Data-Driven ESG Evaluation Index for Global Waste Management Systems

Kai Sato

E-mail: kai203153@gmail.com

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Abstract

This study addresses the imperative need for comprehensive environmental, social, and governance (ESG) metrics in waste management. Effective waste management is pivotal for sustainable development. However, existing waste management indices lack integration and thorough evaluation. To address this gap, our study utilizes 33 datasets from the What A Waste Global Database by the World Bank. By employing the K-nearest neighbors imputation, min-max normalization, and entropy-based weighting for the construction of the index for an objective and standardized evaluation of waste management systems. Our findings unveil a curvilinear correlation between population density and ESG index scores, exposing unique challenges for low and high-density cities. Higher recycling percentages correlate positively with ESG index scores, highlighting efficient waste collection, citizen involvement, and sustainability endeavors. Country-level analysis reveals regional variations, with European and select Asian countries excelling in waste management ESG efforts. The relationship between GDP per capita and ESG scores adheres to the "Environmental Kuznets Curve," indicating economic development's role in advancing sustainable waste management. Furthermore, the examination of economic and regional groups spotlights the exemplary performance of Scandinavian countries and the G7 in waste management sustainability.

Keywords: ESG, data science, circular economy, waste management,

1. Introduction

As environmental issues and climate change are becoming increasingly problematic, investors are becoming interested in past environmental performance and managerial quality (Murguia et al, 2015). Environmental issues are closely connected to social issues as well. In fact, environmental issues have led to the fall of government, arrests of leading business and political figures, violence, and social and economic hardship in the past (Lester, 2015). In order to catalyze the initiatives working on these issues, ESG investing has established its profound role. Understanding how ESG issues become financially material can enhance risk-adjusted returns for companies and return-first investors, and create market-based incentives for regulators, NGOs, and impact-first investors to align behavior with social and environmental outcomes (Freiberg, 2020). Thus, the disclosure of environmental information influences investment allocation decisions (Holm, 2008). However, two main issues related to ESG metrics undermine their reliability: a lack of transparency and a lack of convergence (Florian, 2022). In the status quo, there is research potential for how to establish an effective and standardized ESG information disclosure system and scoring system (Gao, 2020). This paper aims to aid in fulfilling this research potential by researching the objective ESG index for a comprehensive evaluation of waste management systems.

Effective waste management has implications for saving the environment (M. Almuneef et al, 2003). Proper management and treatment of solid waste are not just ecological concerns; they also influence the overall well-being and prosperity of societies (Kaza et al., 2018). As such, evaluating waste management systems has become integral to understanding a region’s commitment to sustainable development (United Nations, 2020). A critical component of this evaluation lies in the creation of comprehensive indices that provide a synthesized and all-encompassing assessment of waste management practices (Kaza et al., 2018).

While the landscape of waste management is rich with data, a significant gap remains unfilled: the absence of an integrated index that harmonizes diverse metrics into a cohesive whole (Buenrostro et al., 2020; Chen et al., 2021). Various datasets offer insights into different dimensions of waste management, yet their integration into a comprehensive evaluative framework remains a formidable challenge (Buenrostro et al., 2020). Through the judicious application of data and advanced methodologies, this research seeks to fulfill these research potentials and distill the intricate web of waste management practices into a singular, quantifiable index.

The bedrock of this undertaking rests upon the What A Waste Global Database, curated by the World Bank. Renowned for its rigor in data collection and analysis, this database serves as a robust foundation for comprehending waste management practices across diverse global contexts (World Bank, 2023; Kaza et al., 2018).

However, crafting an ESG evaluation index necessitates an objective and systematic approach that goes beyond the mechanical amalgamation of data points (Buenrostro et al., 2020).

Therefore, this study puts a great emphasis on using objective methods to construct the ESG index. KNN imputation, min-max normalization, and entropy weight method are selected.

This paper delves into the complexities of waste management systems through the construction of the ESG evaluation index, serving as an effective tool for evaluating waste management systems across diverse global contexts. This research aims to catalyze private and federal ESG investments towards a circular economy and a sustainable future by providing a comprehensive framework for assessing waste management systems.

2. Method

2.1 Data Sourcing

To attain an unbiased comprehension of recycling systems, a dataset comprising 367 cities across 164 countries was sourced from the What A Waste Global Database by the World Bank. This dataset was harnessed for calculating the ESG evaluation index.

Despite providing extensive data on solid waste management, a comprehensive index that provides an overall evaluation of these waste management systems has not yet been constructed. The information provided in the What A Waste Global Database is the best available, based on a thorough analysis of current literature and limited discussions with waste agencies and relevant authorities (World Bank, 2023).

This study adheres to the practice of assessing indicators in terms of their relevance and data accessibility in accordance with the fundamental tenet of systematicity. Per this principle, indicators with significant data gaps are disregarded. This process culminates in the creation of the ESG evaluation index that includes 33 distinct indicators.

2.2 Data Processing

The extensive data provided by the World Bank is insufficient to comprehensively gauge waste management systems. Scrutinizing a single indicator—recycling rates, for example—does not provide a complete view of the system's ESG initiatives. This research combines the indicators using an objective methodology to comprehensively analyze the available data to evaluate waste management systems.

2.2.1 Missing Data Imputation. This research incorporated the K-nearest neighbors (KNN) imputation method to fill in predictive data for missing values on the What A Waste Global Database. KNN imputation method uses k-nearest neighbor algorithms to estimate and replace missing data (Gimpy, 2014). Furthermore, handling missing data with K-NN-based imputation can reach the accuracy of complete data in each case with a low accuracy difference (Murti, 2019). By using an objective method with high accuracy and little chance of obstructing the data structure, a complete evaluation of the waste management systems is achieved.

2.2.2 Indicator Normalization. In order to fixate the numerous indicators on the same scale, the min-max normalization technique was employed to standardize metrics that exhibit diverse characteristics and units of measurement. Min-max normalization is a straightforward method that allows data to be adjusted within predefined boundaries (Patro, 2015). Since the indicators of the What A Waste Global Database can hint at both positive and negative ESG impacts as a waste management system, all indicators were classified into positive and negative groups. Indicators of the positive group were normalized according to the formula below:

$$r_{ij} = \frac{x - x_{min}}{x_{max} - x_{min}}$$

Indicators of the negative group were normalized with:

$$r_{ij} = 1 - \frac{x - x_{min}}{x_{max} - x_{min}}$$

where x_{min} and x_{max} represent the minimum and maximum values of an indicator, respectively and r_{ij} denotes the normalized decision matrix for the jth indicator of the ith city. Furthermore, a minimal and maximum bias in r_{ij} was induced to avoid getting zero values in the normalized data.

2.2.3 Indicator Weighing. The entropy weight method (EWM) was selected to weigh the selected indicators for the construction of the index. In contrast to various subjective weighting models, the primary advantage of the EWM lies in its ability to eliminate the influence of subjective human factors on indicator weights (Yuxin, 2020). This significantly enhances the objectivity of the overall evaluation results (Yuxin, 2020).

As the degree of dispersion of data increases, so does the level of differentiation, resulting in a higher potential for information extraction. Consequently, the index should be assigned a higher weight in such cases, and vice versa (Yuxin, 2020).

Based on Chenbo et al (2014), the EWM was applied to this research in order to calculate the index score.

The calculation of the entropy values of the jth indicator (e_j) is as follows:

$$e_j = -\frac{1}{ln(m)} \sum_{i=1}^{m} r_{ij}\, ln\, r_{ij}, \quad j = 1, 2, ..., n,$$

where m denotes the number of cities in the sample.

The degree of diversification for the jth indicator (d_j) was calculated as follows:

$$d_j = 1 - e_j$$

The weights of the jth indicator can then be calculated by:

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j}, \quad j = 1, 2, ..., n,$$

The calculation of the degree of diversification serves the purpose of establishing a positive correlation between the initial entropy calculation and indicator weights. This is important because the entropy value exhibits a negative correlation with the amount of information.

Finally, to calculate the weighted decision matrix of the jth indicator for the ith city (p_{ij}), the weights are multiplied by the normalized decision matrix:

$$p_{ij} = w_j r_{ij}$$

2.2.4 Index Score Calculation. After the completion of the weighted decision matrix for all data values, the comprehensive evaluation of each city's waste management systems with respect to their ESG efforts is realized through the calculation of the overall ESG index score. This score, formulated as follows:

$$F_i = \sum_{j=1}^{n} p_{ij}, \quad j = 1, 2, ..., n,$$

provides a holistic perspective on the performance of each analyzed city's waste management practices. This objective index accounts for a range of factors and evaluates the effectiveness of their ESG endeavors. The resultant ESG index score serves as a quantifiable measure that aids in comparing and contrasting sustainability efforts across different cities.

3. Results and Discussion

The resulting index scores for waste management systems in 367 cities are presented in Table 1 in the Appendix. The weights, given to each of the datasets used for the calculation of the ESG scores are shown in Table 2 in the Appendix.

3.1 ESG index score analysis: relationship with population density

First, the relationship between the city's overall ESG index score was compared with its population density.

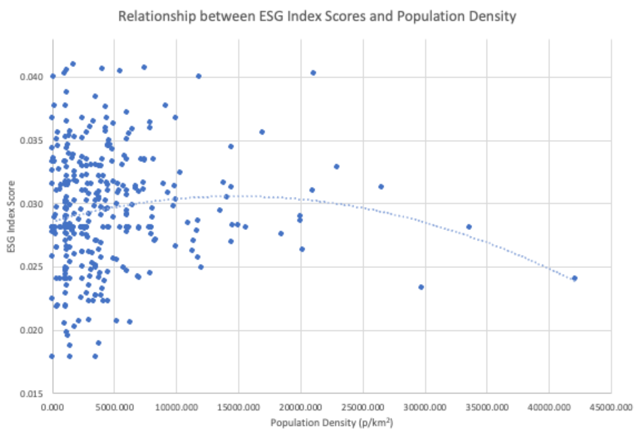

Fig. 1. Relationship between population density and the ESG index score of measured cities. The graph showcases a curvilinear trend, with ESG index scores initially rising with population density until an optimal point of around 16,000 people/km², after which scores begin to decline. This trend suggests distinct waste management challenges faced by low and high-population-density cities.

Figure 1 shows the general trendline between the population density of the measured cities and the ESG index score that it received. This research uncovered a positive trend in ESG index scores as population density increased, followed by a negative trend after reaching an optimal population density of around 16,000 people/km². While the dispersion of the index scores in the lower population density cities has resulted in a subtle increase in ESG index scores as population density increases, a steeper drop in ESG index scores can be seen after reaching the optimal population density.

A reason for this curvilinear trend can be hinted from the systems of most waste management systems. Cities of low population density will face challenges in recovering the costs of transportation while only collecting little revenue from citizens and revenue from selling recycled materials. Therefore, there are few investment opportunities for developing waste management systems in those cities. However, the low population density cities with high ESG index scores are able to combat these issues by reducing the waste collection days to lower their transportation costs and advocating for cost-efficient waste management systems like recycling where they can recover waste management costs as much as possible by selling recycled materials. Thus, recycling serves as a method to lower waste management costs for cities struggling to recover them.

Conversely, in cities of high population density, urbanization and the complexities of the required waste management systems to handle large volumes of waste come into play (Voukkali, 2023).

Governments must develop a sophisticated system to collect waste from a large population of people and manage it in a small area of land. Cities that are incapable of doing so, for reasons like lack of funding, resulting in people with no access to waste management systems, or the participation of informal sectors in the waste collection systems, as those cities are generally troubled by unemployment and poverty as well (Eneh, 2021). These hinder the development of sustainable waste management systems, resulting in issues in the environmental, social, or governance sectors.

3.2 Analysis of individual datasets

This research used the World Bank's What a Waste Database to curate and analyze 33 datasets. Although the final ESG index score is collectively drawn from the 33 datasets, the general trendline between a city's score for one dataset and its final ESG index score was investigated.

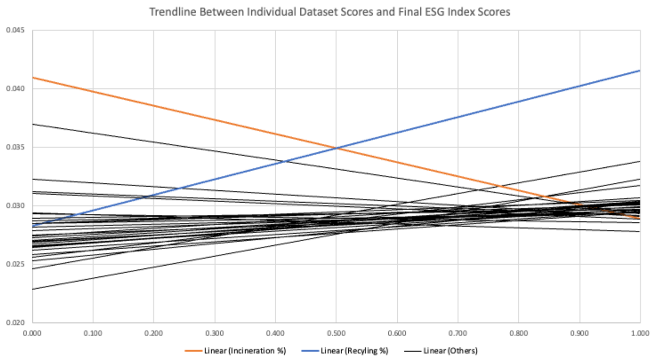

Fig. 2. The correlation between recycling percentages and the final ESG index scores. Higher recycling percentages exhibit a positive connection with superior ESG index scores, reflecting the impact of efficient waste collection systems, citizen participation, and sustainability efforts in waste management.

As shown in Figure 2, the normalized values for recycling percent showed a significant correlation to a city's final ESG index score. Cities with a higher percentage of recycling used to treat their waste seemed to generate high ESG index scores. Compared to other datasets used to calculate the final ESG index score, recycling as a percentage of methods used to treat waste acts as a modest indicator of the overall quality of the waste management system towards a sustainable circular economy future.

Reasons for this may lie in the funds and work necessary to develop a waste management system that is capable of producing a high recycling rate. In order for recycling to be done, the system must have a sophisticated collection system, often aided by the citizens' participation in sorting to reduce the costs and advocate for an efficient waste management system. Moreover, the opportunity cost for choosing to recycle positively impacted the final ESG index score, as any method of treatment except recycling or composting is negatively evaluated on the index. Therefore, increasing the recycling rate is connected to a necessity for an improvement in the governance factor in making the public participate in sorting and building an efficient collection system, as well as in the environmental sector, by lowering the need to use environmentally negative methods of waste treatment. These are mutually beneficial and should be the main focus when developing a sustainable waste management system towards a circular economy.

However, also seen in Figure 2, the normalized scores for incineration rate correlate most negatively with the final ESG index score. This means that a high incineration rate correlates with a high ESG index score of a city. While this is not the correlation that is optimistic for a sustainable future, as this research categorized incineration as a negative method of waste treatment, this phenomenon can be explained by many of the cities with low ESG index scores using other methods like open dump, or large percentage of waste not being treated at all. Due to this, cities with waste management systems that depend on incineration as a method of waste treatment generally received greater scores than cities with little to no incineration, and instead, are dumping their waste without treatment. While this may disadvantage the cities with a developed system of waste management but relying on incineration for treatment, those cities should look up to cities receiving higher ESG index scores and advocate for recycling as an alternative to other waste treatment methods. (Koufodimos et al, 2002) outline this, claiming that recycling and composting will be an essential part of contemporary waste management strategies, while incineration seems to be a conditionally feasible solution.

While some individual datasets may indicate a city's performance as the overall ESG index score, these partial insights are insufficient to gain a comprehensive view and evaluation of the diverse waste management systems in the world. This research uses an objective method to weigh and evaluate the datasets collectively and provide a final ESG index score. These can be beneficial for better comparison and analysis of the world's waste management systems at a city-level view and to base these analyses and scores on developing a better waste management system for a sustainable future.

3.3 ESG index score analysis: country-level

This research also analyzed the average ESG index scores for individual countries. While many of the waste management systems are city-level scale, many are highly dependent on federal support to finance their systems. This analysis provides insight into the countries' support and initiatives for the development of effective waste management systems.

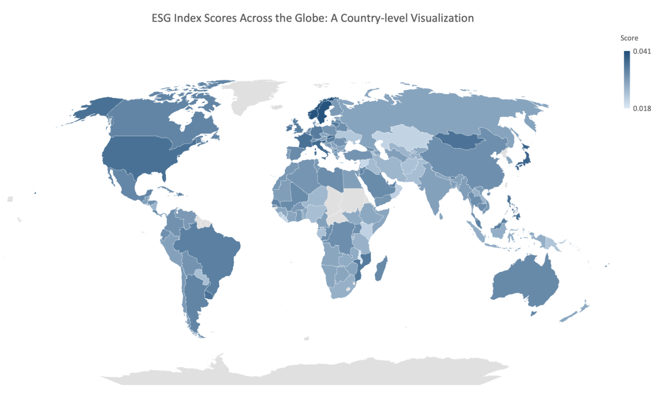

Fig. 3. Map displaying the average ESG index scores for countries across the world. The map highlights regional variations, with European countries and a few Asian and American nations leading in waste management ESG efforts, while some African and Asian countries lag behind.

Figure 3 displays a country's mean ESG index scores on a map. Countries in Europe, like Lithuania, Ireland, France, Italy, and the Slovak Republic dominate the countries over 0.035, with European states of Sweden, Norway, and Slovenia being the only countries achieving scores above 0.040. Other countries above 0.035 include several countries in Asia—Mongolia, Philippines, Kuwait, and Japan—the US in North America, Uruguay in South America, and Mozambique in Africa. At the other end, however; Asian and African countries dominate with seven Asian states—Syria, Kazakhstan, Maldives, Oman, Afghanistan, Pakistan, and Armenia—and five African states—Malawi, Liberia, Kenya, Sierra Leone, and Gabon—receiving scores less than 0.025. Other states in this group include the Solomon Islands and Papua New Guinea in Oceania, Ukraine in Europe, and Paraguay in South America.

To further analyze these trends, the distribution of the ESG index scores for each continent was graphed as shown in Figure 4.

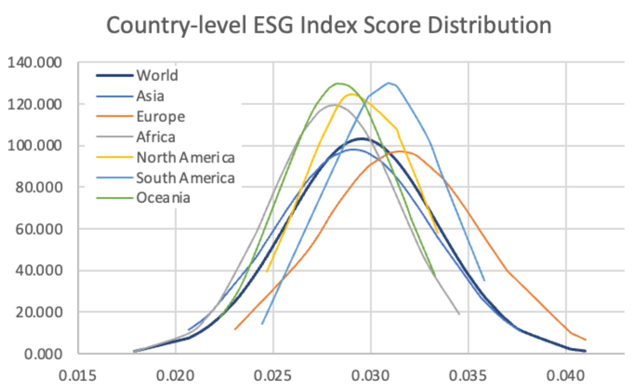

Fig. 4 The distribution of ESG index scores across continents; reveals variations in the mean scores. African and Oceanic countries exhibit lower mean scores, while Asia, Europe, and North America possess wider spreads of scores.

The ESG index scores for Africa, North and South America, and Oceania, are distributed densely, with African countries concentrated at the lowest end out of all continents, followed by Oceania, North America, and then South America. For Asia and Europe, the spread is wider, but the general mean for the ESG index scores for Asia is greater than for Africa and Oceania. European countries record the highest mean ESG index score among all continents. Therefore, while there are more Asian countries in the lower end as illustrated in the previous paragraph, the number of countries in Asia makes the spread of data wide and raises their mean score compared to nations in other continents.

3.4 ESG index score analysis: GDP per capita comparison

The average ESG index scores for each country were evaluated against their GDP per capita, as shown in Figure 5.

Fig. 5. The relationship between GDP per capita and ESG index scores. The graph demonstrates an increasing trend until a plateau is reached at approximately 80,000 USD, suggesting the role of economic development in advancing waste management systems.

The general trendline of increasing ESG index scores as GDP per capita increases was seen until it plateaus after around 80,000 USD. This may be explained by the municipalities in charge of the waste management systems being able to charge more from its users and thus invest and operate the system at a higher cost. Higher investments in the development and operation of waste management systems allow for more sustainability and efficiency while staying away from hiring informal workers to keep costs low as well as boost their governance scores by utilizing their funds to construct an effective governance structure for their waste management systems. Panmayoutou (2000) outlines this claim, by stating that although a country's economic development is not fixed by its environmental quality, this changes as a country's income level reaches a point where it can afford a more efficient infrastructure and a cleaner environment. This implied relationship demonstrated as the "Environmental Kuznets Curve," is seen in this research as well. The analyzed cities and countries can be categorized as: a) countries without a developed waste management system, where waste is left untreated or openly dumped, b) countries with an operating waste management system but are inefficient, and rely on unsustainable methods to treat their waste, or c) Countries with the infrastructures necessary to support an effective, efficient, and sustainable waste management system. In the status quo, most countries lie in the middle section, with a few currently making the transition to the last category. In order to progress toward a sustainable future, all countries must be equipped with waste management systems in the final category.

However, countries with low GDP per capita, and additionally, low GDP, face challenges due to increasing waste generation, high costs, lack of understanding, and inability to make financial investments (Guerrero et al, 2015). Thus, issues such as informal workers and using unsustainable methods to treat their waste to keep costs low, arise. The developed countries, in addition to further improving their own waste management system to reach the final category, and especially the countries in the plateau region of Figure 5, should make further commitments to financially or technologically support the development of effective waste management systems in less developed countries that are still stuck in the first category.

3.6 ESG index score analysis: regional and global level

Numerous international forums, organizations, and groups of countries work together to set specific goals or support each other to move forward with their environmental initiatives. Many also have specific targets or mutual rules on waste management. This research observed these international groups, both economic and regional, to see their advancements in developing effective waste management systems.

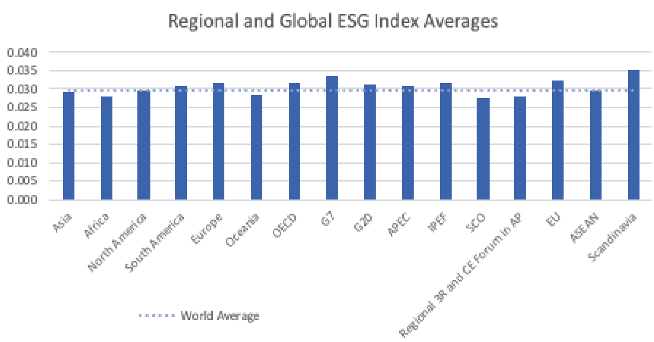

Fig. 6. The average ESG index scores for various regional and economic groups. Scandinavian countries lead in ESG scores, while different economic and regional alliances show varying levels of progress in waste management sustainability.

The mean values for each continent, as discussed above, are ranked from Africa at the bottom, Oceania, Asia, and North America, then South America and Europe above the world average. For geographical groups of EU, ASEAN, and Scandinavia, ASEAN countries fall just below the world average, the EU with a relatively high average, and Scandinavian countries hold the highest average ESG index scores out of every other group analyzed. Known for their spearheading environmental initiatives, the Scandinavian countries do not upset this image for its development of waste management systems as well. For other economic groups of countries, the SCO and countries participating in the Regional 3R and Circular Economy Forum in Asia and the Pacific fall below the world average. With the Regional 3R and Circular Economy Forum in Asia and the Pacific being the only group that focuses specifically on waste management and recycling for a circular economy, the countries within it fail to meet the expectations to lead the world in developing effective waste management systems and instead, lag behind.

The G7 countries, as the world's most advanced economies, lead the other groups of countries united by economic levels. At the recent G7 summit in Hiroshima, the G7 Ministers of Climate, Energy, and the Environment (2023) addressed the importance of enhancing resource efficiency and circularity along value chains to reduce primary resource use and support the efforts to address the triple crisis. In the communique, the G7 countries have also shown their commitment to achieving net-zero emissions by 2050 from the waste sector, stressing the importance of measuring circularity and environmental impacts and sharing and utilizing data along entire value chains to enable further collaboration between manufacturers and recyclers, among other actors. The G7 plans to lead the way and support low and middle-income countries to increase resource efficiency and circularity in their economies while also addressing the urgent need for infrastructure through financial and technical support. The role of MDBs and other financial institutions in mobilizing financial support toward such projects and initiatives to support developing countries is significant.

These resources should optimally be utilized to catalyze the movement towards a circular economy and develop effective waste management systems for a sustainable future.

4. Conclusion

This research employed a dataset of 367 cities from various countries to construct an ESG evaluation index for waste management. Missing data were addressed using K-nearest neighbors imputation, followed by indicator normalization and entropy-based weighting for the calculation of the final ESG Index scores for a comprehensive evaluation of waste management systems. Analysis of the ESG index scores against population density showed a curvilinear relationship. With the increase in population density, ESG scores exhibit a rising trend until they reach an optimal density of approximately 16,000 people per square kilometer, beyond which they start to decline. This is explained by low-density cities facing challenges recovering transportation costs and lack of investment opportunities, while high-density cities grapple with urbanization complexities, informal sectors, and poverty, hindering sustainable waste management development. A positive correlation emerged between higher recycling percentages and enhanced ESG index scores. Conversely, high incineration rates correlated negatively with ESG scores, possibly due to the prevalence of incineration. Individual datasets provide partial insights, and thus, this index provides a deeper analysis. Country-level analysis revealed European dominance in higher scores (above 0.035), whereas Asian and African nations were more prevalent at the lower end. The distribution of data showcased densely spread ESG index scores for Africa, North and South America, and Oceania, while Asia and Europe exhibited broader spreads. The general trend indicated that ESG scores increased in tandem with rising GDP per capita until reaching a plateau of around 80,000 USD, aligning with the proposed "Environmental Kuznets Curve." This suggests that higher-income countries can invest in more sustainable and efficient waste management systems, mitigating informal labor and bolstering governance structures.

At an international level, Scandinavian countries displayed the highest scores, with the G7 demonstrating positive results from their international collaboration.

Based on the results above, this paper proposes a few recommendations for international collaboration and policies. First of all, the future development of waste management systems should be centered around two goals. First, countries that are yet to develop a waste management system, and are currently dumping waste, or leaving them untreated should receive the necessary funds through either investment or loans, to develop a functioning system for the collection and treatment of waste in the country. Governmental collaboration with Multilateral Development Banks (MDBs) and other international financial institutions is necessary to secure the required funds and technological assistance for the construction of effective waste management systems. For this, developed countries should maintain transparency in their waste management, as well as use their voice to allocate their funds in the MDBs for projects to design and build waste management systems in those countries. In the process, international or local entities may be involved in providing technological aid for infrastructures. Designing an effective waste management system is crucial in boosting environmental considerations, as well as for the people to stay away from health and safety hazards caused by the lack of access to waste management systems. Secondly, focus on the transition to sustainable waste management systems should be given priority for governmental policies in the more developed countries. Developed countries, like those in the G7, should lead the way in designing and operating an effective and sustainable waste management system, to demonstrate to the less developed countries, what to look upon. The transition to recycling is a necessity for a circular economy and a sustainable future.

There are several limitations to this research that could be further elaborated on in future research. This research only employed the entropy weight method to weigh the datasets due to an emphasis on the objectivity of ESG evaluation methods. The application of alternative methods, such as incorporating expert opinions to subjectively assess dataset weights, might unveil novel insights into the waste management systems of cities. Furthermore, conducting a longitudinal study by using an updated dataset and analyzing the trends of cities and countries may provide further insight into the progression of the development of waste management systems. Using datasets with fewer missing values will also add to the validity of the research.

5. Appendix

Table A1. ESG index scores for waste management systems in 367 cities

Cty	INDEX SCORE	Cty	INDEX SCORE	Cty	INDEX SCORE	Cty	INDEX SCORE	Cty	INDEX SCORE	Cty	INDEX SCORE	Cty	INDEX SCORE	Cty	INDEX SCORE	Cty	INDEX SCORE	Cty	INDEX SCORE
Ljubljana (Slovenia)	0.041	Pristina (Kosovo)	0.035	Rufisque (Senegal)	0.033	Beijing (China)	0.031	Caracas (Venezuela, RB)	0.030	Tadipatri (India)	0.028	Debre Tabor (Ethiopia)	0.028	Kemerovo (Russian Federation)	0.028	Kotor (Montenegro)	0.026	Srinagar (India)	0.024
Milano (Italy)	0.041	Cuttack (India)	0.035	HarareÂ (Zimbabwe)	0.033	Minsk (Belarus)	0.031	Phuentsholin gÂ (Bhutan)	0.030	Vijaywada (India)	0.028	Bati (Ethiopia)	0.028	Badimalika (Nepal)	0.028	Tehran (Iran, Islamic Rep.)	0.026	HiratÂ (Afghanistan)	0.024
Berlin (Germany)	0.041	Kurunegala (Sri Lanka)	0.035	Algiers (Algeria)	0.033	Vavaâ€™u (Tonga)	0.031	Santiago De Chile (Chile)	0.030	Banja Luka (Bosnia and Herzegovina)	0.028	Halaba Kulito (Ethiopia)	0.028	Kochi (India)	0.028	Yangon (Myanmar)	0.026	Port Moresby (Papua New Guinea)	0.024
Bergen (Norway)	0.041	Dublin (Ireland)	0.035	Mandalay (Myanmar)	0.033	Quito (Ecuador)	0.031	Monterrey (Mexico)	0.030	Itanagar (India)	0.028	Dembi Dolo (Ethiopia)	0.028	Jutiapa (Guatemala)	0.028	Kota (India)	0.026	Tashkent (Uzbekistan)	0.023
Stockholm (Sweden)	0.040	Bern (Switzerland)	0.035	Greater Mumbai (India)	0.033	Ahmedabad (India)	0.031	San Miguelito (Panama)	0.030	Seoul (Korea, Rep.)	0.028	Riihimaki (Finland)	0.028	Korca (Albania)	0.028	Ludhiana (India)	0.025	Karachi (Pakistan)	0.023
Paris (France)	0.040	Ottawa (Canada)	0.035	Abu Dhabi (United Arab Emirates)	0.033	Tunis (Tunisia)	0.031	Pohnpei (Micronesia, Fed. Sts.)	0.030	Dhaka (Bangladesh)	0.028	Turku (Finland)	0.028	Juba (South Sudan)	0.028	Niamey (Niger)	0.025	San Lorenzo (Paraguay)	0.023
Oslo (Norway)	0.040	Bristol (United Kingdom)	0.035	Sikasso (Mali)	0.033	Chennai (India)	0.031	Moroni (Comoros)	0.030	Luanda (Angola)	0.028	Kumasi (Ghana)	0.028	Lome (Togo)	0.028	Ghaziabad (India)	0.025	Allahabad (India)	0.023
BorÃ¥s (Sweden)	0.040	Moscow (Russian Federation)	0.035	Alajuela (Costa Rica)	0.033	BogotÃ¡ (Colombia)	0.031	Bhopal (India)	0.030	Pago Pago (American Samoa)	0.028	Labe (Equatorial Guinea)	0.028	Nicosia (Cyprus)	0.028	Ciudad Del Este (Paraguay)	0.025	Bujumbura (Burundi)	0.023
Osaka (Japan)	0.040	Maputo (Mozambique)	0.035	Skopje (Macedonia, FYR)	0.032	Lisbon (Portugal)	0.031	Bucharest (Romania)	0.030	Vienna (Austria)	0.028	Douglas (Isle of Man)	0.028	Greater Hyderabad Â (India)	0.028	AsunciÃ³n (Paraguay)	0.025	Tangier (Morocco)	0.023
Bratislava (Slovak Republic)	0.039	Novi Sad (Serbia)	0.035	Guadalajara (Mexico)	0.032	Cali (Colombia)	0.031	Thessaloniki (Greece)	0.030	Kayanza (Burundi)	0.028	Saipan (Northern Mariana Islands)	0.028	Wellington (New Zealand)	0.028	Rudrapur (India)	0.025	EldoretÂ (Kenya)	0.023
Budapest (Hungary)	0.038	Ciudada AutÃ³noma De Buenos Aires (Caba). (Argentina)	0.034	Cluj-Napoca (Romania)	0.032	Bamako (Mali)	0.031	Zagreb (Croatia)	0.030	Brussels (Belgium)	0.028	Windhoek (Namibia)	0.028	Saida (Lebanon)	0.028	Amritsar (India)	0.025	St.petersburg (Russian Federation)	0.023
Yokohama (Japan)	0.038	Beni Mellal (Morocco)	0.034	San JosÃ© (Costa Rica)	0.032	Rio De Janeiro (Brazil)	0.031	Cakovec (Croatia)	0.030	Porto Novo (Benin)	0.028	Ilorin (Nigeria)	0.028	Kiev (Ukraine)	0.027	Baghdad (Iraq)	0.025	Johannesburg Â (South Africa)	0.023
Kitakyushu (Japan)	0.038	Soldanesti (Moldova)	0.034	Antananarivo (Madagascar)	0.032	Rajshahi (Bangladesh)	0.031	Hanoi (Vietnam)	0.030	Cotonou (Benin)	0.028	Kano (Nigeria)	0.028	Kanpur (India)	0.027	Bishkek (Kyrgyz Republic)	0.025	Puerto Cabezas (Nicaragua)	0.022
Toyama (Japan)	0.038	Amsterdam (Netherlands)	0.034	Sfax (Tunisia)	0.032	Navi Mumbai (India)	0.031	Chisinau (Moldova)	0.029	Bobo Dioulasso (Burkina Faso)	0.028	Oyo (Nigeria)	0.028	Podgorica (Montenegro)	0.027	Trincomalee (Sri Lanka)	0.025	Honiara (Solomon Islands)	0.022

Washington Dc (United States)	0.038	CÃ³rdoba (Argentina)	0.034	Suva (Fiji)	0.032	Manama (Bahrain)	0.031	Gweru (Zimbabwe)	0.029	Ruse (Bulgaria)	0.028	Eindhoven (Netherlands)	0.028	Moratuwa (Sri Lanka)	0.027	Spitak (Armenia)	0.025	Freetown (Sierra Leone)	0.022
Kobe (Japan)	0.037	Vilnius (Lithuania)	0.034	San Pedro Sula (Honduras)	0.032	Yaounde (Cameroon)	0.031	San Pedro (Belize)	0.029	Burgas (Bulgaria)	0.028	Auckland (New Zealand)	0.028	Bengaluru (India)	0.027	PanamÃ¡ City (Panama)	0.025	Belgrade (Serbia)	0.022
Leh (India)	0.037	Distrito Federal, Brasilia (Brazil)	0.034	Sarajevo (Bosnia and Herzegovina)	0.032	Banjul (Gambia, The)	0.031	Chittagong (Bangladesh)	0.029	Gaborone (Botswana)	0.028	Lodzi (Poland)	0.028	Bhaktapur (Nepal)	0.027	GwaliorÂ (India)	0.025	Birgunj (Nepal)	0.022
Kuwait City (Kuwait)	0.037	KrakÃ³w (Poland)	0.034	Ouagadougou (Burkina Faso)	0.032	Kratovo (Macedonia, FYR)	0.031	Nouakchott (Mauritania)	0.029	Vancouver (Canada)	0.028	GuimarÃ£es (Portugal)	0.028	Biratnagar (Nepal)	0.027	Atyrau (Kazakhstan)	0.025	Gjilan (Kosovo)	0.022
Liege (Belgium)	0.037	Ann Arbor (United States)	0.034	Tbilisi (Georgia)	0.032	Medellin (Colombia)	0.031	Dili (Timor-Leste)	0.029	Zurich (Switzerland)	0.028	Ramallah (West Bank and Gaza)	0.028	Koror (Palau)	0.027	San Salvador (El Salvador)	0.025	Bharatpur (Nepal)	0.022
Tenali (India)	0.037	Dhankuta (Nepal)	0.034	Tripoli (Libya)	0.032	La Paz (Bolivia)	0.031	Guatemala City (Guatemala)	0.029	Abidjan (Côte d'Ivoire)	0.028	Hargeysa (Somalia)	0.028	DushanbeÂ (Tajikistan)	0.027	Jodhpur (India)	0.025	Muscat (Oman)	0.022
Seattle (United States)	0.036	Dubai (United Arab Emirates)	0.034	Dhanbad (India)	0.032	Pimpri-Chinchwad (India)	0.031	Perth (Australia)	0.029	Limbe (Cameroon)	0.028	Bursa Mm (Metropolitan Municipality) (Turkey)	0.028	Jakarta (Indonesia)	0.027	Bhubaneswar (India)	0.025	Nyagatare (Rwanda)	0.022
Thimphu (Bhutan)	0.036	Tel Aviv (Israel)	0.033	Riga (Latvia)	0.032	Madrid (Spain)	0.031	Mysore (India)	0.029	Douala (Cameroon)	0.028	Mountain Kilimanjaro (Tanzania)	0.028	Lalitpur (Nepal)	0.027	Dar Es Salaam (Tanzania)	0.025	Fuahmulah (Maldives)	0.021
Sao Paulo (Brazil)	0.036	Kuala Lumpur (Malaysia)	0.033	Phnom Penh (Cambodia)	0.032	Riyadh (Saudi Arabia)	0.031	Managua (Nicaragua)	0.029	Bafoussam (Cameroon)	0.028	Namangan (Uzbekistan)	0.028	Port Au Prince (Haiti)	0.027	Mbare (Zimbabwe)	0.024	Monrovia (Liberia)	0.021
Warangal (India)	0.036	Imphal (India)	0.033	Accra (Ghana)	0.032	Dharan (Nepal)	0.031	Cairo (Egypt, Arab Rep.)	0.029	Paralimini (Cyprus)	0.028	Cape Town (South Africa)	0.028	Lusaka (Zambia)	0.027	Kabul (Afghanistan)	0.024	Damascus (Syrian Arab Republic)	0.021
Cebu (Philippines)	0.036	Doha (Qatar)	0.033	Jerusalem (Israel)	0.032	Lahore (Pakistan)	0.031	Debrecen (Hungary)	0.029	Karlovy Vary (Czech Republic)	0.028	Soweto (South Africa)	0.028	Khujand (Tajikistan)	0.027	ColÃ³n (Panama)	0.024	Nairobi (Kenya)	0.021
Naha (Japan)	0.036	Santo Domingo (Dominican Republic)	0.033	Lucknow (India)	0.032	Beirut (Lebanon)	0.030	Ashgabat (Turkmenistan)	0.029	Prague (Czech Republic)	0.028	Durban (South Africa)	0.028	Tongatapu (Tonga)	0.027	Faridabad (India)	0.024	Addu (Maldives)	0.020
Toronto (Canada)	0.036	KigaliÂ (Rwanda)	0.033	Liepaja (Latvia)	0.032	SanaÃ¡ (Yemen, Rep.)	0.030	Addis Ababa (Ethiopia)	0.029	Hamburg (Germany)	0.028	NdolaÂ (Zambia)	0.028	Vientiane (Lao PDR)	0.026	Vanadzor (Armenia)	0.024	Patna (India)	0.020
Montevideo (Uruguay)	0.036	Nashik (India)	0.033	Majuro (Marshall Islands)	0.032	Rosario (Argentina)	0.030	Athens (Greece)	0.029	Copenhagen (Denmark)	0.028	Kadoma City (Zimbabwe)	0.028	Indore (India)	0.026	Libreville (Gabon)	0.024	Ibadan (Nigeria)	0.020
Guwahati (India)	0.036	Rabat (Morocco)	0.033	Pokhara (Nepal)	0.032	Coimbatore (India)	0.030	Bhimeshwor (Nepal)	0.029	Mostaganem (Algeria)	0.028	Norton (Zimbabwe)	0.028	Colombo (Sri Lanka)	0.026	Rajkot (India)	0.024	Sialkot (Pakistan)	0.020
Melbourne (Australia)	0.036	Oulu (Finland)	0.033	Angers-Loire Metropole (France)	0.032	Tegucigalpa (Honduras)	0.030	Cusco (Peru)	0.029	Tallinn (Estonia)	0.028	Chinhoyi (Zimbabwe)	0.028	Bloemfontein Â (South Africa)	0.026	Jalalabad (Afghanistan)	0.024	Lagos (Nigeria)	0.019
Canberra (Australia)	0.036	Sakarya Mm (Turkey)	0.033	Kinshasa (Congo, Dem. Rep.)	0.032	Butwal (Nepal)	0.030	Baku (Azerbaijan)	0.029	Tartummaa (Estonia)	0.028	Kariba (Zimbabwe)	0.028	Delhi (India)	0.026	Kandahar (Afghanistan)	0.024	Pavlograd (Ukraine)	0.019
Quezon City (Philippines)	0.036	Upolu (Apia) (Samoa)	0.033	Dolisie (Congo, Rep.)	0.032	Djiibouti City (Djibouti)	0.030	Kathmandu (Nepal)	0.029	Adola Woyu (Ethiopia)	0.028	Masvingo City (Zimbabwe)	0.028	Moshi (Tanzania)	0.026	Mazar-E-Sharif (Afghanistan)	0.024	Kostanay (Kazakhstan)	0.018
Ulaanbaatar (Mongolia)	0.036	Parma (Italy)	0.033	Jaipur (India)	0.032	Osh (Kyrgyz Republic)	0.030	Pune (India)	0.029	Bule Hora (Ethiopia)	0.028	SakubvaÂ (Zimbabwe)	0.028	Jaffna (Sri Lanka)	0.026	Muyinga (Burundi)	0.024	Blantyre (Malawi)	0.018
MÃ©xico City (Mexico)	0.035	Pamplona (Spain)	0.033	Bangkok (Thailand)	0.032	Patuakhali (Bangladesh)	0.030	Rangpur (Bangladesh)	0.029	Maichew (Ethiopia)	0.028	Kozhikode (India)	0.028	Sousse (Tunisia)	0.026	Ngozi (Burundi)	0.024	Lilongwe (Malawi)	0.018
Kaunas (Lithuania)	0.035	London (United Kingdom)	0.033	Havana (Cuba)	0.031	Ho Chi Minh City (Vietnam)	0.030	Surat (India)	0.028	Tepi (Ethiopia)	0.028	Conakry (Guinea)	0.028	South Tarawa (Kiribati)	0.026	Dire Dawa (Ethiopia)	0.024		
Vishakhapatnam (India)	0.035	Amman (Jordan)	0.033	Kampala (Uganda)	0.031	Antigua Guatemala	0.030	Vlora (Albania)	0.028	Gerbe Guracha	0.028	Funafuti (Tuvalu)	0.028	Belize City (Belize)	0.026	Male (Maldives)	0.024		

						(Guatemala)				(Ethiopia)							
Trnava (Slovak Republic)	0.035	Jeddah (Saudi Arabia)	0.033	Grodno (Belarus)	0.031	Shimla (India)	0.030	Port Vila (Vanuatu)	0.028	Weldiya (Ethiopia)	0.028	Dehiwala Mt. Lavinia Municipal Council (Sri Lanka)	0.028	Nagpur (India)	0.026	Tirunelveli (India)	0.024

Table A2. ESG index scores for waste management systems in 367 cities

Category	Indicator	Sign(±)	Weight
Environment Pillar	Waste collected (% of total waste)	1	20.41%
	Advanced thermal treatment (% of total waste)	-1	1.49%
	Anaerobic digestion (% of total waste)	-1	0.55%
	Compost (% of total waste)	1	3.08%
	Controlled landfill (% of total waste)	-1	2.49%
	Incineration (% of total waste)	-1	0.20%
	Landfill unspecified (% of total waste)	-1	0.48%
	Open dump (% of total waste)	-1	3.81%
	Other (% of total waste)	-1	0.66%
	Recycling (% of total waste)	1	8.03%
	Sanitary landfill & landfill gas system (% of total waste)	-1	1.91%
	Unaccounted for (% of total waste)	-1	6.26%
	Transportation distance from city center to main landfill or dumpsite (km)	-1	16.67%
	Separation of cans & metals (Y/N)	1	1.44%
	Separation of glass (Y/N)	1	1.43%
	Separation of organics (Y/N)	1	1.41%
	Separation of other materials (Y/N)	1	1.52%
	Separation of paper cardboard (Y/N)	1	1.47%
	Separation of plastics & packaging (Y/N)	1	1.46%
	Source separation (Y/N)	1	1.33%
Social Pillar	Child waste pickers (% of total workers)	-1	21.63%
	Female waste pickers (% of total workers)	-1	22.69%
	Informal sector pickers (% of total workers)	-1	7.84%
	Population access to WMS (% of total population)	1	9.72%
Governance Pillar	Department dedicated to solid waste management (Y/N)	1	1.54%
	Environmental assessment for solid waste (Y/N) management in the past 5 years (Y/N)	1	1.30%
	Information system for solid waste management (Y/N)	1	1.24%
	Performed a social assessment for solid waste management in the past 5 years (Y/N)	1	1.27%
	Unit enforcing solid waste issues in the city such as illegal dumping or littering (Y/N)	1	1.50%
	Long term integrated solid waste master plan (Y/N)	1	1.41%
	Master plan is being implemented (Y/N)	1	1.41%
	Solid waste management rules and regulations (Y/N)	1	1.55%
	Communication summary of key solid waste information made periodically available to the public (Y/N)	1	1.58%

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