Resources, Conservation and Recycling 114 (2016) 32–41

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

Performance evaluation and benchmarking of global waste management systems

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ARTICLE INFO

Article history:
Received 16 March 2016
Received in revised form 8 June 2016
Accepted 21 June 2016
Available online 14 July 2016

Keywords:
Waste management
Economic benefits
Environmental benefits
Waste mapping
Zero waste

ABSTRACT

This paper presents the environmental and economic benefits of global waste management systems in the context of zero waste practices. The study analysed the waste management performance of 168 countries around the globe and evaluated their performance using the zero waste tool. The Zero Waste Index measures the material substitution potential of waste. This is done by taking into account the amount of materials recovered from waste, which potentially substitute the demand for virgin materials. By substituting virgin materials' demand, we could potentially substitute the demand for energy, water, and avoid greenhouse gas (GHG) emission. The study analysed waste management systems in 168 countries and presented its findings using the mapping techniques of Geographic Information Systems (GIS). The findings of the study suggested that globally, an average person generated around 435 kg of waste each year, out of which an estimated 50 kg of materials (paper, plastic, metal, glass and others) potentially substitute the demand for the extraction of virgin materials. By substituting the demand for virgin materials, through 'zero waste activities', an average person could potentially save around 216 kWh of energy, 0.05 kg GHG and 36 L of processed water. Globally, each person would then potentially save around $61.3 annually, of which $17 would arise from materials substitution, and $44 from energy substitution. The study suggested that energy substitution potentially contributed over twice the economic benefits as materials substitution in resource recovery from waste.

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1. Introduction

Sustainable waste management is one of the most important global environmental agendas in the twenty- first century (UNEP, 2012). The quantity of global waste increases as the population and the level of resource consumption rise over time (Chalkias and Lasaridi, 2011). The increased generation of waste is also causing greater environmental degradation: in particular pollution of land, water, and air due to unsustainable waste disposal and management methods. According to the Intergovernmental Panel on Climate Change (IPCC) report, the waste sector contributes less than 5% of global GHG emissions, which is very low compared to the energy and industrial sectors (more than 65%) (Bogner et al., 2007). As a result, the waste sector has been given lower priority in climatic adaptation and problem mitigation. This study argues that even though the waste sector contributes lesser GHG emissions into the atmosphere, there are greater opportunities that are ignored and often not considered, especially the benefits of recycling and resource recovery from waste.

Globally, a waste management system primarily relies on technology driven 'end-of-life' waste collection, management and treatment systems. Till today, landfill is considered as one of the cheapest and most widely applied waste disposal options (Hoornweg and Bhada-Tata, 2012); however, landfill can be an expensive option if the cost of environmental pollution and depletion of resources are considered (Eriksson et al., 2005). Recycling of waste not only increases the efficiency of resources, but also reduces environmental burdens.

Material recovery from waste by the 'up-cycling' and 'recycling' techniques have direct (primary and secondary materials) and indirect (energy, water and emissions) benefits (Giugliano et al., 2011; Zaman and Lehmann, 2013). For instance, the material that is recovered from waste paper substitutes the demand of primary virgin material(lumber) for the production of new paper goods. By substituting the demand for virgin materials, it also substitutes the need for energy, water and emissions during the extraction of resources (Zaman and Lehmann, 2013). In addition, the material and environmental benefits of resource recovery from waste bears economic benefits as the material contributes to economic activities. Valu-

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http://dx.doi.org/10.1016/j.resconrec.2016.06.020
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able material loss through insufficient recycling and an inefficient resource recovery infrastructure also amounts to economic loss and causes sustainability problems (Xevgenos et al., 2015). Therefore, it is important to evaluate waste management performance based on the environmental and economic benefits of resource recovery activities.

This study aims to evaluate the benchmarking performance of global waste management systems by highlighting their environmental and economic benefits in different countries. The study considers non-hazardous household solid waste thatis usually managed by the local municipal authority. The environmental and economic benefits of waste management systems are analysed using the Zero Waste Index (ZWI), and the results are presented using the mapping techniques of Geographic Information Systems (GIS).

2. Literature review

Studies on global waste management performance are limited due to the lack of reliable and accurate data representing municipal solid waste. Researchers often relied on the reports published by the international government and non-government organisations such as the World Bank, the United Nations, and the European Union etc. to measure waste management performance on a global scale. The UN-Habitat published a report in 2010 which analysed the waste management strategy and performance of 22 cities around the globe (UN-Habitat, 2010). The World Bank published a report in 2012 where the collection, management, treatment, and disposal of waste in countries from various income groups were analysed (Hoornweg and Bhada-Tata, 2012). It is evident from both publications that the data used in analysing the state of the global waste management performance was often incompatible with the time of the reported data (as the reported years varied in different countries) and the types of waste (it significantly varies in different countries). Therefore, the lack of reliable data availability and compatibility made it difficult to benchmark the performance of global waste management systems.

Various tools are available for evaluating the benchmarking performance of waste management, such as life cycle assessment, multi-criteria decision analysis, etc. Often these tools are the simplifications of the actual facts as the waste management systems are complex and difficult to generalise from case studies (Finnveden et al., 2007). A number of studies have applied various decision making tools to evaluate waste management performances, such as life cycle assessment (Christensen et al., 2007; De Benedetto and Klemeš, 2009), life cycle costing (Gluch and Baumann, 2004; Nakamura and Kondo, 2006), cost-benefit analysis (Yuan et al., 2011; Weng and Fujiwara, 2011), multi-criteria decision making (Tseng, 2009; Vego et al., 2008), consensus analysis model (Hung et al., 2007; Petts, 1995), material and substance flow analysis (Belevi, 2002; Chancerel, 2010), integrated solid waste management framework (Wilson et al., 2012; Wilson et al., 2013), analytical hierarchy model (Jamasb and Nepal, 2010; Su et al., 2007), and system dynamic model (Dyson and Chang, 2005; Kollikkathara et al., 2010).

Along with these decision making tools, Geographic Information Systems (GIS) have been used to promulgate better decisions in waste management planning. GIS mapping has been applied in various studies to analyse waste avoidance (Li et al., 2005), waste collection and transportation (Lovett et al., 1997; Tavares et al., 2009), suitable location of waste-to-energy plants (Baetz, 1990), and selection of landfill sites (Chang et al., 2008; Sumathi et al., 2008). The study applies the GIS mapping technique to visualize waste management performance on a global scale.

2.1. Methods

The study compiled and updated national waste management data from various sources, including the United Nations waste data (United Nations, 2011), the World Bank waste data (Hoornweg and Bhada-Tata, 2012), the OECD waste data (OECD, 2015), the Eurostat waste data (Eurostat, 2015), and the data from various published sources (IADB, 2015; Indexmundi, 2015; UNEP, 2012; etc.). The annual waste data were generated in different years, ranging from 2000 to 2014 in different sources. Due to data unavailability it is not possible to refer a specific year for all the countries considered in the study, thus, waste performance is evaluated based on a generic annual benchmarking context rather thana specific year. A total of 168 countries are deliberated on in this study to analyse waste management performance and the results presented in the GIS mapping technique. The countries are categorised into four different groups: high- income country (HIC), upper middle-income country (UMIC), lower middle- income country (LMIC) and low-income country (LIC), based on their per capita income or gross domestic product (GDP), as stated by the World Bank (Hoornweg and Bhada-Tata, 2012); Eurostat, 2015; OECD, 2015.

Zero waste is an emerging philosophy which is referred as "designing and managing products and processes to systematically avoid and eliminate the volume and toxicity of waste and materials, conserve and recover all resources, and not burn or bury them" (ZWIA, 2009). One of the key focues of the zero waste strategies is conservation of resources. There is a growing popularity in considering zero waste strategies as best practices. The study applied the Zero Waste Index (ZWI) tool to measure the environmental benefits of waste management systems. The ZWI measures the potentiality of virgin materials to be offset by waste management systems. It is assumed that the amount of material that is recovered from waste would offset the extraction of the same amount of virgin material, and this eventually saves and avoids energy, GHG and water usage during the extraction process. Therefore, the ZWI measures the material substitution efficiency and energy, as well as GHG and water savings of the waste management systems. The ZWI is calculated by using the following Eq. (1):

Zero waste index (ZWI):

$$ZWI = \frac{\sum_1^n MSWij \times SFij}{\sum_1^n MSWi} \quad (1)$$

where,

MSWi j = amount of waste stream i (i = 1, 2, 3. . ..n = paper, plastic, metal, etc.) managed by system j (j = 1, 2, 3 . . . n = amount of waste avoided, recycled, treated, etc.)

SFi j = Substitution factor for the amount of waste stream i (i = 1, 2, 3. . ..n = paper, plastic, metal, etc.) managed by system j (j = 1, 2, 3 . . . n = amount of waste avoided, recycled, treated, etc.)

MSWi = Total amount of municipal solid waste managed (i = 1, 2, 3. . ..n = paper, plastic, metal, etc.)

The performance of resource recovery is measured by considering the virgin materials' substitution efficiency presented by Zaman and Lehmann (2013). In addition, the ZWI measures energy, GHG and water savings by taking into account the recovered materials. The material substitution efficiency is calculated by using the material substation factor used in Table 1.

The ZWI is used to analyse waste management performance of Adelaide, Stockholm and San Francisco (Zaman and Lehmann, 2013). The study asserted that the ZWI could provide more precise analysis of environmental benefits in the presence of high quality data. It is also evident from the previous publications (Zaman and Lehamnn, 2013; Zaman, 2014) that the tool can be used at a country or global scale. However, the outcome of the model is depends on the quality of data used for evaluating the performance and this

Table 1
Substitution factor in different waste streams and management options (Zaman and Lehmann, 2013).

Waste management systems	Waste category	Virgin material substitution efficiency (tonnes)	Energy substitution efficiency (GJLHV/tonne)	GHG emissions reduction (CO_2e/tonne)	Water saving (kL/tonne)
Recycling	Paper	0.84–1.00	6.33–10.76	0.60–3.20	2.91
	Glass	0.90–0.99	6.07–6.85	0.18–0.62	2.30
	Metal	0.79–0.96	36.09–191.42	1.40–17.8	5.97–181.77
	Plastic	0.90–0.97	38.81–64.08	0.95–1.88	−11.37
	Mixed	0.25–0.45	5.00–15.0	1.15	2.0–10
Composting	Organic	0.60–0.65	0.18–0.47	0.25–0.75	0.44
Incineration	Mixed MW[a]	0.00	0.972–2.995[b]	0.12–0.55	0.00
Landfill	Mixed MW[a]	0.00	0.00–0.84[c]	(−)0.42–1.2	0.00

[a] Average composition of municipal waste (MW).
[b] Heat capture efficiency of waste to energy (WTE) technology 15–30%.
[c] Energy from the landfill facility. A positive value represents the savings, and a negative value represents the demand or depletion.

can be true for any evaluation model or tool. Since, there is no study that evaluates the resource recovery from waste at a global scale, the study focuses on measuring environmental benefits at a global scale using available country data.

The economic benefits of waste management systems are measured by considering the generic market price of the recovered materials. Recycling and resource recovery activities are often driven by the market economy, and thus an economic evaluation of the resource benefits is emphasised in this study. It is important to acknowledge that due to globalization and its effects on the global economy, local recycling markets depend on, and are affected by, the local as well as the global commodity (material) market prices. Therefore economic benefits can vary significantly in differing geographical locations. However, in this study, a generalised market price of various recycled/recovered materials is dwelt on to measure the overall waste management performance in the context of economic benefits. Table 2 shows the unit market price of selected virgin materials. The average market prices of various primary materials used to quantify the total monetary value of resource recovered in the countries are shown in Table 2.

The environmental benefits of waste management systems are thus calculated by using the data on material substitution and environmental benefits in Eq. (1), and the economic benefits are calculated using the unit prices of the materials and resources. This study acknowledges that both resource and economic benefits depend on specific technologies, regulatory policies, and the market economy, and therefore the findings of the study should not be used as an 'absolute' benefit, rather as a potential indication of the progress and performance of the waste management systems. However, it is highly important to analyse and benchmark global waste management systems, because, it provides a reasonable level of understanding and projects the potential benefits. Since there is presently a void in measuring global waste management performance based on environmental and economic benefits, this study justifies its importance, despite the lack of data on resource substitution and economic benefits at the local level.

3. Results

The study analysed the waste management systems of 168 countries around the world. Among the countries, 38 countries were from LIC, 45 countries from LMIC, 39 countries from UMIC, and the remaining 46 countries from HIC. The study is based on secondary data on waste management in different countries. The study is exploratory in nature, thus, the findings mainly focus on the 'what question' which is benchmarking of global performance, rather than 'why question' which is the rationale of such findings.

3.1. Correlation between Gross Domestic Product (GDP) and waste performance

This study applied the Pearson Correlation analysis (2-tailed) to understand the relationship between per capita GDP and various waste management indicators of the 168 countries (N = 168). The study found that there is a positive correlation ($p < 0.001$) between the GDP and the per capita waste generation (r = 0.539), and similarly, a positive correlation ($p < 0.001$) between the GDP and the per capita recycling (r = 0.637), GDP and the amount of per capita substituted virgin materials ($p < 0.00$), r = 0.673), and the GDP and the economic benefits of the waste management system ($p < 0.001$, r = 0.674). It is evident from the Pearson Correlation analysis that economic advancement plays a significant role in waste management systems, therefore it is important to keep in mind the economic benefits of the resource recovery of waste. Table 3 shows the relationship between GDP and waste performance.

3.2. Global waste management performance

A total 3.36 billion population of 168 countries was covered in this study. Annually an estimated 1.46 billion tonnes of municipal solid waste was generated, which is equivalent to 435 kg/person per year. The population in high income countries produced more waste compared to the population in low income countries. Fig. 1 shows the distribution of waste generation (per capita) in different countries. Kuwait has the highest recorded per capita waste generation of 2087 kg/year and Ghana has the lowest recorded per capita waste generation of 33 kg/year. The findings of Table 3, it shows that a higher GDP increase in people's purchase power encourages more consumption and resulstin higher waste generation. Kuwait has a comperatively high rate of per capita waste generation (global average 480 kg/person) which could be a data anomaly of taking into consideration construction and demolition wasteas municipal solid waste. Since secondary data were used in the study, it is not possible to determine the exact reason for such higher waste generation rates. In contrast to the higher waste generation figures of Kuwait, Ghana generates a lower amount of waste as the GDP is also low in Ghana.

Globally, an average person recycled around 75 kg of waste (including composting) annually, which is equivalent to a 17% recycling rate. Fig. 2 represents the annual waste recycling distribution in 168 countries. In regards to waste recycling, Singapore has the highest per capita waste recycling rate of 720 kg/year, followed by Kuwait (390 kg/year), Ireland (367 kg/year) and Germany (362 kg/year). Only 31 out of the studied 168 countries have a recycling rate of over 100 kg/year, and the recycling rate is very low (less than 20 kg/year to nil) in most of the low income countries.

Table 2
Unit market price of various virgin materials.

Materials	Unit price ($ US)	Average price ($ US)	References
Paper	80–875/t	477	WRAP (2015) and Indexmundi (2015)
Plastic	139–300/t	219	WRAP (2015)
Glass	15–41/t	28	WRAP (2015)
Metal	186–1589/t	887	WRAP (2015) and Indexmundi (2015)
Mixed	–	104	Minimum average price
Compost	100–410/t	255	Alibaba (2015)
Energy (GJLHV)	20.3/ kWh	55.6	EUC (2015)
GHG (CO2e)	1–14/tonne	7.5	APH (2013)
Water (kL)	0.92/m3	0.92	ELD (2010)

Table 3
Correlation between GDP and waste performances.

Indicators	Correlation types	Significance level (p)	r value	R^2 value
Per capita GDP vs per capita waste generation	+	0.000	0.539	0.29
Per capita GDP vs per capita waste recycle	+	0.000	0.637	0.41
Per capita GDP vs per capita virgin material substitution	+	0.000	0.673	0.45
Per capita GDP vs per capita economic benefits	+	0.000	0.674	0.45

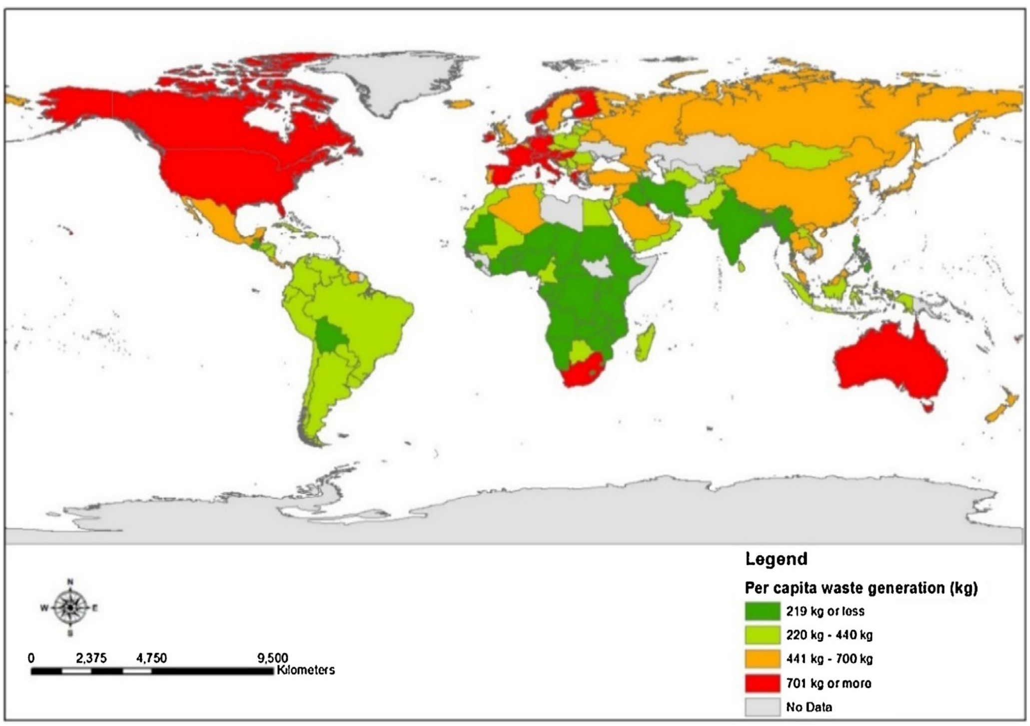

Fig. 1. Annual waste generation in different countries.

With regard to the spatial distribution of waste recycling at a global scale, it is evident from Fig. 2 that waste recycling is very low in the countries in South Asia, Middle East, East Europe and South America. The studies by World Bank (Hoornweg and Bhada-Tata, 2012) and UN-Habitat (2010) assert that lack of financial capacity, waste infrasctrue and incentives make it difficult for developing nations to improve collection and recycling efficiency.

3.3. Environmental benefits of waste management systems

The environmental benefits of waste management are analysed using the ZWI, by measuring potential substituted virgin materials from recovered waste resources. A higher ZWI value means a higher percentage of virgin material substituted by the waste management system. The value of ZWI is highly dependant on both the amount and types of materials recovered from waste. Thus, countries with a comperatively higher waste recycling rates, particularly in metal, glass and plastics, performed the highest in the ZWI. Fig. 3 presents the ZWI in different countries. The global ZWI was measured at 0.072, which, means only 7% of the materials from waste management systems were potentially attributed to the substituted demand for virgin materials. Austria has the highest ZWI of 0.45 followed by Germany (0.44), Belgium (0.42), Singapore (0.41), and the Netherlands (0.40). The ZWI for most of the developing countries was significantly low to almost nil, which indicated that resources were not recovered from waste in most of the developing countries.

3.4. Per capita material savings

Zero waste performance depends on the amount of materials recovered from waste, which eventually substitutes the demand

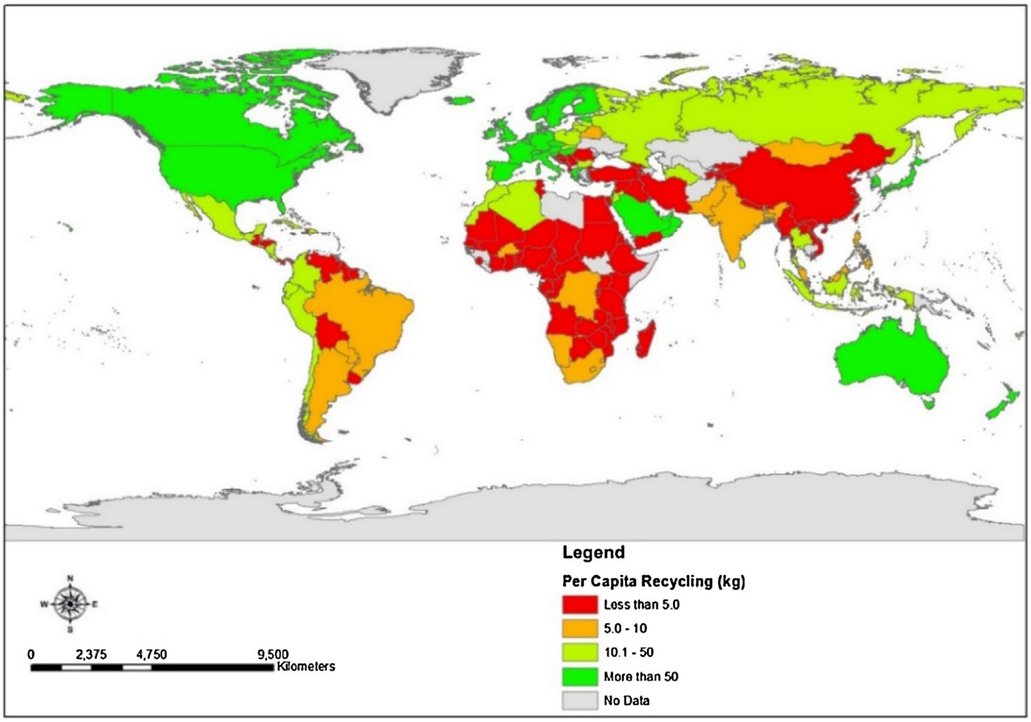

Fig. 2. Annual waste recycling rate in different countries.

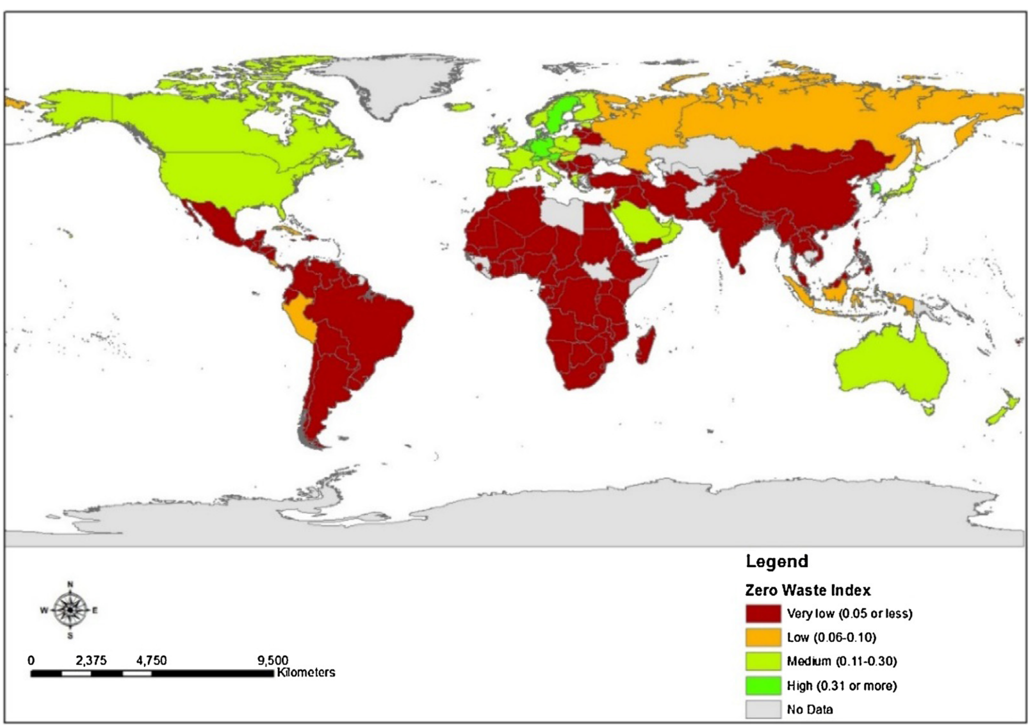

Fig. 3. Zero Waste Indices in different countries.

for virgin materials. Globally, an average person potentially saved and substituted the demand for around 50.9 kg of virgin materials. Singapore performed the best in material recovery from a total waste of 512 kg per person annually, followed by Austria (405.5 kg), Kuwait (394.9 kg), Germany (336.1 kg), and Switzerland (324.4 kg). Amongst upper-middle income countries, the Marshall Islands recovered the highest weight (90 kg) of materials, followed by Iceland (85.3 kg), Estonia (82.7 kg), and Cyprus (75.3 kg). Material recovery in most of the developing countries was very low, down to almost zero as shown in Fig. 4.

3.5. Per capita energy savings

Since recovered materials substitute the demand for resource extraction, this results in saving energy. Similarly, the country that produces energy from waste also extracts energy savings

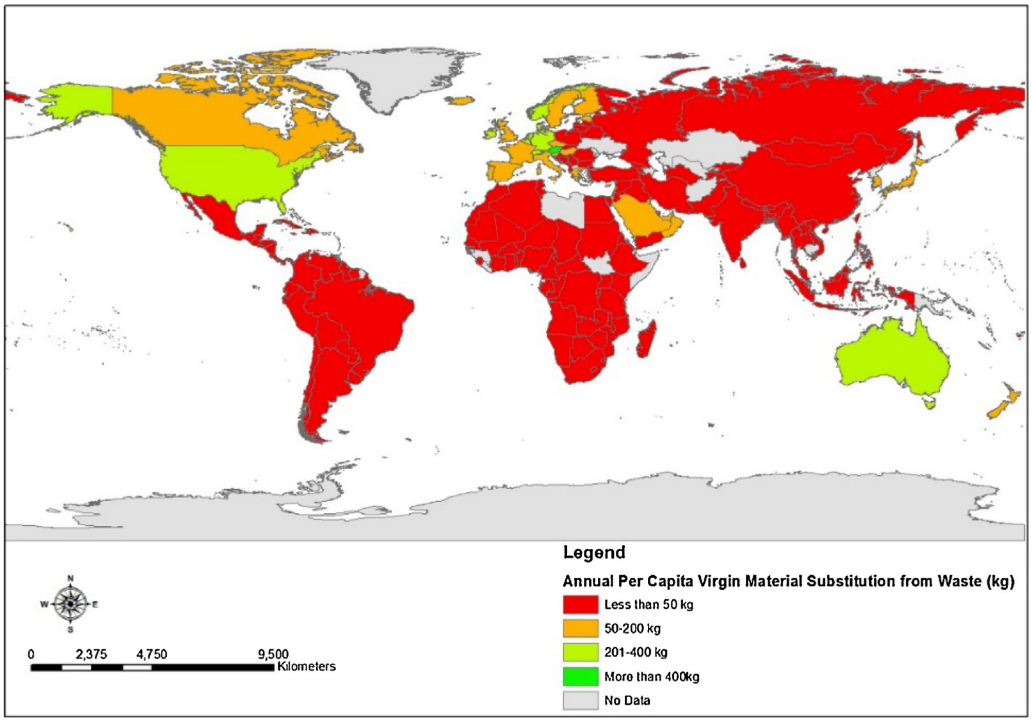

Fig. 4. Per capita virgin material substitution from waste.

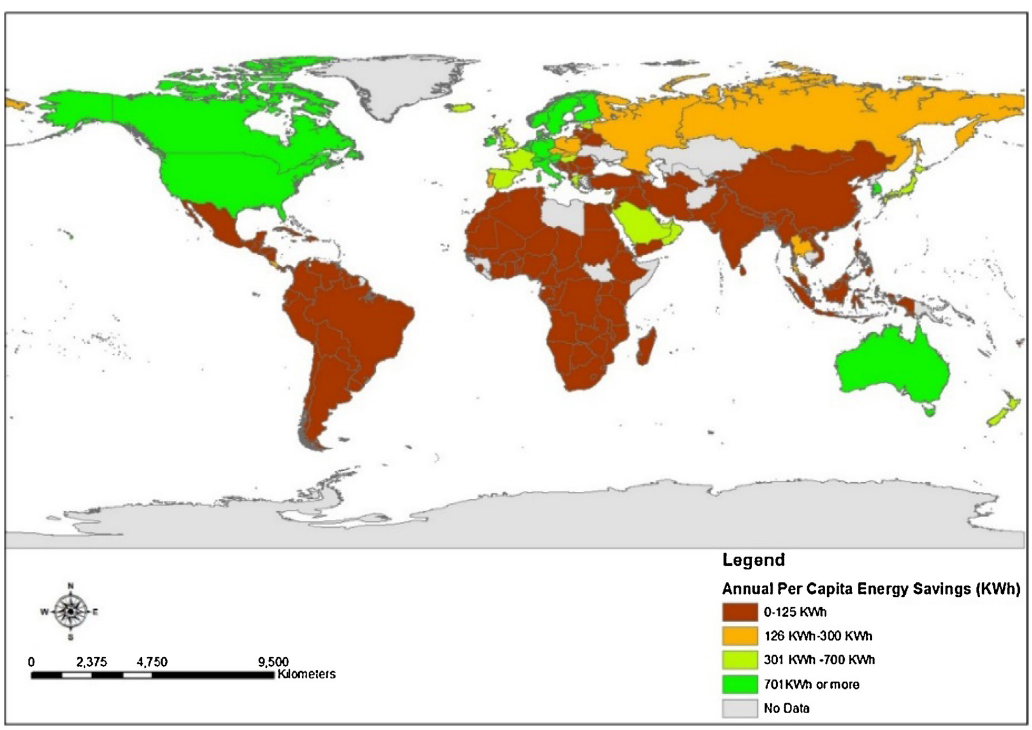

Fig. 5. Per capita energy savings from resource recovery of waste.

from waste management. The study takes into accountthe embodied energy saved through material and energy recovery from waste, which means that the substituted material avoids energy consumtion during the processes associated with mining and processing of natural resources to manufacturing, transport and product delivery. Fig. 5 shows the energy savings figures in different countries. Annually, each person potentially saved around 216 kWh of electricity by substituting the demand for virgin materials and the associated energy demands. Each person in Singapore annually saved around 2825 kWh of energy, followed by Kuwait (1567 kWh), Germany (1432 kWh), Ireland (1378 kWh), and Switzerland (1329 kWh). Despite being one of the leading energy producer from waste countries, Sweden only saved around 849 kWh per person per year. It is also important to acknowledge that data reliability and accuracy is very important to compare the waste management performance between countries.

3.6. Per capita GHG savings or pollution

It is theoretically possible to save GHG emissions when the potentially avoided GHG from substituted materials is higher than the amount of GHG emitted from thermal treatment (such as incineration) and landfills. Therefore, when countries recover more materials from waste than waste landfilling, they can potentially avoid more GHG emissions from their waste management sector. Fig. 6 shows the GHG savings or pollution from resource recovery from waste. Globally, each person potentially avoided around 0.05 kg of GHG emissions; however, by considering the GHG emissions from landfills, each person contributed around 48 kg of GHG emissions to the atmosphere. Annually, each person in Singapore potentially avoided the highest of 634 kg (CO2e) of GHG, followed by Germany (358 kg), Switzerland (355 kg), Austria (333 kg), and the Netherlands (309 kg). On the contrary, annually, each person in Antigua and Barbuda polluted the environment with around 800 kg (CO2e) of GHG followed by St. Lucia (636 kg) and Seychelles (413 kg).

3.7. Per capita water savings or depletion

Recycling of metal has a comperatively higher water substitution benefits than recycling of plastic. Fig. 7 shows water savings or depletion from waste. Globally, each person potentially saved around 36 L of water per year. Annually, each person in Singapore saved around 5101 L of water and the water savings for Kuwait was 362l, Austria 347l, Germany 314 l and Switzerland 297l. Similarly, annually, an average person in the Marshall Islands depleted 167lts of water, Thailand depleted around 65lts and Vanatu depleted around 53lts of water.

3.8. Economic benefits

The potential economic benefits of resource recovery from waste are measured basis the monetary value of the substituted virgin materials. In addition, the total economic benefits are measured by considering the economic benefits of substituted virgin materials as well as the economic benefits of environmental parameters such as energy, water and GHG savings. The study only measures the potential economic benefits of material recovery from waste. The authors understand the importance of transportation and emission costs in overall waste management systems globally. The study excludes transportation and other related costs as they were not available for the 168 countries studied Fig. 8 shows the economic benefits of substituted materials in different countries.

Globally, an average person potentially saved around $17 of resources (substituted virgin material) annually. Singapore is the most economically benefited countries in regards to substituting the demand for virgin materials, and saved around $194, followed by Kuwait ($135), Austria ($127), Germany ($117), and Switzerland ($110). St. Vincent and the Grenadines have the highest economic benefits from UMIC of $19/person/year. The Marshall Islands has the highest economic benefits of substituted virgin materials of $26/person/year. Pakistan has the highest economic benefits of substituted virgin materials of $1/person/year.

Fig. 9 shows the total economic benefits in various countries. The total economic benefits are calculated by keeping in mind the material and environmental benefits of waste management systems. Globally, an average person potentially saved around $61 of resources (materials, energy, GHG and water) annually, which is often unrecognized and unreported in the traditional economic system. A significant proportion (72%) of the total economic benefits of resource recovery from waste came from the susbtition of energy demand (around $44) which more than twice the economic benefits of materials substitution. Annually, an average person in Singapore potentially contributed $764, followed by Kuwait $449, Germany $407, Ireland $380, and Switzerland $379, from their waste management systems.

It is important to mention that the total economic benefits consider the benefits from materials as well as the benefits from environmental protection by saving or avoiding energy, water and GHG emission. Therefore, the 'true' economic benefit may vary in different jurisdictions as the environmental parameters such as carbon or GHG emission tax, or energy and water savings rebate would vary in different countries. An effective impelementation of the "polluter pays principle" based on product stewardship is essential for achieving greater economic and environmental benefits of resource recovery from waste.

4. Further discussion and conclusion

Waste management practices were historically developed to minimize health risks and to reduce the outbreak of various diseases that are a fallout of waste pollution. Apart from minimizing health risks, very often the waste management system has been viewed by the local authorities as an expensive urban service that they need to provide to their citizens. Undoubtedly, there is no denying that the waste management service costs the authorities dearly, but waste management activities also have economic and environmental benefits which are often ignored and not considered as a catalyst of future improvement. This study analysed waste management performances in the context of environmental and economic benefits.

This study argued that the performance of a waste management system has often been expressed mainly by measuring the direct carbon and GHG emissions into the atmosphere from waste, and by ignoring the economic benefits of material recovery from waste. Therefore, tt is important to understand and measure the potential environmental benefits of the waste management system in the context of material recovery, energy, water savings, and GHG reduction through waste management exercises. The study presented environmental benefits with regard to material recovery, energy savings, waste savings, and the avoidance of GHG emissions into the atmosphere. By underlining the monetary value of these environmental benefits the total economic benefits were measured and presented in the article. It is important here to acknowledge that the findings of the study may not be 'absolute' in benchmarking the performance of the global waste management systems due to the gaps in data accuracy, reliability, and compatibility of the reported data. However, the findings of the study are extremely relevant and valuable in the context of identifying the importance of an accurate data capture platform at a global level.

The study also concluded that reliable and accurate data on waste is one of the main challenges in rating of global waste management performance as various countries use asymmetrical measuring and reporting techniques. Due to the lack of a systematic and homogeneous data capture method, the comparability of the available data is flawed. For instance, the waste data used in the World Bank's report for Japan was populated in 2003, which is pretty outdated compared to the data populated in other developed countries; therefore, the overall waste performance in Japan was lower than the countries that used updated data. Waste data in most of the developing countries was only gathered from the urban areas, and resultantly the country average would become lower than the urban average. Therefore, the study does face challenges in measuring the global waste management performance in accordance with the environmental and economic benefits.

The presented analysis in this study is important despite the inaccuracy that may have been caused by the poor data quality, because without measuring and identifying the key problems, it

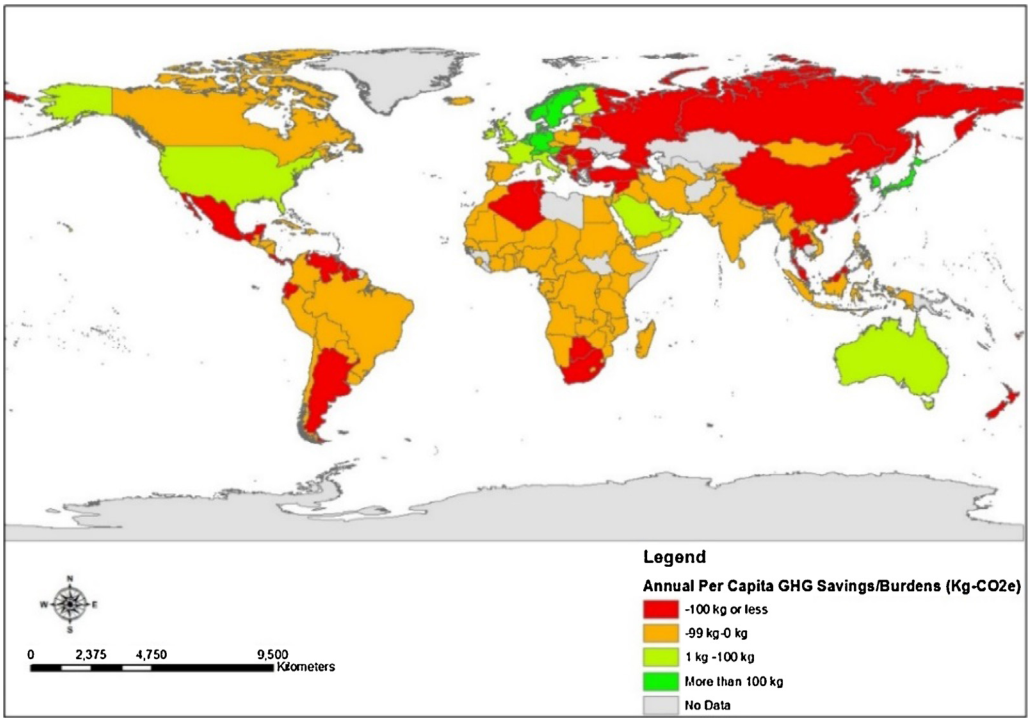

Fig. 6. Per capita GHG savings from resource recovery of waste.

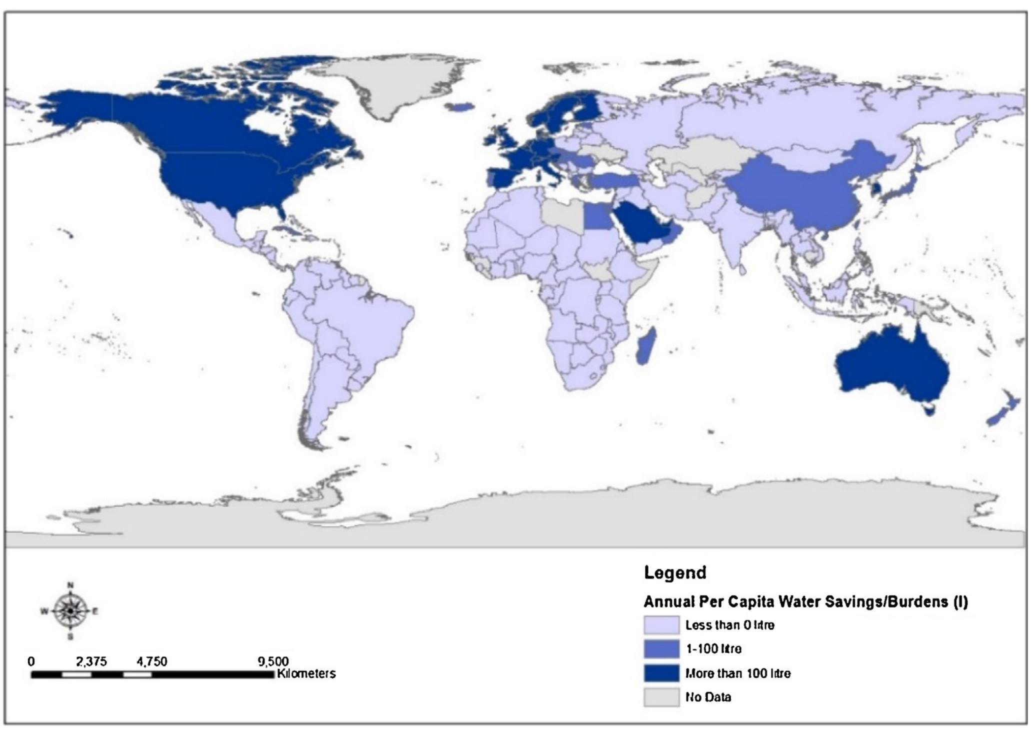

Fig. 7. Per capita water savings from resource recovery of waste.

would not be possible to improve the overall waste management practices in the future. We need an agreed upon and a high quality waste data capture and standardization system on a global scale,governed by international agreements, such as the International Organization for Standardization (ISO) 37120 which, assist in collecting and recording reliable waste data for evaluating performance of cities and communities (ISO, 2014). By developing a uniform data capture platform and acquring more reliable and compatible data, we can be more effective in benchmarking the performance of global waste management systems and in providing the appropriate developmental direction of waste management in the future.

In conclusion, the paper presented the environmental and economic benefits of global waste management systems by advocating zero waste practices. The study analysed the waste management performance of 168 countries around the globe and evaluated their

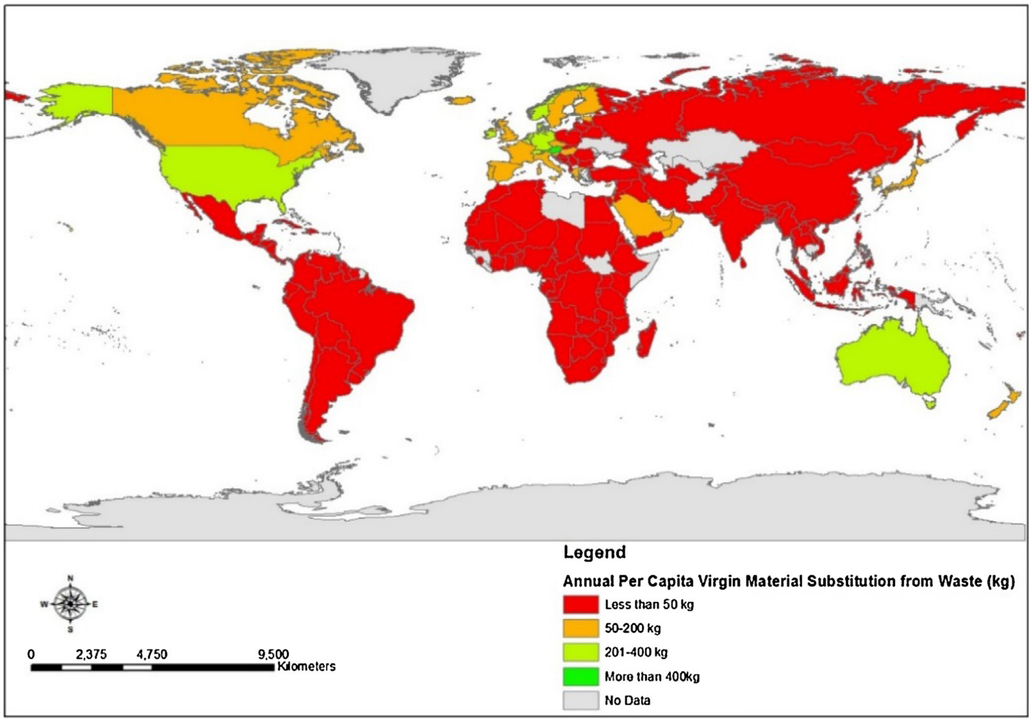

Fig. 8. Economic benefits of substituted virgin materials.

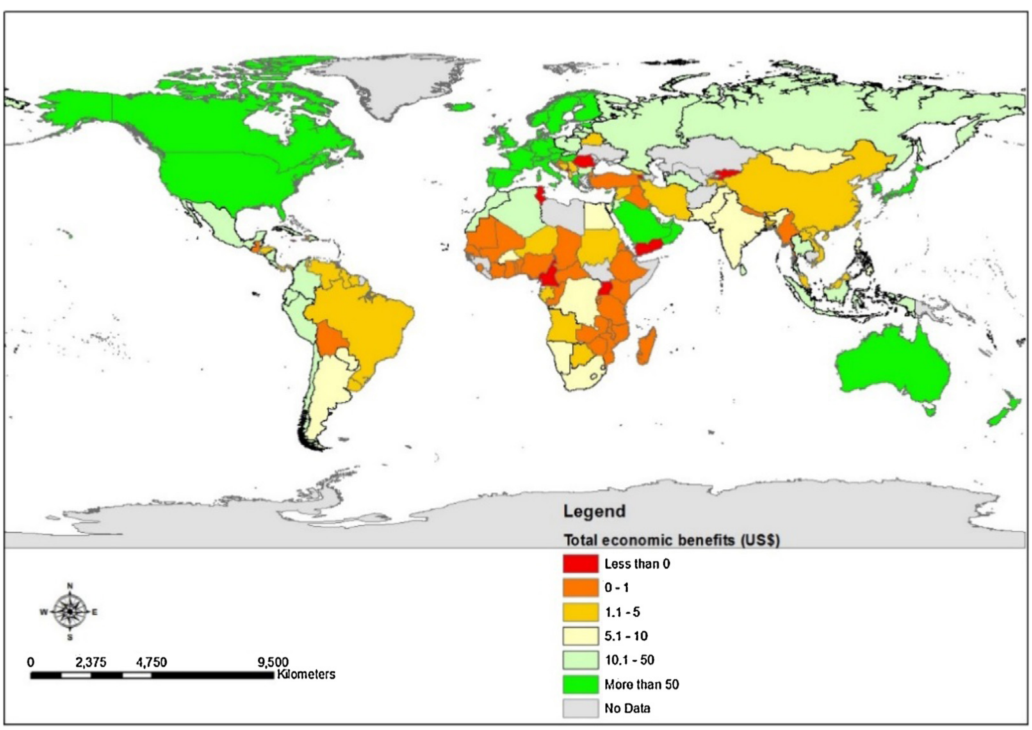

Fig. 9. Total economic benefits of waste.

waste management performance using the zero waste tool. The findings of the study suggested that globally the average person generated around 435 kg of waste each year, and an estimated 50 kg of materials (paper, plastic, metal, glass and others) potentially substitute the demand for the extraction of virgin materials. By substituting the demand for virgin materials, through the zero waste activities, the average person could potentially save around 216 kWh of energy, 0.05 kg GHG and 36 L of processed water. At the global level, each person potentially saved around $61.3 annually, of which $17 was projected from materials substitution, and $44 from energy substitution. The study suggested that energy substitution potentially contributed over twice the economic benefits as materials substitution in resource recovery from waste. The materialrecovery from waste is one of the direct benefits as it substitutes the demands of material extraction., However, energy substitution is an indirect benefit as it is calculated from the embodied energy saving, unless energy is recovered from waste using waste to energy convertion process. The indirect benefit is often ignored and remains unnoticed while developing and prioritizing waste management policies. Since zero waste focuses on resource conservation and optimization of resource recovery from waste, waste management strategies that underpin the zero waste philosophy can play a greater role in improving the overall performance of the global waste management system.

Acknowledgements

The study was completed without the assistance of any external funds. The authors would like to thank three anonymous reviewers for their insightful comments.

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