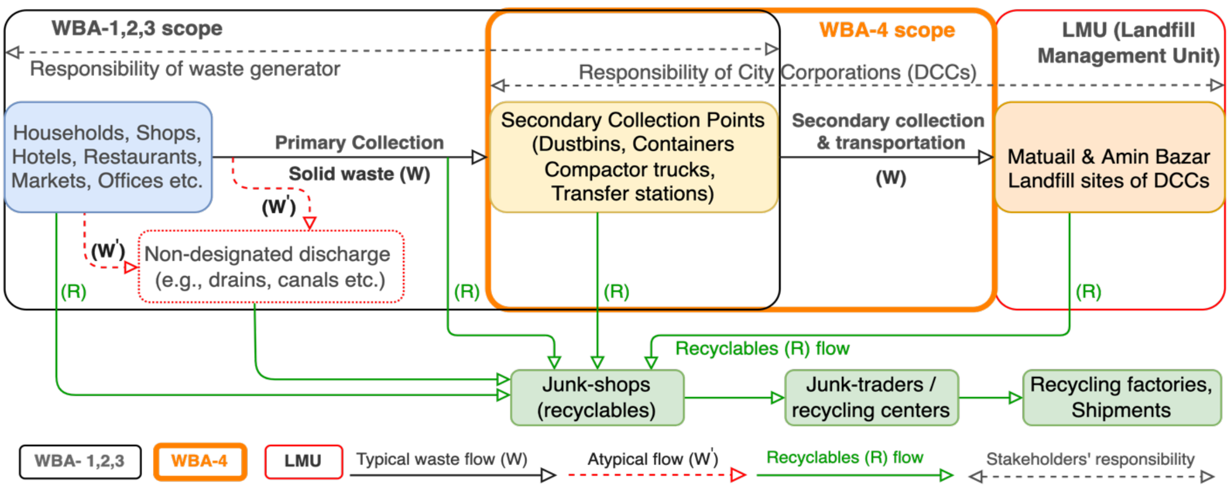


Figure 8-1 Two sequenced waste collection and scope of WBA in Dhaka City

Source: Adapted from Mondal & Kitawaki (2022), DNCC & JICA (2019), DSCC & JICA (2019)

The concept of WBA in terms of theme and components is shown in Table 8-3. There are hard and soft components of WBA. Hard components of WBA are physical facilities (e.g., ward SWM office) and operational logistics (e.g., collection vehicles, safety equipment, etc.). And soft components refer to capacity building, planning, information management, etc. The typical functional elements, outcomes, and contributions to the global goals (i.e., SDGs) are shown in Figure 8-2 in the form of a mind mapping.

Table 8-3 Concept of Ward Based Approach (WBA)

Approaches	WBA-1	WBA-2	WBA-3	WBA-4
Theme	Institutionalize the SWM by ward SWM Offices through decentralizing activities from headquarter to field level	Waste workers' work environment and pride improvement through safety and sanitation	Community based participatory SWM	Collection system modernization and improvement
Hard component	Renovation, construction of ward SWM offices equipped with facilities of toilet, storage, meeting, furniture, notice board, bulletin board, and utilities (water supply, electricity)	Provision, arrangement, supply, usage of safety gears (e.g., masks, hand gloves, apron, gum boots, etc.)	Special cleaning campaign, leaflets, posters, banners etc.	Demolish dustbins, remove containers and FTFP* promotion
Soft component	Ward SWM data management, reporting document preparation, bookkeeping, community meetings, trainings / workshops arrangement, communication, and information point	Cleaners' workshops for occupational health and safety, empower safety and sanitation committee	CUWG training, Community Action Plan (CAP), miking, rally, cultural program etc.	Drivers' training, community, PCSP and DCC meeting for collection planning

Note. FTFP: Fixed Time Fixed Place collection system, DSCC & JICA (2021), Mondal(2011); CAP: Community Action Plan, Prashar et al., (2013); Source: Adapted from interview survey (2022)

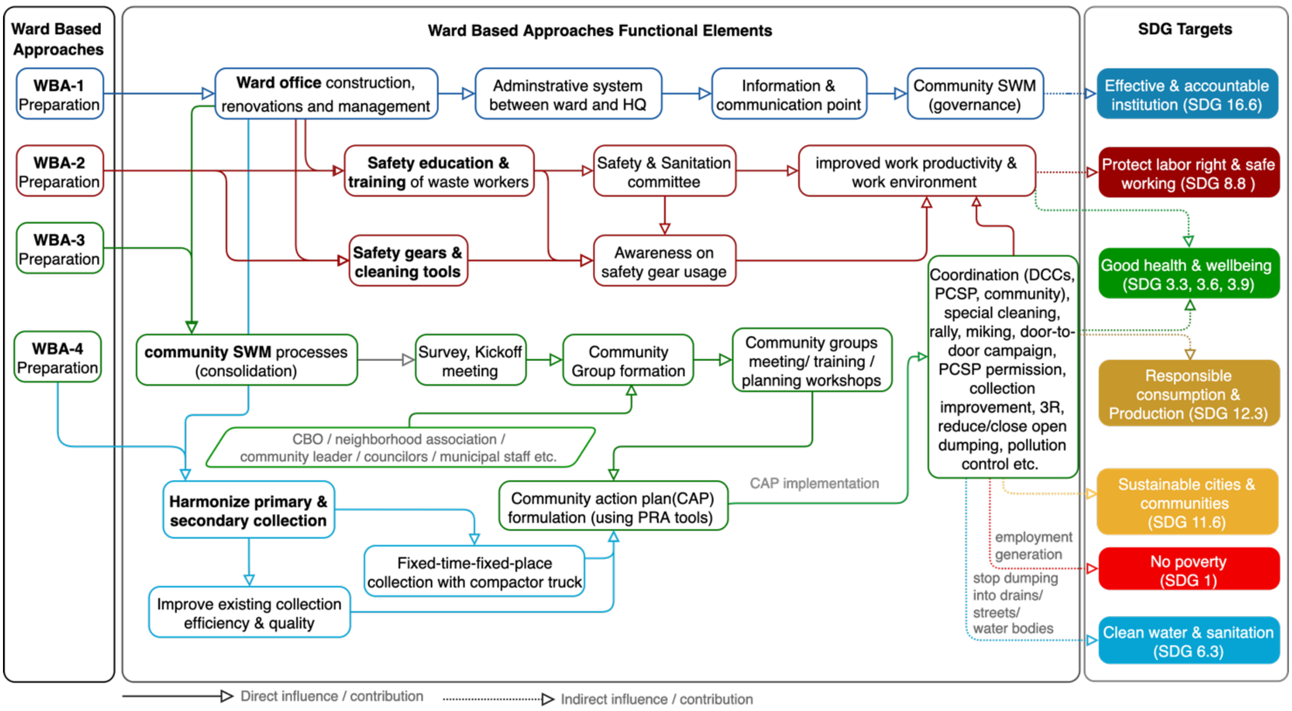


Figure 8-2 Mind map of the synergic effects of WBA activities towards SDGs
Source: authors' survey (2022).

8.4 Brief Scoping Review of WtE Feasibility Studies

This review is mostly taken from Chapter 2, and to make this chapter stand-alone, duplication is made. WtE feasibility has been looked at in different angles and different perspectives as found in existing literatures. World Bank (1999) suggested seven (7) aspects in technical feasibility study which includes *Operation and maintenance; Environmental impact and occupation health.* And these are further divided into thirty-two (32) key criteria for assessment and one of which is calorific value of waste should be $\geq$ 6 MJ/kg in all seasons which it is related to waste quality and collection, where WBA may play role. US EPA(2012) has seen following six (6) factors contribute to the failure or non-feasibility incineration-based waste-to-energy plants: (1) Inability or unwillingness to pay the full treatment fee, insufficient revenue to cover loan and O&M costs; (2) Lack of convertible currency to purchase spare parts; (3) O&M failures (e.g., lack of skilled workers);(4) Problems with the waste quality and quantity (e.g., calorific value); (5) Poor plant management, and (6) Inadequate institutional arrangements. Therefore, they are needed to be examined critically while carrying out feasibility studies. Song et al., (2017) carried out PESTEL analysis for systematic analysis of macro-environment in China citing several others from different regions of the world. PESTEL framework guides a comprehensive analysis considering six (6) domains such as Political (e.g., legislation, policies), Economic (e.g., major sources of income, investment intensity, investment mode, subsidies from government, energy price, scale of investment etc.), Social (e.g., public concern, culture, solutions to opposition), Technical (e.g., waste composition, heating value, grate or fluidized type, technique with or without axillary fuel like coal), Environmental (e.g., pollution and environmental risk control, environmental protection expenses) and Legal aspects (e.g., industrial, economic, technological, and environmental protection legislation and policies).

Mutz et al., (2017), published from GIZ GmbH coined a decision matrix for developing and emerging countries with twelve (12) essential parameters with forty-eight (48) criteria (i.e., each parameter has 4 distinguishing criteria) to consider local context for justifying pre-conditions for feasibility study. However, more advance evaluation is suggested after initial feasibility assessment. The 12 parameters for feasibility checking are (1) Overall level of waste management; (2) Composition of waste; (3) Calorific value of MSW for thermal processes, organic content; (4) Suitable quantities of waste for WtE; (5) Efficient operation of waste facilities; (6) Additional transportation time and distance for MSW to WtE plant; (7) Marketing and/or final disposal of process residues; (8) Legal framework & environmental requirements for WtE; (9) Financing the management of MSW; (10) Access to foreign currency; (11) Access to energy end-users from WtE; (12) Incentives for low carbon energy generation. IGES, IETC and UNEP (2020) mentioned twenty-four (24) key evaluation criteria at the planning stage of appropriate technology which are composed on six (6) sustainability aspects: (1) **Social**, (2) **Public awareness and residents' cooperation,** (3) Institutional, (4) **Governance capability**, (5) Finance and (6) Technological. This is the latest guiding document for planning and feasibility aspects of WtE incineration, that tells mandatory criteria under social aspect is specific population and appropriate system of waste collection management.

From the scoping review it has been found that social aspect with citizen awareness and engagement are important item in WtE feasibility. Another crucial point is waste calorific value should be in certain level (6 MJ/kg) which may be achieved through proper segregation, controlled collection where community participation is necessary. This chapter seeks to evaluate how WBA can play roles to enhance feasibility options of WtE.

8.5 Methodology to Evaluate Roles of WBA on WtE

8.5.1 Study area

The study area is Dhaka City, the capital of Bangladesh. There are two city corporations (*viz.* DNCC & DSCC). The basic SWM information can be found in different literatures, a summary is shown in Table 8-4. Dhaka City has population more than 12.4 million with density of population over 40,000 inhabitants per square kilometer which makes it the topmost densely populated cities of the world. As shown in Figure 8-3. field level SWM functions are managed by **ward** with the help of municipal cleaning workers, primary collection service providers (PCSP), vehicle drivers, supervising staffs e.g., conservancy inspectors (CI), conservancy officers (CO) etc. Wards are the smallest

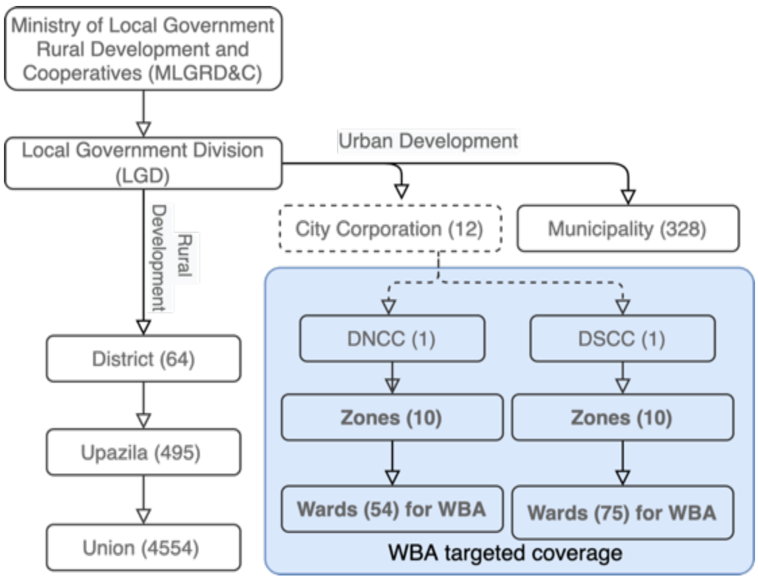


Figure 8-3 Position of ward and coverage of WBA

administrative unit of local government typically governed by ward councilors who are elected by public representatives. There are 129 wards in DCCs. The position of ward and coverage of WBA is shown in Figure 8-3. The numbers in () are the organizational number taken from Bangladesh National Portal (2022).

Table 8-4 SWM information in 2019-2020, if not specified differently, updated form Mondal & Kitawaki (2022)

Solid Waste Management Profile (summary data)	**DNCC**	**DSCC**
Total jurisdiction area, km^2	196.23	109.00
Population in million	6.10	6.30
Average population density, people/km^2	31,488	57,798
SWM Budget (Million BDT)	3,467	5,888[a]
Number of zones	10	10
Total wards (old/new[b])	54(36/18)	75(57/18)
Estimated waste generation, t/d	3,433	3,256
Household waste, t/d	2,094	1,947
Business waste (office, market, hotel, restaurant etc.), t/d	755	1,081
Street, construction waste, t/d	584	228
Household waste generation rate, gm/person/day (income level)[c]	496(high), 483(medium), 193(low)	
Number of landfill site (name of landfill site)	1 (Amin bazar)	1 (Matuail)
Average collection rate	80%	78%
Number of SWM offices (WBA-1)	22	27
Cleaners workshop and safety instruction in 2019-2021 (WBA-2)	59	27
Separation of waste at sources in Jan 2021- May 2022 (WBA-3)	2	2
Number of waste collection vehicle (WBA-4)	163	307
Number of compactor truck (WBA-4A)	46	58
Heavy equipment	16	41
Secondary collection modes	CT, OT, CC	CT, OT, CC
Average landfill disposal, t/d	2,750	2,540
Landfill operation cost, BDT/t	244	426
Number of cleaners (average workers/day)[d]	3,914 (self, 2,479; outsourced, 1,435)	5,168

Note. 1 US$ = 84.78 BDT, CT: Compactor Truck, OT: Open Truck, CC: Container Carrier, [a]information is fiscal year 2017-2018, [b]coverage areas added in 2016, where regular waste collection and management are yet to start fully, [c]waste generation rate for both city corporations are assumed to be save based on sample average of characterization survey, [d]all paid by DCCs.

Source: Adapted from *Waste Reports 2019-2020* by DNCC & JICA (2021); DSCC & JICA, (2021), *New Clean Dhaka Master Plan 2018-2032* by DNCC & JICA (2019), *New Clean Dhaka Master Plan 2018-2032* by DSCC & JICA (2019), Mondal & Kitawaki (2022)

8.5.2 Qualitative data collection

A conceptual framework of the study with data collection is shown in Figure 8-4. Respondents have been chosen from the careful considerations of the most relevant, experienced, knowledgeable, and skillful officials of the sector. Profiles of the respondents briefly articulated in the Table 8- 5.

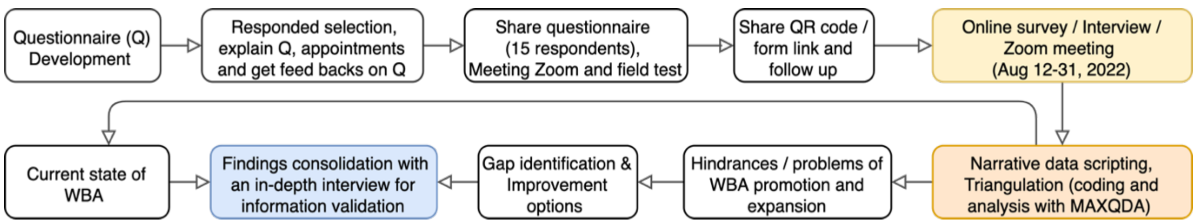


Figure 8-4 Conceptual framework of WBA study

Table 8-5 Profile of the respondents for WBA study

Respondents	Credentials (Affiliation) in Survey Period	Working Experience (year)	Educational Qualifications	Number
WBA model developer	International Consultant	40	M.Sc.	1
Retired DCC's Official	National / UN Consultants	30-40	M.Phil., Ph.D.	2
DCC's WBA staff	Local government employees	20-35	MBA, B.Sc. Eng., B.A.,	3
National SWM staff	Private company	5	B.Sc. Eng.,	1

Note. M.Sc.: Master of Science; M.Phil.: Master of Philosophy; Ph.D.: Doctor of Philosophy; MBA: Master of Business Administration; B.A.: Bachelor of Arts; B.Sc. Eng.: Bachelor of Science in Engineering

As shown in Table 8-6, Questionnaire has been designed based on several investigations' areas of WBA: (1) how components of WBA's contribute WtE feasibility (Questions No. 1 to 4); (2) assessment of current state (Questions No. 5); (3) ways to improve sustainability (Questions No. 6 to 9), (4) likeliness of WBA's role on WtE feasibility (Questions No. 10); (5) waste separation status (Questions No. 11 to 14); (6) issues and hindrances for WBA promotion (Questions No. 15); (8) knowledge, skills and motivational suggestions for WBA promotion (16-20).

Total twenty (20) individual questions have been put forwarded through three (3) answering patterns to scan the respondent's observations and experiences on WBA phenomena. Response taking patterns were as follows: (1) open ended by typing or recording voices as statement of facts with numbers, (2) 4 x 5 matrix-Likert scales, e.g., *4 WBA (1,2,3,4) x 5 functional status (non, slightly, functional, as expected, excellently),* and (3) multiple choice, e.g., *yes*, *no*, *may be*. All the questions and explanatory notes, etc. were in both in native language and English. Survey forms were developed by Microsoft Forms, and accessible from mobile and PC. As all respondents did not answer in Forms, interviews and communications were via email, Zoom, WhatsApp, online voice recording, and Facebook Messenger multiple times for a respondent for deep understanding against the topic questions.

Table 8-6 Online survey questionnaire

No.	Question	Answering Pattern
1	How can a ward office (WBA-1) help the feasibility of WtE?	Open ended, narrative
2	How can the work of waste workers (WBA-2) help the feasibility of WtE?	
3	How can community-lead participatory SWM (WBA-3) help the feasibility of WtE?	
4	How can improving /modernizing collection (WBA-4) help the feasibility of WtE?	
5	What is your assessment of current WBA functional status?	4 x 5 Matrix-Likert scale
6-9	Please list up few points to boost sustainability and function of WBA 1,2,3,4	Open ended narrative
10	How likely is the role of WBA in WtE feasibility?	4 x 5 Matrix-Likert scale
11	In how many wards does your CC have ***waste separation at the source***?	Number
12	In how many wards *segregated* ***primary*** *collection* started in your CC?	
13	In how many wards *segregated* ***secondary*** *collection* started in your CC?	
14	Do you think waste separation is important for waste to energy?	Multiple-choice
15	Please list up issues/hindrances on WBA 1,2,3,4, implementation, and expansion	Open ended, narrative
16-19	Please recommend some knowledge & skills required to implement WBA-1,2,3,4	
20	Please recommend some motivational strategies for WBA-1,2,3,4 implementation	

Note. Slightly paraphrased (shorted) from original Bangla version keeping the senses same

8.5.3 Data analysis methods

Because the data came from different respondents and in different forms (e.g., short, or long texts, voice recordings, zoom recordings), the first step was to generalize by simply writing them down. Then, the information was coded and further classified based on the raw contextual data. Triangulation is employed to obtain a comprehensive and deeper conceptualization of the WBA phenomenon and its connection to WtE, informed by respondents' observations and experiences with MaxQDA.

8.6 Results and Discussions

8.6.1 Decentralization of SWM by ward office (WBA-1) and WtE feasibility

Ward SWM office helps citizens get involved in local SWM and tries to solve problems locally. CI is a steward of the office. It can be considered as a common platform for participatory SWM at the grassroots level. The waste collection and cleaning activities are carried out daily by thousands of touch-labors. A significant number of them are women. A community level office (i.e., ward SWM office) helps to record their presence, hold meetings, store cleaning equipment, set up toilets, provide shelter in extreme weather conditions, etc. It also serves as a source of information and data for the community SWM and can control the quality of waste entering the incinerator through regular monitoring by CI and the cleaners' supervisor (called *Sardar*).

Some offices under WBA-1 keep the information of waste (e.g., trips/day, tons/day etc.), vehicles (e.g., open truck, compactor truck etc.,), cleaners (e.g., contact, attendance etc.), shops/market representees contacts, community/housing/neighborhood association leaders contacts, ward councilors / secretaries contacts, information, PCSP (Primary Collection Service Providers) information etc. The respondents suggested that strategic discussions are possible through information sharing, consensus building with citizens, political leaders, recycling facilities from ward offices to ensure waste quality and quantity, recycling activities, etc. Political leaders can use the ward SWM office to sensitize and mobilize citizen. The recycling pattern within the ward (i.e., community level) is mostly dirty without health-safety consideration. Ward office can take the roles for gradual shifting to quality recycling or environmentally sustainable recycling. Megacities (e.g., Tokyo) have ward offices to control and manage waste management including incineration plants with all facilities and arrangement for citizen e.g., environmental education, meeting place, social safety, and services etc.

(personal communication, August 11, 2022). Some categories of waste for incineration plant to be emphasized and some to be avoided which needs constant monitoring and regular consultation, education by municipal staff towards citizen / community association, vehicle drivers, primary waste collectors etc. Therefore, CI should play a role as focal point for information, education and communication from the common platform, ward SWM under WBA-1.

The number of SWM offices (as of 2021) is 23 (out of 54) in DNCC and 28 (out of 75) in DSCC, which has proven to be insufficient to provide improved SWM services (i.e., physical and governance components) and to monitor waste quality, community engagement, etc. And the ward office should not only be used for cleaners, but it needs to be more accessible, and provisions made for community meetings, children's SWM education, it said. Ward office functions should be strengthened (e.g., through staff and resources) and expanded (e.g., by locally solving SWM issues, ward level management of vehicles and cleaners, campaign and education management, residence registration, etc.), as is the case in other developed economies, such as the 23 wards of the Tokyo Metropolitan Government.

8.6.2 Waste workers work environment, pride, safety (WBA-2) and WtE feasibility

WBA-2 addresses the work environment, safety, and productivity of the four (4) types of waste workers, i.e., (1) street, sidewalk, foot-over bridge, and market cleaners (2) drain cleaners, (3) primary waste collectors, and (4) vehicle crews. Approximately 9000 cleaners work daily under the DCCs. In addition, about 6000 waste collectors work daily for Primary Collection Service Providers (i.e., non-municipal entities). They are the touch-labor and directly exposed to waste and contribute to increase the waste collection rate and control the waste flow. They are responsible to enhance the quantity of collection and increase the informal recycling amount. Efforts need to be made to ensure their waste quality awareness which should be going to the plant, and which are not as for example, vehicles with fallen trees, leaves, garden trimmings have higher energy content they should be going to the incineration plant on the other hand construction waste or drain cleaning waste should be going to the landfill site without mix together. Similarly, restaurant waste with food content and moisture content may go to anaerobic digestion plant while the vegetable waste from green kitchen market can go to straight way to composting plant without any mixing. Such information and education are necessary under WBA 2 to the waste workers through proper signs and symbols of waste as respondents mentioned. However, according to the survey, 59 and 27 cleaners' workshops were held in DNCC and DSCC respectively between 2019 and 2021.

Four (4) main insufficiencies to overcome: *the number of cleaners' workshops compared to the wards, the availability and use of safety equipment, knowledge on signs and symbols of waste, the formation and activation of safety and sanitation committees* (i.e., consisting of representatives of the cleaners and municipal staff in each district). Although cleaners are part of the government staff and do a noble job, their work is still neglected by many as lower caste work and not much is done for their work pride, except for the few workshops and the recent allocation of new housing and health facilities.

Respondents also suggested moving away from the traditional management of cleaners at the organizational level. They can be provided with more welfare (i.e., insurance, housing, health care, etc.) to achieve higher productivity under privatization with almost no cost increment. Entrepreneurship, microfinance, cooperative, knowledge, motivation, capacity building models, etc. can be associated with them to enable them to make a better living. In such case DCCs can channel corporate social responsibility (CSR) funds from business communities, if feel to have.

8.6.3 Community based participatory SWM (WBA-3) and WtE feasibility

WBA-3 deals with community level SWM planning and implementation through issue analyses workshops and action planning in the form of CAPs (community action plan). This platform is considered as the most important channel to disseminate information to community level households within a ward. WtE requires strong community participation for new collection system such as plastic / paper bag collection, segregation at source, to face anti-incinerator movements etc. Improve waste treatment might require increase service charge or revised tax tariff which require consultation, piloting etc. where WBA 3 framework can help to do this. On the other hand, massive environmental education is necessary for waste categorization and such activities can be incorporation in CAPs utilizing PRA tools, as postulated by Prashar et al. (2013) and Chambers R. (Chambers, 1994a, 1994b).

8.6.4 Modernizing and improving collection system (WBA-4) and WtE feasibility

Under WBA 4, a fixed time, fixed place (FTFP) collection system has been introduced in many places in Dhaka City, replacing removable containers and dustbins under WBA-4.

And FTFP does not require the rickshaws of PCSPs. Finally, PCSPs feel their business is threatened, and although FTFP is a cleaner and more efficient collection, it could not be well advertised and scaled up. An improved and efficient collection system is a prerequisite for continuous and quality waste supply to WtE plant. According to the survey results, this could only be possible with compactor trucks that can leach additional moisture or protect waste from rainwater and easily dump it into the incinerator's waste bunker. At DNCC and DSCC, there are only 46 and 58 compactor trucks of different capacities (i.e., tons) that are unlikely to be sufficient to consistently feed at least 500 tons per day unless they make more than 2 trips per day and are assigned to specific areas to collect high-value waste. Existing cases of allocation of vehicles hinder compliance with the collection schedule due to cross-border collection in several wards but most respondents mentioned that vehicles should be allocated against each ward without being moved to another ward which improves the capacity of a ward in terms of decentralization of governance.

8.6.5 Factors hindering WBA functions and feasibility of WtE

The seven (7) major factors are believed to be hindering effective functioning of WBA or general SWM, thus will hamper WtE sustainability unless measures are undertaken in DCCs: *(1) lack of human resources, (2) poor knowledge management, (3) weak budget utilization potentials, (4) modest stakeholders' collaboration, (5) irrational organizational focus, (6) lack of good governance, and (7) improper collection.* If these factors are not carefully managed, the WBA may not function effectively and may not contribute towards WtE feasibility effectively.

There is an urgent need for enough knowledgeable, capable, and motivated employees. And the number of employees is far less than the number of officially authorized positions. There are not enough qualified graduates because the base salary is low and the educational qualifications of many are low particularly in the Conservancy Wing of waste management department. There is no clear career progression when compared to other sectors or government agencies such as police, defense, etc., while the workload for Conservancy Inspectors (CI), Conversancy Officers (CO), etc. is quite high with various risks to implement basic WBA activities. There is not much motivation or incentive. There is a need to train newly hired senior officials and field staff. One of the most important lessons learned is that one CI alone is not sufficient to efficiently carry out all WBA components in a ward. He should be assisted by another CI from other ward or CO along with senior officials (from headquarters).

Knowledge management (KM) and KM system as reviewed by Alavi, M., Leidner, D.E. (2001) are mostly absent and officially they are not fully established yet in DNCC and DSCC's waste management. They are being practiced inadequately by the organization due to lack of KM culture and infrastructures. Respondent mentioned that it is not only in SWM sector but its common in most of the sector and government offices in Bangladesh. The most crucial problem is temporary departmental heads of Waste Management Department (WMD) mobilized from other department of separate organization who typically do not have proper SWM system design or service delivery experiences in a megacities local government setup. Though it does not take much time to conceptualize the SWM system and service delivery mechanisms and routine duties as *explicit knowledge*, but they need to be back to original place mostly before making a significant contribution to take the SWM to the next level in both *governance* (e.g., *SWM service users & providers inclusivity*, sound institution and proactive policies. and financial sustainability) and *physical* (e.g., collection, 3R, and treatment & disposal) components by creating *tacit knowledge*. SWM components are simplified under the concept of integrated SWM by Wilson et al., (2014). It has been responded that there is "very minimum culture," and "limited administrative process" for promoting *knowledge management* or maintaining *corporate memory*. Through on the job training (OJT), particularly technical assistance projects of JICA or other donors may help as mentioned by some respondents.

Though there are *allocated budgets* but due to lack of demonstrated skills and complicacies in cost adjustments a vast majority of the community SWM budget (WBA) are not utilized. The vast majority of the non-engineering wing staff (e.g., CI, CO) felt adjustment of the money is complicated and time consuming. However, on the other hand, engineering wing staff feels opposite as its common and easy. Construction, procurements etc. are routine job of engineering staff already mainstreamed, however, conservancy wing staff are still not confident, skillful, and interested enough on the spending public money.

Stakeholders' collaboration for research and development is almost missing. There is no mature or officially established collaborative practices among universities, government (i.e., DCCs) and private organizations (e.g., industries, NGOs), which is mostly common in most of the developed economies as authors found. External sources mobilization in terms of corporate finance (e.g., donation for cleaning or safety equipment or materials) and human recourses (e.g., volunteers, civil society) are existing but their volume is limited and materialized on the specific occasions only (e.g., for festival waste management, slaughter waste or cattle market management etc.). Responded mentioned these resources coverage is possible to be expanded in other sectors as for examples: procuring ward office furniture (WBA-1), environmental education (WBA-3), cleaners training and safety gears procurement (WBA-2), primary collection improvement (WBA-4). *Organizational focus* is much on engineering rather than management which is very short-sighted approach. There is lack of combination and *longer-term plan and rolling plan* such as time-bound target-oriented plan for daily execution to achieve long term goal. Most of the works are *event based (i.e., temporary)* not routine or regular basis to have long term impact, like special cleaning, environmental education etc. There is much work on the *regular cleaning* but *little work to minimize the cleaning needs* such as how to ensure not to make the roads or drains dirty, how to stop illegal disposal etc. And efficient and modern collection vehicles and equipment are inevitable as operational logistics. The purchasing officials needs to pay special attention towards their quality, operation, and maintenance. However, there are records that couple of compactor trucks, mechanical street sweeper could not last long and within a noticeably short time, they were damaged. There is not yet zone or ward wise plan connecting the central SWM master plan to the city.

There is lack of *good governance* in many aspects such as accountability, transparency, rule of law, inclusivity, participation etc. However, survey identified priority issues are to have more official order for grass-roots official to implement WBA, gap of experience sharing in both directions of horizontal (i.e., parallel or peers) and vertical (i.e., top down or bottom up) communications among field level and decision-making level official. Unavailability of WBA related previous records (i.e., list of WBA activities, challenges to implement activities, learnings from those activities etc.,), Resource and reasonability allocations are not yet clear and rational to implement all WBA components. There is lack of information discloser system to community level about WBA components.

Improper collection exists in Dhaka City in terms of segregated collection. Majority of the respondents mentioned the necessity to segregate waste and follow the SWM Rules (SWM Rules, 2021) about segregated collection, however, still there is mixed discharge and informal separation and subsequent collection. Rules notifies to arrange different collection facility based on types; however, it may take time to realize such option. The current stage of segregation is done for *monetary gain* by the marginal people of the society; but it needs conversion to *environmental gain* by the gross people of the society through scaling up of segregation at source.

8.6.6 WBA sustainability factors

Assuming enough staff are being recruited, considering that there are other sustainability factors which need to be nurtured more to activate and scale up WBA, they are summarized in Table 8-7. WBA sustainability relies on five (5) thematic factors, which are as follows: (1) *Knowledge & skills for WBA, (2) Motivation, (3) Articulated guiding aids, (4) Key stakeholders' engagement, (5) Governance strengths.*

Knowledge means the concepts or ideas or information for the WBA topic(s) based on the practical training (e.g., learning) and hands-on work (e.g., experience) of city staff. And skills are expertise developed through demonstration and experience. On the other hand, motivation is the trigger for knowledge and skills for WBA. ***Motivation*** is a catalyst for interest to engage in WBA through initiative. It has been shown that employees with higher motivation (i.e., more enthusiasm) have more affinity to gain knowledge and skills to promote SWM through WBA, as evidenced by records of self-initiatives. Examples of DNCC/DSCC staff self-initiatives include finding a place for a SWM office in the community (WBA-1), providing safety equipment, reviewing its use, and conducting group meetings and safety training for cleaners (WBA-2) with routine monitoring of cleaning activities, organizing community meetings in various communities (e.g., housing associations, merchant associations, market committees, etc.) on various topics such as closing open dumps or introducing waste separation, etc. (WBA-3) and harmonization of primary and secondary collection to make the collection system more efficient and effective (WBA-4).

Articulated guides include various documents to promote and implement the WBA. For example, WBA DVD, an audiovisual documentary showing the concept of the various WBA components and their organization and function. WBA manuals show various WBA processes, principles, and progress in the form of a brochure. Community SWM guidelines show functional steps with the process and principles of participatory SWM. It shows the stakeholders with their roles and provides a guidance on formulating a community action plan (CAP). Community Unit Working Group (CUWG) and Primary Collection Service Providers (PCSP) training modules are developed.

Table 8-7 Sustainability factors of WBA*

Thematic factors	WBA-1	WBA-2	WBA-3	WBA-4
Knowledge & skills for WBA	PPR to use government fund. Design, drawing, BOQ, estimate, tendering for construction; book-keeping SWM data, ward profile etc.	Training & workshops of waste workers, health and safety, leadership, facilitation & communication; street, drain and market cleaning tools, usage and activities, all roads, and drains network of a ward, SWM Rules	Environment and environmental education, Communication and facilitation of community meetings, trainings and various awareness raising programs, Effective language to facilitate community activities, PRA tools and principles, Participatory monitoring, CAP formulation with governance component, 3R, SWM Rules	Communication and facilitation, PRA tools and principles, CAP formulation with physical component, waste collection design, harmonize (*viz.* time, place, process) primary and secondary collection, all roads of a ward, collection and transportation plan, collection methods and design, loading capacity, fuel consumption ratio of different vehicles, SWM Rules etc.
Motivation WBA	Growing dignity and pride waste staff and waste workers. Potential for self-initiative	Growing dignity and pride waste staff and waste workers, grouping and leadership developments, Potential for self-initiative	Growing dignity and pride waste staff and waste workers. Potential for self-initiative	Growing dignity and pride waste staff and waste workers. Potential for self-initiative
Articulated guiding principles	DVD, WBA Manual, data formats and templates, ward profile, reporting system etc.	DVD, WBA Manual, Cleaners working manual	DVD, WBA Manual, training modules (e.g., CUWG, PCSP), CAP, Community SWM guidelines	DVD, WBA Manual, PCSP Training module, CUWG training module, CAP
Key stakeholders	CI, Asst./Executive Engineer	CI, Safety & Sanitation Committee	CI, CUWG, Ward Councilor, PCSP	CI, Ward Councilor, PCSP
Governance Strengths	Office orders for WBA considering routing work and reporting from ward SWM office (Office Order, 2010; Office order, 2012), Training of counterpart in home and abroad, WBA Core group formation with additional workforce and wing, and budget support (e.g., for community SWM, ward office construction and utility, safety gears, safety, and sanitation training etc.)			

Note. PPR: Public Procurement Rules 2008; PRA: Participatory Rural Appraisal, Chambers (Chambers, 1994a, 1994b); CUWG: Community Unit Working Group; CAP: Community Action Plan; CI: Conservancy Inspector; PCSP: Primary Collection Service Provider; *It is assumed that enough working staff are in place

The main actors for the various WBA components may vary slightly by site or station. However, there are three (3) primary stakeholders involved while considering ***stakeholders engagement***. These include the municipality (i.e., municipal staff, ward councilors), PCSP (i.e., primary collectors and organizations), CUWG (i.e., community association, shopkeepers' association, market committee, etc.). Together, they can all play a significant role in improving waste collection efficiency and waste quality for WtE facilities by informing, educating, and enlightening the community.

According to the respondents, the strengths of the governance characteristics need to improve more but it is not happening. While there are service directives, formal training, and certification for domestic and international staff, more work is needed in assigning responsibilities to staff, in decision making regarding the WBA, and in resource allocation to make it more sustainable.

The recommendations to improve sustainability are (1) continuous promotion of CI, CO through incentives, paid leave, promotions, recruitment of qualified graduates; (2) opinion survey and exchange opinions among citizens, students, and mass media on SWM. Students need to visit collection areas and landfills and support of DNCC or DSCC; (3) Implement the Clean Dhaka Master Plan with an organizational structure for waste management and efficient staffing to make a difference; (4) Greater community involvement in oversight responsibilities by WBA as demonstrated in DNCC (e.g., Uttara R/A, Niketan Society R/A) and DSCC (e.g., Lane 28, Dhanmondi R/A); (5) there is a need to implement WBA performance measurement with recognized indicators and monitoring processes; (6) create an award tradition among WBA officials for WBA (e.g., zonal and citywide); (7) annual training program for WBA and annual reporting system; (8) build a knowledge management culture and infrastructure that preserves organizational memory. WBA may function more effectively keeping city clean and contributing to WtE if factors are considered and managed effectively.

8.7 Conclusion on WBA and WtE Feasibility

WBA can influence the feasibility of WtE. However, the WBA implementation as routine work management is to be maximized to realize its contribution towards feasibility of WtE. Motivation of the staff members (CIs, COs, etc.) for promoting WBA is found important key factor for sustainability of WBA, which can be boost by work recognition, salary structure modification, incentives, promotion, sufficient staff deployment etc.

WBA-1 (ward office functioning) can be considered as information-education-communication hub and grass-roots coordination and monitoring center for a ward for entire components of WBA. However, there are smaller number of wards SWM offices than actual demand. Each ward should have one well-equipped ward SWM office to provide daily SWM service smoothly to the citizen. The number of ward offices (40%) is currently less than the actual need. Conservancy Inspectors (CIs) play the vital role as focal points for information, education, and communication for SWM, with a ward office under WBA-1, serving as a common community-centered platform. CIs' motivation for WBA is an important sustainably factor that must be reinforced by the service benefits. Ward SWM office can be the center for management of solid waste at the community level (e.g., vehicles, cleaners, communities, collection, primary collectors, education, and training, etc.) to ensure quality waste collection and transport to the WtE facility.

WBA-2 (cleaners working environment and productivity) can ensure 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.). About, 15,000 municipal and non-municipal cleaners are working daily for primary collection, cleaning of streets, drains and markets. Waste signs and symbols have been started to develop and can be taught to waste workers and citizens within WBA-2 and WBA-3. Waste workers need education on which types of waste destine to the WtE facility and which do not, or which are good for WtE under WBA-2. WBA-2 can directly help for categorical waste storage and subsequent transport to WtE facilities (e.g., combustible fractions) or landfill site (e.g., drain cleaning waste).

WBA-4 (waste collection) can facilitate to improve waste collection efficiency and effectiveness. Only compactor to be used for waste collection which is destined to incinerator plant. However, their existing number might be insufficient to ensure regular feeding quantity (ton/day) of the large WtE plant.

WBA-3 can maximize collecting revised tariff for WtE, boost waste quality by separation at source and oppose anti-incinerator views. 3R based environmental education must be resumed immediately.

Seven (7) major impeding factors were identified (e.g., poor knowledge management, lacking expected human resources, weak budge utilization etc.) and described in this chapter. In addition, five (5) sustainability factors (e.g., Knowledge & skills for WBA, staff motivation, articulated guiding aids, key stakeholders' engagement, *governance strengths*) were addressed to overcome the hindering factors and enhance feasibility based on the respondents' propositions. Exemplifications are made with actualization in the local context of Dhaka City.

It is noticeably clear that the WBA can positively influence the feasibility of WtE incineration; therefore, its functions should be strengthened and advanced through various organizational supports. However, DCCs may need additional supports such with the passage of time for better adaptation and implementation considering WBA as routine work and maximize its contribution to WtE and improve local SWM. Existing workforces are not sufficient to implement full scale WBA in all the wards, outsourcing support services can help in this regard.

CHAPTER 9: CONCLUSIONS AND RECOMMENDATIONS

9.1 Contextual Summary of Research

This research was undertaken to find ways to improve waste quality (LHV) to contribute to WtE feasibility as well as the sustainability of MSWM, taking into account the technical and governance considerations. An empirical model for determining the lower heating value of waste was developed and applied to investigate the feasibility of waste-to-energy. In parallel, governance characteristics were studied. The focus was on examining the governance potential, a key waste collection stakeholder (PCSP), and grassroots waste management processes and approaches (WBA) to understand their prevailing and potential influences on the sustainability of SWM through WtE incineration. This study concludes that the governance aspects themselves must be strengthened to improve the feasibility of WtE incineration and the sustainability of waste management. There are various needs to build capacity among stakeholders and optimize policies and practices to adapt to WtE incineration technology.

9.2 Conclusions on Technical Aspect towards WtE Feasibility

Following statistical procedures for multiple regression, models are developed to predict with the proposal of simplified models. With the aim of determining regression coefficients for each physical component (i.e., explanatory variable), 90 composite data sets are used in the three reference models based on globally distributed data sets, and their average is used to develop models. The models developed in this study are the first models based on the physical composition of solid waste in Bangladesh. The data used for model development is based on a comprehensive survey to characterize the wastes in the DCCs.

The proposed model is used for future LHV prediction, and it may also be used in other areas where waste characteristics are similar. 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 as estimated by developed model. Developed model values are consistent with other reference model values in terms of fluctuation pattern with waste sources and dispersion. 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%). Since it takes time for decision makers (e.g., various studies, fund securing, preliminary design, tendering, detail design, construction, commissioning etc.) for WtE, this study clarifies that current timing is rational enough to adopt WtE incineration in terms of feasible LHV of waste from selected areas.

9.3 Conclusions on Governance Characteristics towards WtE Feasibility

There are many stakeholders whose roles vary in the planning, permitting, installation, commissioning, and operational phases. However, city corporations to be responsible for collection and quality waste feed to the plant. Capacity building and mobilization of these stakeholders are necessary as many are still unaware about categorization. WtE incineration is included in high-level plans, such as the Solid Waste Management Master Plans and the 8th Five-year plan of Bangladesh etc. Local government leaders have considered WtE incineration as priority. Local governments are used to take assistance from expert committees and consultants to implement projects. Energy ministries and power utilities can develop technical standards and procedures for power sales and set the selling price according to established procedures. However, no feed-in tariff has been set yet, but power purchase prices are published in the national dailies in 2021 and 2022 at 20.91 to 21.78 cents per $kW \cdot h$.

There are hidden and probable potential those can be explored and utilized through discussion and consensus building like fiscal (i.e., budget, subsidies etc.) supports and monetary (i.e., tax incentive or waiver) support which may drastically influence the feasibility of WtE. Authorities can decide specific areas with special tariff for WtE incineration waste collection such as market areas, office areas, large hotels, commercial hubs etc.

9.4 Conclusions on Policies and Practices of PCSPs

PCSPs are the main actors in municipal SWM in Dhaka City. To improve the sustainability of waste management in Dhaka City, there is an urgent need to pay special attention to formalizing PCSPs by reforming policies or creating bylaws and benchmarking performance indicators on how they should be governed. Socio-political power plays a critical role in the management of primary collection service. City authorities have not been able to manage primary collection service effectively many times. The lack of a reliable set of rules also leads to a lack of good governance. As sociopolitical hegemony shows, power groups can exert some control over authoritarian power, resulting in higher service fees, poor service delivery, and mostly nonappearances of complaints. Some cases, the mindsets of some political leaders need to be changed by sacrificing their greed. It is inevitable to rationalize the performance indicators, service fees, PCSPs deposit, and try to continue the practice of good governance. Without such rationalizations, PCSPs may hinder the feasibility of WtE.

If PCSPs can be mobilized well through capacity development, they can contribute well to high quality waste collection by maximizing combustible fractions and minimizing unacceptable waste to the WtE facility. This will increase the LHV and have a positive impact on the feasibility of WtE incineration.

9.5 Conclusions on Roles of WBA towards Feasibility of WtE

The WBA can influence the feasibility of WtE by improving waste collection and ensuring quality. Through the participatory community based SWM process under WBA, stakeholders (*viz*. PCSPs, citizens, and DCCs) can be educated, advocate and function for waste quality, and improve waste collection efficiency in tons per day. However, the WBA needs to be adapted and implemented as routine work management to maximize its contribution to WtE feasibility. Motivating employees to promote WBA is a key factor for sustainability, which can be increased through recognition of work, revision of pay scales, incentives, promotion, etc.

WBA-1 (Ward Office) can be considered as an information, education, and communication hub and grass-roots coordination center for a ward for other components of WBA. However, the number of SWM offices in the wards is less than the actual need. Each ward should have a well-equipped ward SWM office to provide smooth daily SWM service to citizens. There are a total of 129 (DNCC 54 and DSCC 75) wards in Dhaka City, but only 51 (DNCC 23, DSCC 28) ward SWM offices.

WBA-2 (cleaners working environment and productivity) can ensure quality of waste by minimizing objectionable of waste (metals, stones, sands, construction waste, drain sludge etc.) and maximizing combustible fractions (e.g., paper, plastics, fabrics, garden trimmings, leaves etc.).

WBA 3 (community SWM) can help for improved tariff structure, environmental education for waste sorting and their categorical signs and symbols. Community action plans can help to implement and monitor quality waste discharge and collection suitable for WtE incarnation by harmonizing PCSPs.

WBA-4 (waste collection) can facilitate to improve waste collection efficiency and effectiveness using compactor truck. Only compactor to be used for waste collection which destined to be incinerator plant. However, their number at this moment is less unless each can make more than 2 trips per day in case of plant capacity equal or greater than 500 t/d. FTFP system is cleaner and efficient where compactors accessibility is high, but it could not be scaled up due to the PCSPs insist.

The seven (7) major factors are believed to be hindering effective functioning of WBA or general SWM, thus will hamper WtE sustainability unless measures are undertaken in DCCs: *(1) lack of human resources, (2) poor knowledge management, (3) weak budget utilization potentials, (4) modest stakeholders' collaboration, (5) irrational organizational focus, (6) lack of good governance, (7) improper collection. Knowledge management (KM)* systems are mostly absent and officially they are not satisfactorily established in DNCC and DSCC's waste management. They are being practiced inadequately by the organization due to lack of *KM culture and infrastructures.* Through on the job training (OJT) under technical assistance projects of JICA or other donors may help as mentioned by some respondents.

If enough staffs are ensured in place, following five (5) sustainability factors need to be nurtured to activate and scale up WBA aiming to contribute sustainable SWM incorporating WtE incineration: (1) *Knowledge & skills management for WBA, (2) Motivation (e.g., staff* *incentives), (3) Articulated guiding aids, (4) Key stakeholders' engagement, (5) Governance strengths (e.g., office orders).*

9.6 Limitations of the Research

There are important limitations to both the *technical* and *governance* aspects of this study. For the *technical* aspects, the most important limitation was that the model values were not validated by extensive laboratory testing with samples from throughout the year. In addition, there are many scenarios that could be tested, such as the fact that many developing cities have abundant materials for co-incineration, such as coconut shells, waste tires, clothing, factory waste, or waste plastics etc. On the other hand, in terms of the *governance* aspect, the study involves WtE actors, SWM stakeholders such as PCSPs or informal collectors and WBAs, which may not be common in many other cities in developing countries. Therefore, the replication or utilization potential for the governance knowledge gathered in this study is likely to be low with respect to the phenomena in developing countries.

9.7 Recommendations to Way Forward

Several recommendations for further studies emerge from this study to help improve the feasibility of WtE and increase the sustainability of SWM, both in technical and governance (i.e., management) aspects. They are described below:

- It is necessary to compare and optimize the developed model with laboratory test results.
- One theory of change can be developed for WBA promotion and another for primary collection service provider application, registration, monitoring, and database management with performance benchmarking.
- There are several waste management performance indicators in the literature that can be adapted or improved for use in specific cities. The existing limitation of published indicators is they only can help to understand the current situation, but they need to be in the form of more localized indicators with priority ranking procedures in addition to performance ranking procedures. For a waste-to-energy project, the key performance indicators (KPIs), their prerequisites, and the process for measuring the indicators are critical for feasibility at the outset and sustainability in the operational phase along with a sustainable integrated SWM system. KPIs can be considered as a sustainability goal.

The process for measuring social, environmental, and economic benefits and burdens needs to be researched and tailored to local conditions.

- Governance theory and practice need to be further explored in terms of developing institutional and organizational memory, knowledge management, and improving decision-making behavior. Research is needed on how to advance such efforts by applying game theory to stakeholder decision making, modeling privatization, and studying carbon footprints to channel credits from developed economies to developing countries to improve WtE feasibility and SWM sustainability.

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