

Cross-Country Analysis on Waste Generation, Collection Service Coverage, Intermediate Treatment, and Final Disposal in Solid Waste Management

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Abstract: In this paper, the trends of waste collection coverage, intermediate treatment, and final disposal of solid waste in the world are analyzed based on the cross-country analysis of waste management statistics. As a result, the improvement of waste collection service coverage strongly correlates with the increase of Human Development Index (HDI) and economic growth (GDP/capita). The introduction of intermediate treatments also correlates with economic growth, in which compost production and material recycling firstly become widespread in the low to middle-income stages, then following these, waste-to-energy incineration technology surges from middle to high-income stages. Anaerobic digestion also emerges from middle to high-income stages but in a limited scale. The method of final disposal of solid waste widely varies but in general open dumping decreases according to the economic growth, and sanitary landfilling increases.

Keywords: waste management service coverage, intermediate treatment, final disposal, economic growth, human development index

I. Introduction

The amount of waste generated is increasing with the progress of economic development and urbanization in most country/region, especially in developing countries. On average the developed countries typically generate 521.95–759.2 kg/capita/year and 109.5–525.6 kg/capita/year typically by developing countries [1]. In response to such a rapid increase in the amount of waste generated, in order to maintain public health, expanding waste collection and transportation and final disposal services has been practiced in many countries.

Solid waste management (SWM) service, waste collection, intermediate treatment, and final disposal, is generally performed as a municipal service delivered by local governments or municipalities. Thus, the waste collection service, intermediate treatment, and final disposal are generally planned and implemented by these authorities. However, in many countries, the capacity of final disposal sites is limited, and it is becoming difficult to acquire land for constructing new landfill sites. For this reason, not only establishing well-organized SWM service delivery, but also a waste reduction policy has been adopted in SWM by many local governments/authorities [2].

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There are two main methods for reducing waste in SWM. It is the prevention or suppression of waste generation at source (Reduce) and the waste diversion (Reuse, Recycle) in the waste stream using reuse and recycle technologies. The practices that implement these three activities in two categories are collectively called the 3R [3].

TABLE I. SOLID WASTE MANAGEMENT FLOW, PROCESS, 3R, AND INDICATORS

SWM Flow	Process	Indicators
Waste generation	Waste reduction at source (REDUCE)	Generation rate
Waste collection	Waste collection (REUSE)	Service coverage
Intermediate treatment	Waste diversion including Composting, Anaerobic digestion, Material recycling, and Energy recovery (REUSE, RECOVERY, RECYCLE)	Composting rate Recycling rate (Reduction rate)
Final disposal	Dumping, Landfilling, Gas recovery, and environmental protection (RECOVERY RECYCLE)	Landfilling rate Closure of open dumpsites

As shown in the TABLE I, the state of waste generation is closely related to economic activities urbanization, and people's life style, and the key factor is the public awareness on waste issue. REDUCE in 3R is often indicate the behavior to minimize the waste generation. The waste generation rate (kg/capita/year) is the indicator showing the situation.

Waste collection is the response/countermeasure to the solid waste generated, without which the public health condition will deteriorate. The waste collection service coverage is the criteria for well-organized waste collection service, where high percentage towards 100% coverage can secure the public health condition through removing the waste from residential area.

Intermediate treatment has been applied for these reuse and recycle practices, where the throughput of solid waste

stream is expected to be decrease drastically, diversion of the waste stream. Various types of intermediate treatment technology have been developed so far, but the waste diversion is generally classified into four channels; composting, anaerobic digestion, material recycling, and energy recovery (waste-to-energy). The intermediate treatment is closely related with the REUSE and RECYCLE (including RECOVERY) in the 3R practice.

In this paper, global trends of waste collection service coverage, intermediate treatment, and final disposal are discussed using the method of cross-country analysis of solid waste management statistical data of each country, and the author discuss about the policy direction of SWM based on the analytical results.

II. Data and Method

A. *Country Statistical Data of Solid Waste Management*

The statistical data on solid waste management in each country used in this study is a compilation of the World Bank What a Waste Global Database (The World Bank, 2018; datacatalog.worldbank.org/search/dataset/0039597) [2] based on the data published by 192 countries. Most data are measured around 2017 but some are in late 2010s, before the period of COVID-19 pandemic.

B. *Cross-country Analysis*

The cross-country analysis is the comparison of some specific units of analysis (in this case solid waste management statistics) across the countries. It aims to capture differences and similarities respect to the variables analyzed.

Cross-country analysis does not show time-series changes over time, it only shows the correlation of each parameter at some point in time. But if we consider the world trend of development-centered development policies as adopted by many countries of the international community

today, the degree of economic growth indirectly indicates some sort of chronological component. The human development index (HDI) also includes time-series factors of social and human development.

In this paper, economic development (GDP/capita) and human development (HDI) are compared with several parameters of SWM, as shown in Fig.1.

In order to make statistical analysis, a BellCurve for Excel was used with Microsoft Excel.

III. Results of Cross-Country Analysis

A. *Waste Generation*

Waste generation is increased by economic and social factors such as economic growth, urbanization and population growth. However, it changes greatly depending on the conditions of the country or city, geographical and cultural background, people's awareness of the environment, etc., and also depends on the degree of establishment of governance, institution, administration, and waste management system.

Fig. 2 shows the cross-country plot of correlation between the annual amount of solid waste generated per capita (kg/capita/year) and the gross domestic product (GDP/capita). The relationship between the two parameters shows a positive power correlation, and the larger the gross domestic product, the larger the amount of waste generated. Such relationships are also known from previous studies [1][2][4], and it has been reported that such relationships are often found in continuous monitoring in a country [5]. Similar to the above, there is a clear positive correlation between waste generation and HDI (Fig.3). Many countries are currently aiming for economic growth and human development, therefore it is inevitable that the amount of waste generated will continue to increase. However, as is clear from Figs. 2 and 3, there are a considerable ranges for the average trends, respectively. These show that there are unique conditions in development except economic and human developments factors.

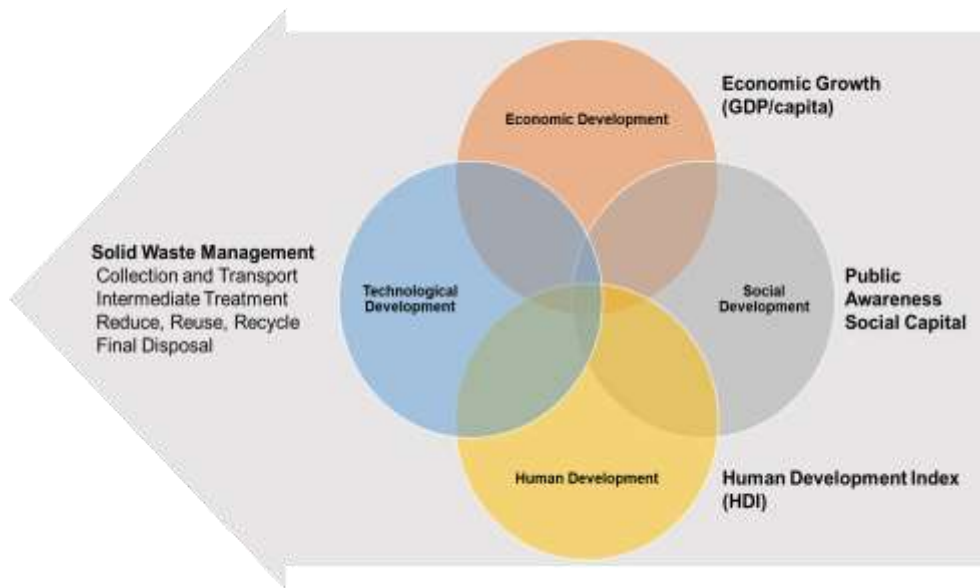


Figure 1. Development of solid waste management through economic, social, human, and technological developments.

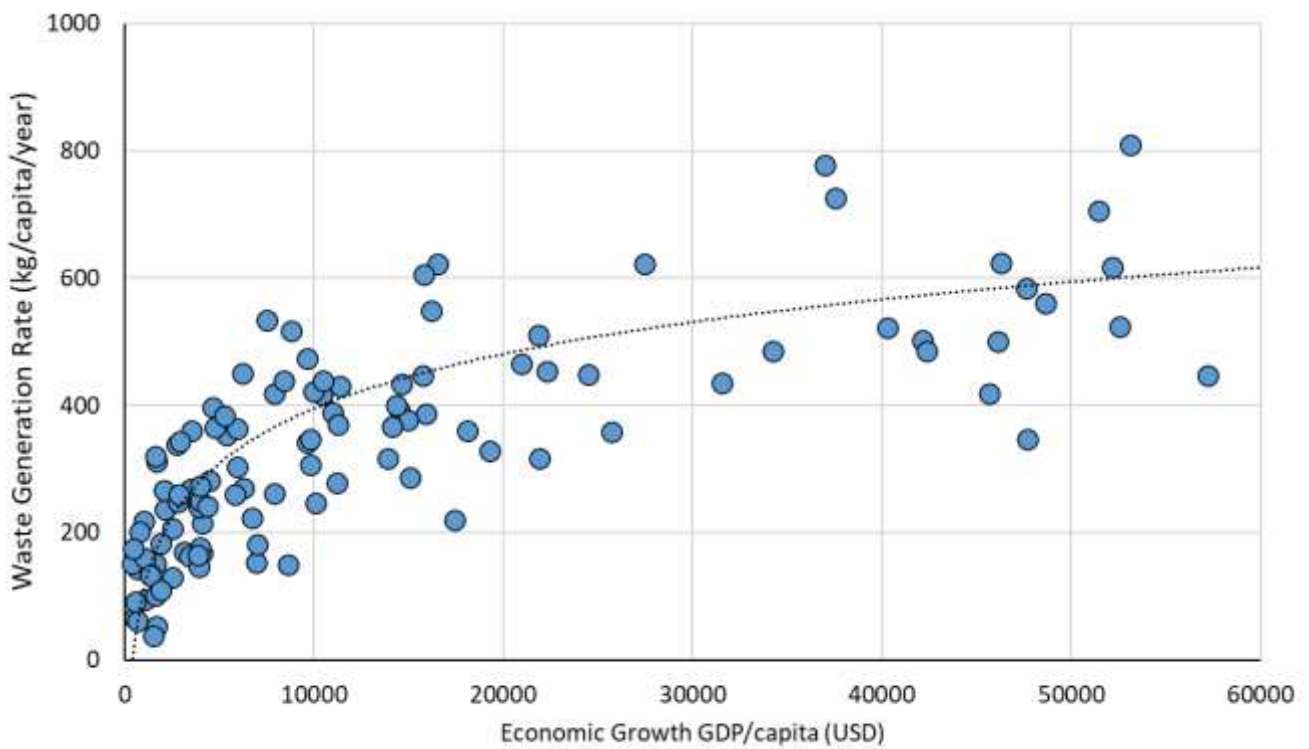


Figure 2. Cross-country correlation between the waste generation rate (kg/capita/year) and the economic growth.

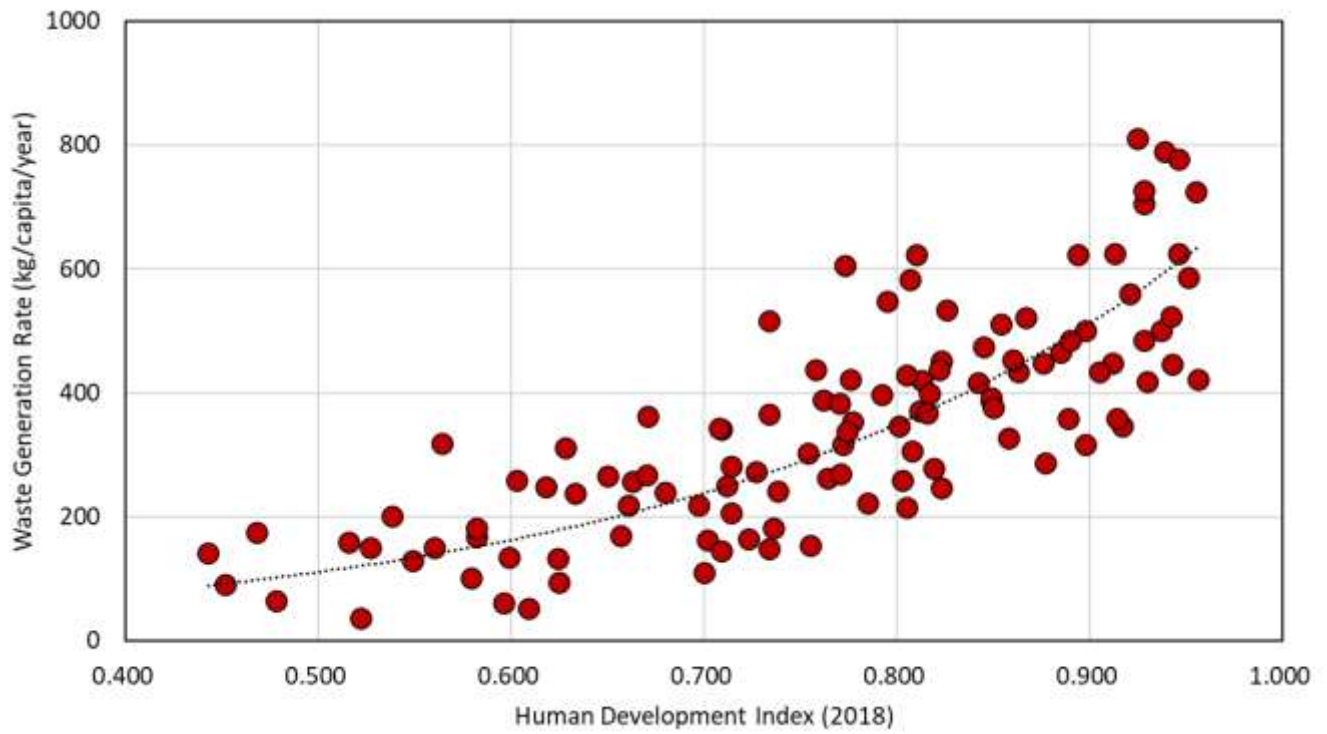


Figure 3. Cross-country correlation between the waste generation rate (kg/capita/year) and Human Development Index (UNDP, 2018).

B. *SWM Service Coverage*

A cross-country plot of average service coverage and gross domestic product for waste collection and transportation is shown in Fig. 2, and a plot of average service coverage and Human Development Index (HDI) [6] is shown in Fig. 3.

The service coverage rate referred to here is whether the actual service is provided at the rate of the total population or administrative division of the area covered by the service, and is indicated by %. It is 100% when the administrative services are fully distributed. The term "waste collection service coverage" as used herein refers to the ratio of the target area or population to which regular collection is planned by the public or private waste management service providers. It does not indicate quality of service, such as collection frequency.

The service coverage shows a positive logarithmic correlation with both GDP and HDI, but the correlation with HDI has a relatively strong correlation (Fig. 3). In addition, the correlation with GDP (Fig. 2) shows that the variability is very large in developing countries (GDP/capita < 10,000 USD) where the coverage rate is sometimes low at 50% or less. There is inadequate service coverage and no access to waste collection service (for example in the case of Nigeria [11]).

The Human Development Index (HDI) is an index that measures basic dimensions of human development. The three basic dimensions are: (i) a long and healthy life which is measured by life expectancy; (ii) access to education which is measured by expected years of schooling of children at school-entry age and mean years of schooling of the adult population; and (iii) a decent standard of living which is measured by Gross National Income per capita (GNI/capita) adjusted for the price level of the country.

It is widely known that the HDI is partly overlapping with the economic development indicator, GDP/capita, but it include more social and human development factors [6]. The correlation shown in Fig.3 indicates that the increase of service coverage improves local living environment for people and also provide a better public health conditions.

Therefore, improving the service coverage rate is an issue that is directly linked to social development, economic development, and human development; and in developing countries, improving the service coverage rate is a high priority in SWM. Improving the service coverage rate not only means expanding the target population and target area, but also means that the SWM services are surely provided regularly in the area, which is related to the strengthening of waste collection and transportation capacity of SWM implementing authority.

C. *Intermediate Treatment of Solid Waste*

The intermediate treatment is complicated, unlike the waste generation and the service coverage in SWM. This is because the introduction of intermediate treatment is greatly

influenced by unique geographical, climatic, natural and environmental conditions, as well as socio-economic and industrial conditions of the country/region. .

In this study, the following four methods represent intermediate treatment; (i) Composting of biodegradable organic waste, (ii) Material recycling, such as metals, plastics, papers, glass, and so on, (iii) Anaerobic digestion of biodegradable organic waste, and (iv) Incineration or gasification of solid waste including Waste-to-Energy.

It should be noted that those introductions require appropriate separation at source or sorting of recyclable from mixed waste, before the treatment as a prerequisite.

Fig. 4 indicate the relationship between recycled/recovered percentage to the total generated waste and Gross Domestic Product per capita (GDP/capita). Characteristic trend of each recyclable is as follows:

(i) Composting is widely addressed in SWM of low to high income countries, but its treatment rate to the total waste generated is generally less than 20% of total waste generation. Although the content of biodegradable waste within the municipal solid waste is 50% or more in low-income countries, less than half of the solid waste is treated. Averaged trend of introduction of composting in the intermediate treatment gradually increase according to the economic development as a linear correlation (see the Trend of Compost in Fig.4).

(ii) Material recycling is also, like composting, widely undertaken from low-income to high-income countries. The treatment rate (%) for total waste generated is 10 - 30% in average, which is higher than that of composting. Even in developing countries, it is recycled up to nearly 40%. In developing countries (GDP/capita < 10,000 USD), it is sometimes recycled to nearly 40%. This shows that the market economy incentive is working; an unintentional 3Rs. Like composting, recycling rates can be higher in high-income economies, reaching up to 60%.

(iii) The intermediate treatment of anaerobic digestion is limitedly applied in SWM. Not many countries/regions have introduced anaerobic digestion as an intermediate treatment, and the treatment rate in the amount of total waste generated is small (1%>).

(iv) The large-scale waste incineration facility positioned in the SWM system is one of the important options of intermediate treatment. It treats a relatively large amount of solid waste in a short time and has a very large waste reduction function. In recent facilities, it is possible to generate electricity using the heat energy. However, the initial cost is the highest among the all intermediate processing technologies, and operation and maintenance also requires specialized engineers (human resource). For that reason, introduction of waste incineration technology has not been realized in low-income countries. At the economic level, the introduction is permitted at GDP/capita < 2,800 USD according to the world data, and most large-scale facilities have been introduced in high-income countries with GDP/capita <10,000 USD.

Looking at the correlation between the GDP/capita and the treatment rate to total waste generated (Fig. 5), it shows a positive power correlation rather than a linear correlations such as for composting or material recycling, and the incineration facility increases rapidly in high-income economies. In some cases, up to 80% of the total amount of waste is incinerated.

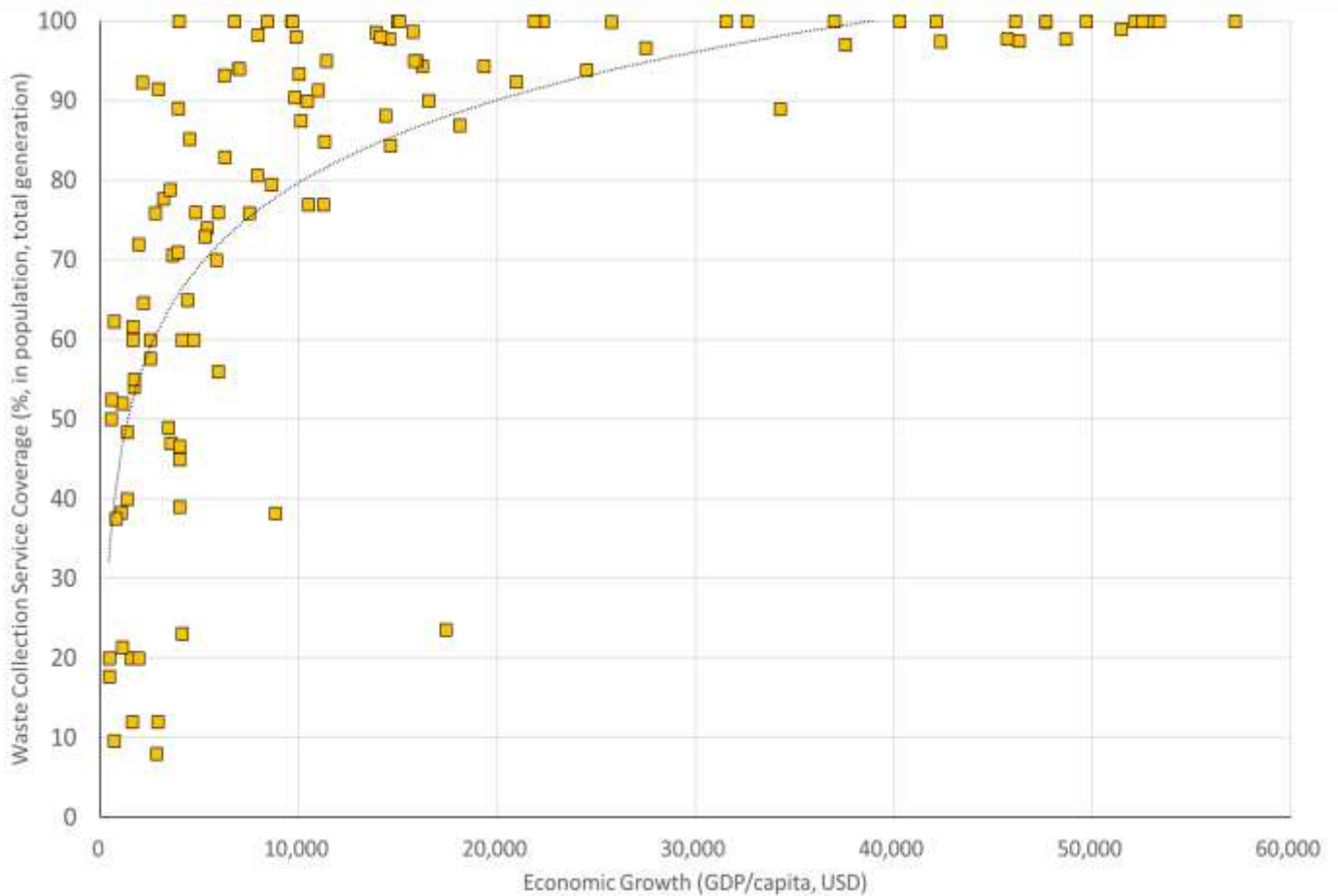


Figure 4. Cross-country plot between waste collection service coverage (%) and economic growth (GDP/capita, USD 2017)

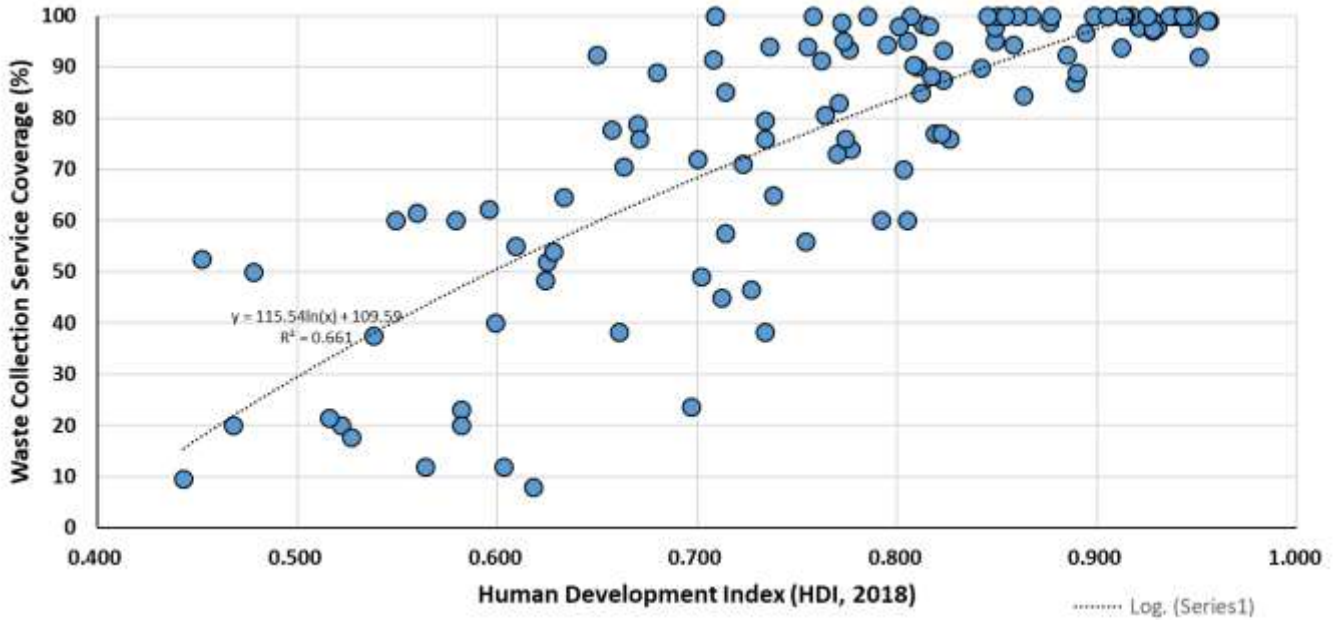


Figure 5. Cross-country plot between waste collection service coverage (%) and Human Development Index (HDI; 2018)

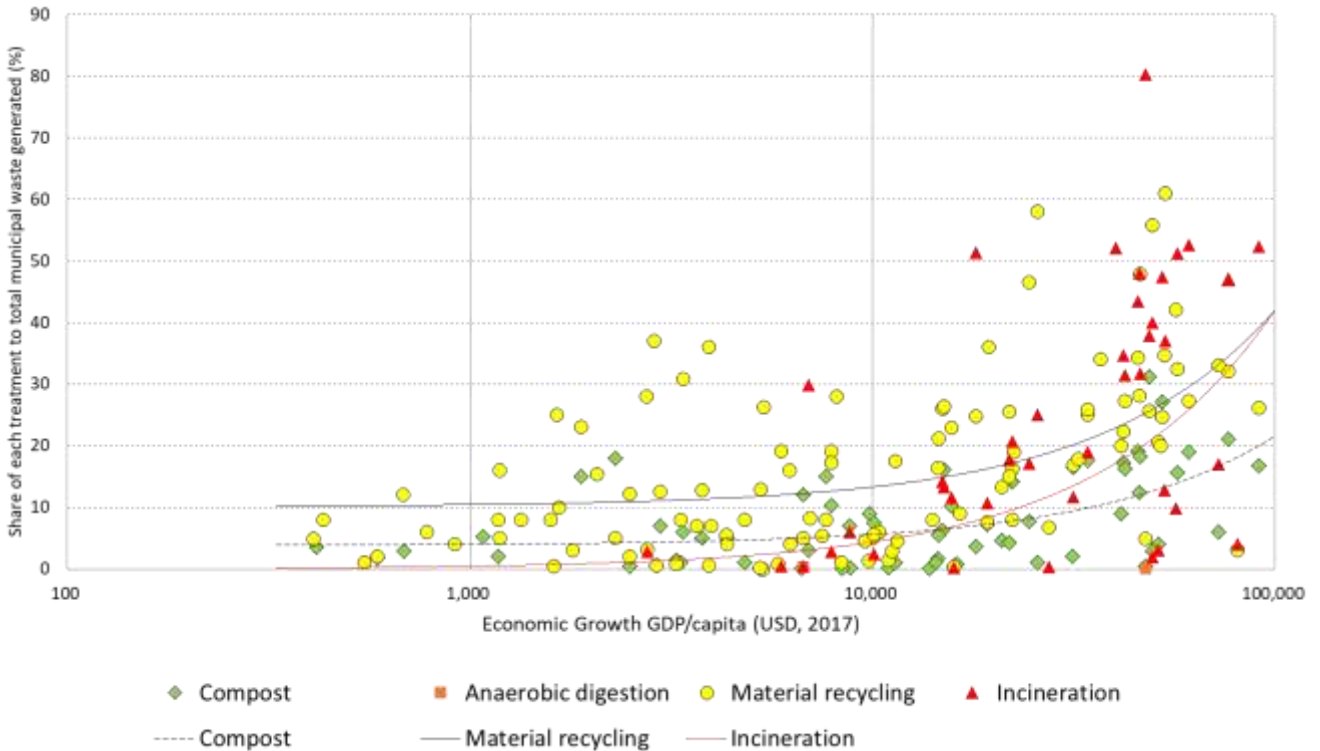


Figure 6. Cross-country correlation between intermediate treatment methods; composting, anaerobic digestion, material recycling, and incineration, (percentage of total generated waste amount) and economic growth (GDP/capita, USD 2017)

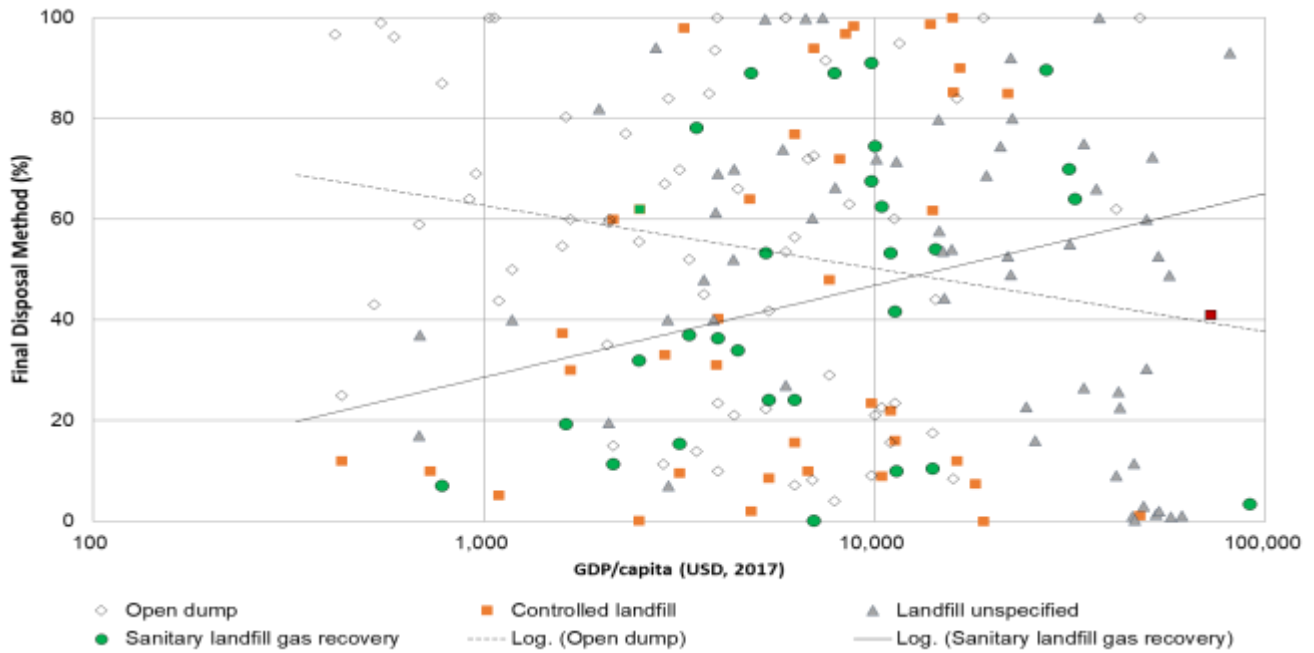


Figure 7. Cross-country correlation between final disposal methods; open dump, controlled landfill, landfill not specified, and sanitary landfill with gas recovery, and economic growth (GDP/capita, USD 2017)

As a result, most of the collected solid waste is reused, recycled, and energy recovered by some intermediate treatment processing, and only the residue after some treatment is landfilled [7]

D. **Final Disposal of Solid Waste**

Final disposal is the final destination for waste stream and is the place where environmental pollution and destruction are potentially most likely occur. If the intermediate treatment is done properly, the problem will be alleviated considerably, but in reality, in many developing countries, more than half of solid waste generated is landfilled without any treatment. In such cases, emission of greenhouse gases is often expected from the dumpsite. Moreover, there is no problem in the case of a sanitary landfill where the structure of the disposal site is designed to minimize emissions (gas and leachate) which cause environmental pollution, but in the case of open dumpsite where no measures are actually taken, the environment pollution inevitably occurs [8].

Fig. 6 show the cross-country plot of various final disposal methods according to the gross domestic product (GDP/capita). There is seemingly no clear correlation among those given methods (open dump, controlled dump, sanitary landfill with gas recovery, landfill unspecified) and economic growth level, but statistically weak trend of increase of sanitary landfill with gas recovery and decrease of open dumpsite. Open dumping, often associated with open burning, is the disposal method with the most environmental/public health load factors [12], and the environmental/public health load factors decrease as control dumps and sanitary landfills are applied. This, although highly

variable, suggests that, in the broader picture, economic growth will gradually reduce environmental burden factors. However, the drivers [13] of improving final disposal is not only economy or financing, but largely depending on administrative, social, and public awareness level on the environment.

IV. **Global Trends in SWM and the Implications**

With reference to the global waste management trends outlined above, it is necessary to consider the following items at each waste management stage (waste generation, collection, intermediate treatment, and final disposal) of SWM:

- (1) Waste generation stage: 1) the waste generation unit is an effective indicator showing the waste generation potential. By comparing with the world trend curve (Fig. 1), it is possible to evaluate the waste generation in given country/region. 2) raising awareness on the environment and waste issues of people and entire society, 3) It is necessary to establish a institutional system to promote the prevention/reduction of waste generation, and 4) the construction of *wastewise* [9] economic society, such as a sound material cycle society, circular economy [10].
- (2) Waste Collection stage: 1) the waste collection service coverage (%) is useful indicator to indicate the present service level (Fig. 2), 2) the service coverage depends on not only financing for investment of waste collection infrastructure, but also on social, economic, and human development. Therefore, comparison with HDI is effective, which provides

the viewpoints of social and human developments..

- (3) Intermediate Treatment stage: 1) it is appropriate to quantify the share of the treated amount in the total amount of waste generated for each intermediate treatment method (Fig. 3), 2) one of the important purposes of intermediate treatment is to avoid direct disposal of untreated solid waste, 3) it is necessary to introduce appropriate intermediate treatment technologies for minimizing the amount of solid waste flowing into the final disposal site, 4) this contributes to prolonging the life of landfills, preventing environmental contamination/pollution, and reducing the potential for greenhouse gas emission, 5) the intermediate treatment technology must be selected by the natural environment and social and economic context, but considering the trends of the world, composting and material recycling are appropriate for low to middle income stage, 6) as the economy develops into middle to high income stage, it is desirable to introduce incineration technology and eventually Waste-to-Energy in parallel with composting and material recycling.
- (4) Regarding the final disposal, 1) it is necessary to close open dump sites at an early stage and switch to disposal to a sanitary landfill for all solid waste landfills. 2) The disposed waste amount in sanitary landfills and its ratio to the total amount of solid waste generated are effective indicators showing the state of final disposal.

v. Conclusions

In this paper, the global trends and issues of SWM in waste generation stage, collection stage, intermediate treatment stage, and final disposal stage are explored through comprehensively analyzing the statistical data of SWM in each country/region.

Cross-country analysis of statistical data on SWM can provide many implications for developing waste management policies and planning. The premise of this approach is the existence of data.

However, especially in developing countries, monitoring is often inadequate, and often unreliable, objective, and accurate SWM data are not available. This is considered to be caused by at least the following points: (i) Inadequate human and financial resources, (ii) Inadequate legal system and standards for solid waste management, (iii) Weak monitoring system, and (iv) Plan-Do-Check-Action (PDCA) cycle management based on SWM data is not well established.

The World Bank dataset was used as the base data for this study, and while it is the most comprehensive dataset available today, further investigation into the reliability and accuracy of each individual data will be required. It is also related to the issue of comprehensive capacity development for solid waste management [10] in each country.

It is necessary to formulate and implement waste management policies and plans based on facts and data, and the challenge is to strengthen data acquisition for that purpose.

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Conflict of Interest

The author declares no potential conflict of interest with respect to the research, authorship, and/or publication of this article.

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