学　位　論　文　内　容　の　要　旨

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学　位　論　文　題　名

Development of Waste Management Strategies based on Recycling and Energy Recovery in Indonesia
(資源・エネルギー回収に基づくインドネシア廃棄物管理戦略の構築)

The global situation on municipal solid waste (MSW) is worsening and greatly affected by population number and Indonesia, like other Southeast Asian countries with high population growth, is needed to minimize both this problem and the related greenhouse gas (GHG) emissions. The Government of Indonesia set the reduction targets of MSW at 30% by 2025 and GHG emissions (of the waste sector) at 0.38% by 2030 and required to systematically deploy recycling and energy recovery oriented MSW facilities. However, the unavailability of a national plan on waste management to address the ranging population sizes in Indonesia hindered the development. Thus, the general objective of this research is to develop a national plan with specific strategies based on recycling and energy recovery to attain the national targets of landfilled waste reduction at 30% and the waste sector of GHG emissions reduction at 0.38% in Indonesia.

Indonesia is implementing different MSW facilities to improve recycling and energy recovery with waste banks (WBs) at the source where residents can obtain revenue by selling recyclables, transfer stations (TSs) as the majority starting point before transported to the landfill, Material Recovery Facilities (MRFs) with multiple types of equipment supporting the manual recyclable recovery, and incinerators as the acceleration of waste to energy programs, which are going to be established in the different population group of cities/regions (Areas). However, Indonesia has limited MSW data on the location and size of the facilities, transportation routes, and landfills information, which is essential to be analyzed in each Area. Therefore, Surabaya City, which stood out as one of the best cities in the MSW management aspect and has complete data as mentioned above, was determined as the pilot study to fill in the missing data by constructing Surabaya Model to be utilized in further analysis in this research.

Surabaya Model was developed as a prior study of national scale expansion model to evaluate both current and newly proposed MSW system, comparing the cost and GHG emissions generated by focusing on replacement of TS to MRF, targeting the reduction of MSW at 30%. The geographic Information System (GIS) was used to deploy all surveyed TSs, MRFs, landfill, and the transportation route from each location to the landfill. The distance generated and frequency of transportation were then utilized to calculate the fuel for transportation cost. Four scenarios were analyzed and Scenario 3: Distributed MRF System was found to have the lowest overall cost at 59 billion IDR/y with the least number of MRF required at 26 units. However, the integration networking between TS and MRF in this system handicapped the fuel for transportation cost due to the longer total transportation distance. This shows that transportation cost is a sensitive aspect which affected directly on the position of starting point and the landfill. Both items would be highly necessary to successfully broaden the Surabaya Model for a national scale model.

WB promotes resource recovery at the source, yet the actual contribution to the MSW system is still unclear. This part of the research is targeted to clarify the role in the MSW system and its necessity to be implemented in the national model. Interviews were conducted with authorities of WBs in Surabaya for details on the performances. WBs in Surabaya recover 3.5 t/d recyclables from 35,068 households by 755-unit WBs which were considered low in impact, yet WB offered higher quality recyclables and necessary information for further revenue analysis.

Due to insufficient data of MSW facilities for the whole of Indonesia, centroids were used as a representation of starting point based on the residential and/or working (RA) area using QGIS in

the Surabaya Model. This part of the research was divided into two goals, the compatibility check of utilizing centroids by comparing transportation cost, and scenarios development on the national plan of waste management in Indonesia using expanded Surabaya Model to address national targets on landfilled waste and GHG emissions reduction. Surabaya City was divided by district level, which has different population sizes and densities, to compare and verify the hypothesis of determining transportation cost using the centroid of each district as the starting point of transported waste to the landfill. The analysis using RA Centroids resulted in similar data, verifying the theory and possibility to be used in a national-scale model. Centroids were a vital element to establish transportation routes, to project missing landfills, to set up integration between Areas, and to evaluate the cost and GHG emissions reduction. Then the implementation of available MSW facilities was simulated using QGIS in different scenarios to achieve the national goals. Scenario 0 simulates the BAU case for comparison with solely a 3% reduction at TSs. Other scenarios were deploying WBs in Small Areas, MRFs in Medium Areas, 450 t/d capacity incinerators in Big Areas with MRFs handling the uncovered MSW, and 1,000 t/d capacity incinerators in Metropolitan Areas. Scenario 2 and Scenario 3 were like Scenario 1 yet concentrated on the WtE program with different approaches. Scenario 2 with post-integration used the 1,000 t/d capacity incinerator for Metropolitan Areas and take over the nearby Areas if the capacity remained. Scenario 3 with prior integration, on the other hand, utilized both 1,000 and 450 t/d capacity incinerators for Metropolitan Areas and integrate the possible neighboring Areas, with the respective possible transportation distances, to determine the incinerator unit number in advance. All three scenarios were able to pass the targeted landfilled waste reduction with Scenario 3 leading at 64% reduction and the targeted GHG emissions reduction at 0.49%. The performance was compensated with a huge total cost of 1.4 times of BAU due to the OM and investment cost. However, considering the recovery at the source and TWDSs, the tipping cost was decreased while the revenue from recyclables was increased. Thus, the analysis showed that this system resulted in the lowest 19 Mt/y landfilled waste and 14.1 $MtCO_2e/y$ GHG emissions reduction with a reasonable cost for reduction achievements.

In summary, the national plan of waste management in Indonesia with recycling and energy recovery orientation was designed and assessed to meet Indonesia's goals by comparing centroid usage as a representation and determinant of missing MSW facilities to the Surabaya Model which has real comprehensive data. This approach opened new possibilities of implementation possibilities for reproducing the study based on characteristics of environmental parameters in multiple cases with poor MSW facility data.