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学　位　論　文　題　目	Study on the Technical Feasibility of Waste-to-Energy Incineration for Municipal Solid Waste Management in Developing Countries – Case in Dhaka City （和訳：発展途上国における廃棄物発電の技術的実現可能性に関する研究―ダッカ市を事例として）
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【論文審査】Review of the thesis

The author of this dissertation, Mr Md. Shoriful Alam Mondal, has been a practitioner who have been involved in many technical cooperation with Japan International Cooperation Agency (JICA), International organizations such as UN-HABITAT etc. He has abundant experiences in solid waste management and has worked with Japanese consulting companies in Bangladesh. Through such experiences, he came to think that core technologies in solid waste management in developing countries are under transformation from sanitary landfill to "Waste-to-Energy incineration (WtE).

As such, the author prepared this dissertation under tile of "Study on the Technical Feasibility of WtE for Municipal Solid Waste Management in Developing Countries -Case in Dhaka City". This dissertation consists of nine chapters and, i.e., "Chapter 1: Introduction", "Chapter 2: Literature Reviews", "Chapter 3: Methodology", "Chapter 4: Lower Heating Value Assessment by Reference Models", "Chapter 5: Lower Heating Value Model Development and Application to Assess Waste-to-Energy Feasibility", "Chapter 6: Governance for Waste-to-Energy Feasibility", "Chapter 7: Policies and Practices of Primary Collection Service Providers", "Chapter 8: Ward Based Approach and Waste-to-Energy Feasibility in Dhaka City", "Chapter 9: Conclusions and Recommendations". Chapters from 4 to 5 are focusing on technical aspects and chapters from 6 to 8 are focusing on governance issue. This is because of the fact that technology alone is not enough to make solid waste management sustainable and consideration on governance is a prerequisite. Main points of the thesis are as follows;

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. 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 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) 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. For developing & emerging countries, GIZ 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. These are further segmented into thirty-two (32) key criteria for assessment including LHV for energy recovery.

Technical aspect

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.

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.

Governance aspect

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 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.

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·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.

【審査結果】**Summary and decision**

The dissertation aims at the establishment of technical feasibility of WtE in terms of LHV and governance aspects to support technology, which is a prerequisite to make WtE successful. The developed theory is considered as academically valuable and also practically applicable to all developing countries. Especially, it offers Dhaka City with future perspectives of solid waste management. The results of this dissertation can positively contribute to future research works in light of the deliberation criteria of doctoral thesis in the Graduate School of Global and Regional Studies. Therefore, all the members of the review committee judge that this dissertation is worthy of a doctoral degree of Graduate School of Global and Regional Studies, Toyo University.