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Sustainable recycling of municipal solid waste in developing countries

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ABSTRACT

This research focuses on recycling in developing countries as one form of sustainable municipal solid waste management (MSWM). Twenty-three case studies provided municipal solid waste (MSW) generation and recovery rates and composition for compilation and assessment. The average MSW generation rate was 0.77 kg/person/day, with recovery rates from 5–40%. The waste streams of 19 of these case studies consisted of 0–70% recyclables and 17–80% organics.

Qualitative analysis of all 23 case studies identified barriers or incentives to recycling, which resulted in the development of factors influencing recycling of MSW in developing countries. The factors are government policy, government finances, waste characterization, waste collection and segregation, household education, household economics, MSWM (municipal solid waste management) administration, MSWM personnel education, MSWM plan, local recycled-material market, technological and human resources, and land availability.

Necessary and beneficial relationships drawn among these factors revealed the collaborative nature of sustainable MSWM. The functionality of the factor relationships greatly influenced the success of sustainable MSWM. A correlation existed between stakeholder involvement and the three dimensions of sustainability: environment, society, and economy. The only factors driven by all three dimensions (waste collection and segregation, MSWM plan, and local recycled-material market) were those requiring the greatest collaboration with other factors.

1. Introduction

World population continues to rise with projections nearing 7.2 billion by 2015 (UNEP, 2005a). Rapid urbanization accompanies this trend with an estimated two-thirds of the world's people living in cities by 2025. In fact, urban populations in developing countries grow by more than 150,000 people every day (UNDESA, 2005). Although urbanization itself is not necessarily a problem, haphazard and unplanned growth can result in many environmental problems such as public space and riverbank encroachment, air and water pollution, and solid waste generation (UNEP, 2001e).

Municipal solid waste (MSW) is the most complex solid waste stream, as opposed to more homogeneous waste streams resulting from industrial or agricultural activities (Wang and Nie, 2001). Once in the city, even a slight increase in income can cause consumption patterns of people to change (Medina, 1997), which results in waste types and quantities that pose a greater challenge for the municipalities to handle. For example, a study in India showed increases of 49% for population and 67% for MSW during the same time (UNEP, 2001c). "The increasing volumes of waste being generated would not be a problem if waste was viewed as a resource and managed properly" (UNEP, 2001e).

Several technological means exist to divert solid waste typically destined for a landfill, such as incineration with energy production, composting of organic wastes, and material recovery through recycling, all having the potential to be more sustainable methods by which to manage MSW than via landfill. However, with waste streams comprised of 55% or greater organic matter in developing countries, composting is being considered in many parts of the world (especially in the tourist and agricultural sectors) as a method to reduce waste destined for the landfill. Also, incineration for energy recovery can be a costly capital investment for most communities in the developing world, pose societal and environmental health risks if misused (e.g., burning toxic wastes causes harmful air pollution), and shows a less positive energy balance than transforming material via recycling (Oliveira and Rosa, 2003).

The research reported herein focuses on recycling as a sustainable means of diverting the maximum fraction of MSW from landfill disposal, with emphasis on urban and peri-urban areas rather than rural areas of developing countries, and also makes some comparisons to developed countries' MSWM.

Here, sustainable MSWM would not lead to diminished quality of life due to forgone economic opportunities or adverse effects on

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social conditions, human health, and the environment (Mihelcic et al., 2003). The specific research objectives include: (1) understanding previous work on first and third world recycling attitudes and behavior; (2) quantifying MSW generation, composition, and recovery; (3) assessing developing countries' MSWM by identifying barriers and incentives to recycling and deriving key factors influencing sustainable MSWM; and (4) identifying relationships among factors in order to understand the collaborative nature of sustainable recycling of MSW and to examine the correlation to societal, environmental, and economic dimensions of sustainability.

2. Material studied

2.1. Recycling attitudes and behavior

2.1.1. Developed countries

A definite contrast exists between recycling research in developed countries versus developing countries. Mature databases, such as the United Nations Environment Program (UNEP) Global Environment Outlook (GEO) Data Portal and World Research Institute Earth Trends, characterize developed countries' MSW, including waste generation and recovery rates, as well as composition. Developed countries possess heavily industrialized recycling activities that are more or less removed from the daily life of a citizen (e.g., sophisticated curbside recycling programs). Therefore, research on waste recycling in the developed world focuses on technical applications such as models and tools (Daskalopoulos et al., 1998; Barlishen and Baetz, 1995); policy analysis such as command-and-control, and social-psychological and economic incentives (Taylor, 2000); and, extensively, psychological and socio-economic influences on human behaviors. Psychological research efforts include assessments of attitudes toward recycling and perceived versus actual behavior (Kelly et al., 2006; McCarty and Shrum, 1994; Thapa, 1999; Werner and Makela, 1998; Steel, 1996; Chan, 1998). Socio-economic factors correlated with recycling include consumption patterns, education, gender, age, and income (Kishino et al., 1999; Hanyu et al., 2000; Domina and Koch, 2002; Hornik et al., 1995; Owens et al., 2000; Johnson et al., 2004; Steel, 1996).

2.1.2. Developing countries

Research on waste recycling in the developing world places less emphasis on understanding the indirect motives of one's behavior (i.e., recycling research focus in developed countries), but more heavily on the practical, direct factors influencing the institutions and elements associated with MSWM. The only studies performed that seem most similar to research conducted in developed countries were focused on Mexico and China. During a study of reuse and recycling behavior in Mexico, Corral-Verdugo (1997) observed that competencies were the best predictors of actual behavior, whereas beliefs were more indicative of perception of behavior or desired behavior. In the case of recycling, one was more likely to recycle waste when fully understanding the proper way and the reasons to do it as opposed to one simply desiring to recycle.

In a study of recycling behavior in Wuhan, China's fifth largest city, Li (2003) found that gender, age, and household income were three factors most influential to the activity of recycling. Particularly, elderly females responsible for the household duties of low-income families were most likely to recycle (Li, 2003). In exploring the relationship between environmental knowledge and action, factors influencing environmental behavior, and the ways to motivate environmental attitudes and behavior, Harvie and Jaques (2003) learned that residents of China possess greater knowledge of environmental issues and are more willing to participate in activities like recycling than US citizens (Harvie and Jaques, 2003).

While it is noteworthy that this type of research is occurring with regard to developing countries, it is also important to mention here that both Mexico and China are experiencing economic and social development that is uncharacteristic of third world countries. In China, more developed regions, like Hong Kong and other coastal cities, may positively influence the activities in the developing interior regions. The International Monetary Fund classifying Mexico as a developing country, when its gross domestic product defines it as a developed country (CIA, 2004), exemplifies the socio-economic transition occurring in Mexico. Since China and Mexico are transitioning into developed countries, it is not surprising that these two countries have research conducted on themes closely resembling research in developed countries.

Conversely, there is extensive research on the practical aspects that directly influence the institutions and elements associated with MSWM, such as identifying waste problems and their causes, quantifying waste characteristics, and analyzing waste operations. For example, a survey conducted in Nairobi, Kenya assessed citizenry knowledge and attitudes about factors contributing to improper management of waste, as well as on possible solutions to these issues. Of the respondents, 93% reported solid waste as a problem, less than 30% felt that the little amount of recycling was a problem, and approximately 40% suggested to formalize and encourage recycling and that industrialists should invest in recycling (Mwanthi et al., 1997).

3. Methods

3.1. Case study selection

The following two criteria served as the basis in selecting case studies: (1) the country has a socio-economic status of "developing" as designated by the International Monetary Fund (IMF) or economic status of "less developed" based on a country's gross domestic product (GDP), and (2) availability of data representative of the national population or a large urban or peri-urban population center.

A variety of sources, including research journal articles and international government organizations' reports, provided MSWM studies on 31 developing countries. Two of these case studies, Malta and Singapore, actually fulfill the first criteria, but are not included due to their display of too many developed country characteristics. For instance, both countries have gross domestic products an order of magnitude higher than the other countries selected for the study.

Based on the second criteria, case studies on Ghana, Nigeria, Pakistan, Tanzania, Vanuatu, and South Africa are not included for the study due to data insufficiently representing national data or data of a large urban or peri-urban population center. Some case studies contain data that is national data according to its source, whereas others have data for only a portion of the population. If a country case study contained waste characterization data for 10% or greater of the national population, then data from the case study were included in the research.

Table 1 offers a listing of the 12 selected case studies and the information utilized to determine inclusion in the study, as well as the source(s) of data. The categories based on GDP and IMF classification are not consistent with one another, and for this reason, this study includes countries meeting either criterion. In addition, data type does not necessarily correlate to data source; a variety of combinations exists. For example, UNEP did not consistently provide actual national data in its reports, but rather provided data for particular large population centers representing 10% or greater of the national population, which were included in this study.

Table 1
Socio-economic standing, data type, and data source for the 23 selected case studies on Municipal Solid Waste Management in the developing world

Country	Socio-economic standing defined by			
	GDP[a]	IMF[b]	Data Type[c]	Source[d]
Bhutan	LLDC	Developing	National	UNEP (2001b)
Botswana	LLDC	Developing	⩾10%	Bolaane and Ali (2004)
Brazil	LDC	Developing	⩾10%	Wells (1994) and Fehr et al. (2000)
China	LDC	Developing	National	Wang and Nie (2001)
Guyana	LDC	Developing	⩾10%	Závodská (2003)
India	LDC	Developing	National	UNEP (2001c)
Indonesia	LDC	Developing	⩾10%	World Bank (2003a)
Iran	LDC	Developing	⩾10%	Abduli (1995)
Jamaica	LDC	Developing	National	Pendley (2005)
Lao	LLDC	Developing	National	UNEP (2001d)
Lebanon	LDC	Developing	⩾10%	Nuwayhid et al. (1996)
Malaysia	LDC	Developing	National	Kathirvale et al. (2003)
Maldives	LLDC	Developing	⩾10%	UNEP (2002)
Mauritius	LDC	Developing	National	Mohee (2002)
Mexico	DC	Developing	National	Buenrostro and Bocco (2003)
Mongolia	LDC	In transition	⩾10%	World Bank (2004)
Nepal	LLDC	Developing	National	UNEP (2001e)
Philippines	LDC	Developing	National	World Bank (2001)
Sri Lanka	LDC	Developing	National	UNEP (2001f)
Thailand	LDC	Developing	⩾10%	UNEP (2001a) and World Bank (2003b)
Turkey	DC	Developing	National	Metin et al. (2003)
Turkmenistan	LDC	In transition	National	UNEP (2005b)
Vietnam	LDC	Developing	⩾10%	UNEP (2001g)

[a] Definition based on per capita gross domestic product (GDP): developed Country (DC) has per capita GDP >$10,000 USD; less developed Country (LDC) < $5000; least developed Country (LLDC) < $1000. Countries with $5000 < per capita GDP < $10,000 are categorized based on other factors.
[b] Definition based on the International Monetary Fund's discretion.
[c] National: actual national data cited by source. ⩾10%: data for 10% or more of national population, usually an urban or peri-urban population center in the country.
[d] UNEP and World Bank are international non-government organizations offering national reports on solid waste and other environmental issues. Surname indicates data were derived from a journal article. Detailed citations are located in the References section.

3.2. MSW characterization

3.2.1. Variation among case studies

The definition and method to quantify and classify MSW vary among the case studies. For instance, some case studies have data for all three variables of generation, composition, and recovery, whereas others may only have data for one or two of these attributes. Case study waste compositions were conformed to the classification utilized by the European Union (Eurostat, 2003).

3.2.2. Recycling behavior

This study considers material recovery rates of 5% or higher of the waste generated, as provided by country case studies, to be active recycling efforts. Those countries with less than 5% recycling have negligible amounts of recycling, and are not included in the assessment of waste recovery. In comparison, when the U.S. Solid Waste Disposal Act passed in 1965, a little more than 6% of the MSW was recycled (USEPA, 2008). Qualitative data was included in the assessment of waste recovery, because without numeric recovery rates, there is no indication of the extent of material recovery efforts. The extent of material recovery efforts was determined from qualitative data by discerning from the literature the targeted materials, portion of population involved in recycling, and number or types of organizations influencing recovery efforts. This study translates quantitative and qualitative recovery efforts to a bimodal classification (yes/no) of either having or not having active waste recovery efforts. Reducing the recycling behavior data down to a bimodal classification makes it easier to draw comparisons between recycling behavior and the factors generated through this research.

3.2.3. Data quality assessment

Since the data used in this research is a compilation of results from a variety of other sources, this study uses a multidimensional estimation matrix, a common approach in life cycle assessments, to evaluate the quality of the data (Horvath and Junnila, 2003). Data quality assessments indicate uncertainty of referenced data. Table 2 provides the attributes and indicator scores by which this study assessed the quality of MSW characterization data (generation rates, composition, and recycling rates). An overall target indicator score is 2, showing the data to be at least average with the attributes considered.

3.3. Factor development

Examination of over 25 sources listed with the country case studies presented in Table 1 resulted in identification of barriers and incentives to recycling. In this study, whether defined as an incentive or a barrier, both function as factors influencing sustainable MSWM in developing countries. Proposed factors were created as they became apparent in the literature. The proposed factors were placed on one length of a table (data not shown) and the country case studies on the other length of the table. This table captured whether or not there is significant recycling activity and whether each factor is an incentive or barrier in any given country. The factors were individually assigned as incentives or barriers to recycling by interpretation of statements made in the literature. Troschinetz (2005) documented the working table and exact verbiage from the sources supporting such choices.

It is important to note here that for any given factor influencing recycling, one country may perceive it as a barrier, whereas another country may view it as an incentive. This irregularity among the case studies is due to the effect of various social, economic, and environmental pressures. A barrier to recycling either denotes the absence of a particular factor, or in cases where the factor is present, the inadequacy of that factor to positively influence recycling. The converse is true for designation of factors as incentives to recycling.

The emphasis of particular factors over and over again in the literature was an indication of those aspects most critical in determining the success or failure of MSWM. The proposed factors with the most repetition of being either incentives for or barriers

Table 2
Indicator matrix used for data quality assessment (adapted from Horvath and Junnila (2003))

Attribute	Indicator score		
	1	2	3
Acquisition method	Measured data using a statistically robust sampling method	Calculated data based partly on measurements or assumptions	Unknown or estimated data by qualified (expert) or non-qualified source
Representativeness	Data taken over a sufficient period to even out fluctuations	Data taken over a short period	Unknown or incomplete data from short periods
Data age	10 years or less difference to year of study	11–20 years of difference	Age unknown or more than 21 years of difference

to recycling became the final factors in this study. These 12 factors most strongly influence recycling as a sustainable approach to MSWM.

References in the literature supported the relationship assignments among the 12 factors. For instance, one case study noted that a MSWM plan can have more relevance and is more easily implemented when it is developed around an understanding of the waste stream's characterization (i.e., generation rate and composition) (Fehr et al., 2000). Similar references provided by other case studies guided the determination of factors' connections.

4. Results and discussion

4.1. MSW generation

Fig. 1 presents the MSW generation rates for all of the 23 cases studies. Maldives has the highest MSW generation rate due to its greatest economic activity being tourism (UNEP, 2002), making it an exception to the range of 0.3–1.44 kg/person/day (kpd) typical of developing countries. Bhutan, Botswana, and Mexico generate the least amount of MSW on a per capita basis at approximately 0.3 kpd. In contrast, developed countries typically generate 1.43–2.08 kpd. The range of generation rates in this study is of no surprise. The case studies vary greatly with respect to attributes like gross domestic product (GDP) (1400 current international dollars of GDP as purchasing power parity (PPP) per capita in Bhutan to 11,258 current international dollars PPP per capita in Mauritius for 2003) and developmental stage (as shown in Table 1) (WRI, 2005; CIA, 2004, 2005). Factors such as GDP, developmental stage, and others can influence MSW generation rates.

The relationship between MSW generation and income varies with respect to the developmental stage of a nation. As a country develops, its waste generation rate increases. In contrast, a weak correlation exists between income and waste generation for middle- and upper-income countries, and waste generation actually decreases in the wealthiest countries. (Medina, 1997).

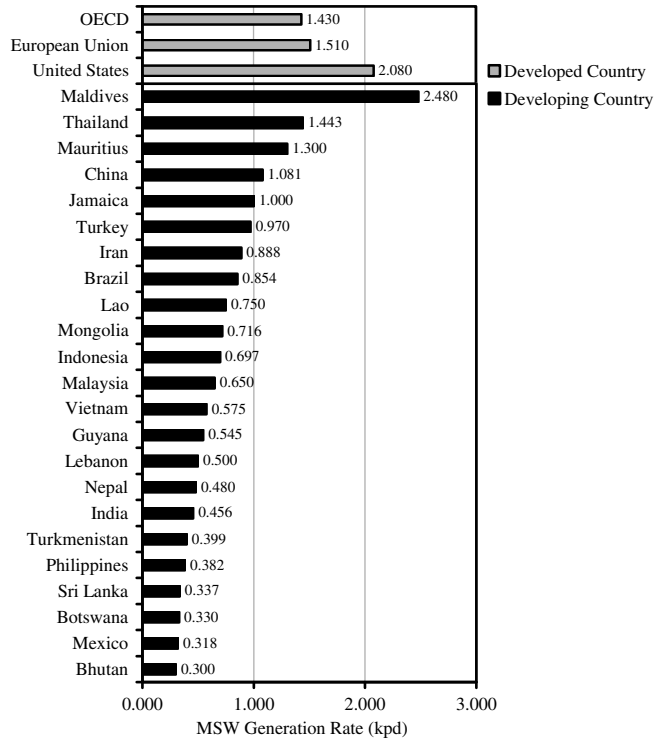

Fig. 1. Municipal solid waste generation rates (kg/person/day) for 23 developing countries compared to rates of developed countries. (OECD, Organization for Economic Cooperation and Development; European Union – Developed Countries only).

Several different elements directly affect the quantity of waste generated in developing countries. The lifestyle (Fehr et al., 2000) that is usually associated with certain incomes can influence consumption rates and patterns (World Bank, 2003a). The number of people in a household has shown a correlation to per capita waste generation as a higher number of people in a given household results in less waste generation per person per day (Bolaane and Ali, 2004). Socio-economic development and the degree of industrialization influence waste generation rates by generally affecting income and consumption patterns (World Bank, 2001). Climate and seasonal changes impact waste generation by having an effect on the amount of organic material generated as a waste product of preparing fresh foods in the seasons or climates that allow such preparation (World Bank, 2001).

4.2. MSW composition

Nineteen developing countries had numerical composition data, and two, Indonesia and Turkmenistan, had qualitative composition data. The Bhutan and Maldives case studies did not provide waste composition data. Fig. 2 graphically illustrates the difference between MSW composition in developed countries versus developing countries. On average, waste streams in developed countries are comprised of half as much organic material, twice the portion of paper and cardboard, and similar fractions of glass and plastic.

The waste category 'Other' includes ash, stone, ceramic, and slag, as well as other undefined materials, and 'Organic' includes bones, shells, leather, and wood. All other category names are reflective of the materials classified under them. The average 55% organic material of the 19 case study countries (see Fig. 2) is consistent with other studies on MSW in developing countries (Blight and Mbande, 1996). Note the high variance in all waste categories, but particularly organic, as illustrated in Fig. 2 by the gray lines spanning the developing countries' data. Seasonal effects, income level (Wells, 1994), domestic fuel supply (Wang and Nie, 2001; Metin et al., 2003), geography, living standards, and climate (World Bank, 2003a; Buenrostro and Bocco, 2003) all affect the MSW composition.

For instance, a greater portion of MSW classified as 'Other' depends upon the domestic fuel supply used; wood and coal result in large portion of inert matter, whereas gas has negligible amounts of solid residue (Wang and Nie, 2001; Metin et al., 2003). Some experts claim that high-income households generate more inorganic material from packaging waste, whereas low-in-

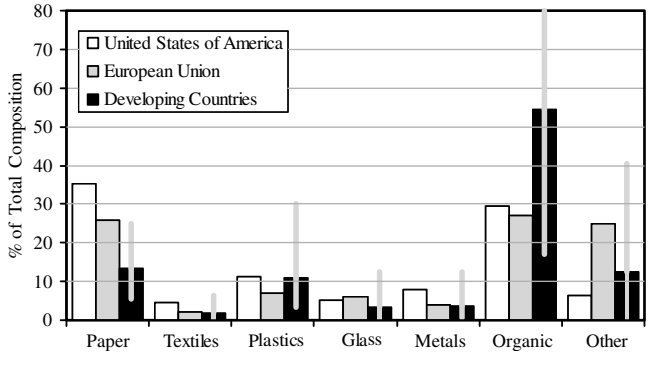

Fig. 2. Comparison of municipal solid waste composition of developed countries (United States and those in the European Union) against the average of 19 developing countries. Vertical bars provide the range of composition of each material type for the developing countries only (USEPA, 2003; Eurostat, 2003; see sources in Table 1).

come households produce more organic material due to preparing food from base ingredients (Wells, 1994). Still, others believe that high-income households may generate the same amount of organic material because they can afford servants to prepare fresh, unpackaged food (Wells, 1994). Also, organic material increases in the waste stream during the summer due to fruit being a bigger part of a person's diet in developing countries (Wells, 1994).

4.3. MSW recovery

Table 3 provides the waste recovery data provided by the literature review. When provided in the case studies, Table 3 notes the percentage of material recovery; otherwise, a diamond symbol (♦) denotes simply the occurrence of material recovery. Mongolia has significant recycling activities as evidenced by scavengers comprising 10% of the capital city's population and a women's federation that operates household collection of recyclables via their "blue bag" campaign (World Bank, 2004). Mexico provided a national material recovery rate of 0.68%, which fell well below the 5% recovery rate inclusion criterion (Buenrostro and Bocco, 2003).

Due to data availability, the information provided in Table 3 varies widely with respect to the degree of detail. The main purpose of Table 3 is to justify the classification of each country's recycling activities as either present or not. Table 3 shows Brazil and Turkey having the highest material recovery rates, which is most likely a result of the roles of Cempre – the Brazilian Recycling Commitment and industry, respectively (Wells, 1994; Metin et al., 2003). Developed countries' recycling rates fall within the developing countries' range of 0–41% material recovery, with the European Union at 18% and the US at approximately 30%.

Developed countries typically utilize curbside recycling programs to collect and sort wastes for recycling processing. Conversely, developing countries utilize the social sector known as scavengers to handle such activities. Scavengers are citizens with low- to no-income that collect materials either dispersed throughout the city or concentrated at dumpsites. These materials are then sold to recycling shops, middlemen, or exporters. Scavengers oftentimes have no choice but to work under poor conditions, putting their health and safety at risk. Many times other citizens and MSWM operators view scavengers as a nuisance. However, Medina (2004) proposes that "when scavenging is supported – ending that exploitation and discrimination – it represents a perfect illustration of sustainable development that can be achieved in the Third World: jobs are created, poverty is reduced, raw material costs for industry are lowered (while improving competitiveness), resources are conserved, pollution is reduced, and the environment is protected." Such a systems-wide perception has the potential to make significant improvements in MSWM in developing countries.

4.4. Data quality assessment

Table 4 provides the results of the data quality assessment. The overall indicator score for the data used in this study is 1.95, meeting the target. There is an apparent correlation between indicator scores and source type. When the source is an individual researcher or research team, the average scores per source indicate higher quality data, whereas, when the source is a summary paper, such as those issued by UNEP and the World Bank, the average scores per source indicate lower quality data. The latter is due to little discussion of methodology in these references, and while the summary reports typically provide citations for the data presented, the sources of data were not easily attainable.

4.5. Twelve factors influencing sustainable recycling of MSW

Table 5 provides the title and description of each factor identified that influences sustainable recycling of MSW, and the degree to which the factor acts as a barrier against recycling in developing countries' MSWM.

The summarized percentage of case studies where a factor acted as a barrier shows MSWM personnel education, waste collection and segregation, and government finances as the three biggest barriers to recycling in developing countries (identified as a barrier in 83%, 79%, and 77% of the case studies respectively). On the other hand, Household Economics is one of the smallest barriers (22% of case studies), which indicates that socio-economic status is not the limiting factor to recycling in developing nations. In other words, a

Table 3
Municipal solid waste (MSW) recovery in 13 developing countries

Country	MSW recovery (%)				
	Overall	Paper	Plastic	Glass	Metal
Botswana	♦		90		65
Brazil	41	30	20[a]	20[b]	49[c]
China	7–10	♦			♦
Guyana	♦			♦[b]	♦
India	♦		♦		
Indonesia	♦	♦	♦	♦	♦
Iran	♦	♦	♦		
Mongolia	♦				
Nepal	5				
Philippines	13	♦	♦	♦	♦
Sri Lanka	♦	♦	♦	♦	♦
Thailand	15	28	14	18	39
Turkey	♦	36	30	25	30
Vietnam	13–20	♦	♦	♦	♦

Percentage numeric values provide quantitative recovery rates. Diamond symbol (♦) qualitatively signifies recycling activity occurs either overall or for a particular material.
[a] Recovery of plastic beverage bottles only.
[b] Recovery of containers only.
[c] Recovery of aluminum cans only.

Table 4
Results of data quality assessment showing indicator score per attribute per source

Country	Source	Acquisition method	Representativeness	Data age
Bhutan	UNEP (2001b)	3	3	1
Botswana	Bolaane and Ali (2004)	1	1	1
Brazil	Wells (1994)	3	3	2
Brazil	Fehr et al. (2000)	1	2	2
China	Wang and Nie (2001)	2	3	1
Guyana	Závodská (2003)	1	1	2
India	UNEP (2001c)	2	3	2
Indonesia	World Bank (2003a)	3	3	1
Iran	Abduli (1995)	1	2	2
Jamaica	Pendley (2005)	2	3	2
Lao	UNEP (2001d)	3	3	1
Lebanon	Nuwayhid et al. (1996)	1	2	2
Malaysia	Kathirvale et al. (2003)	1	1	1
Maldives	UNEP (2002)	3	3	1
Mauritius	Mohee (2002)	1	1	1
Mexico	Buenrostro and Bocco (2003)	2	3	1
Mongolia	World Bank (2004)	3	3	1
Nepal	UNEP (2001e)	1	3	1
Philippines	World Bank (2001)	2	3	1
Sri Lanka	UNEP (2001f)	2	3	1
Thailand	UNEP (2001a)	3	3	2
Thailand	World Bank (2003b)	2	3	1
Turkey	Metin et al. (2003)	2	2	1
Turkmenistan	UNEP (2005b)	2	3	2
Vietnam	UNEP (2001g)	2	3	1

Table 2 provides descriptions of attributes.

Table 5
Summary of 12 factors influencing recycling as an element of sustainable municipal solid waste management in developing countries

Title	Description	Percent of case studies as a barrier
Government policy	Presence of regulations, enforcement of laws, and use of incentive schemes	63
Government finances	Cost of operations, budget allocation to MSWM, stability/reliability of funds	77
Waste characterization	Assessment of generation and recovery rates, and composition of waste stream	67
Waste collection and segregation	Presence and efficiency of formal or informal collection and separation by scavengers, the municipality, or private contractors	79
Household education	Extent of knowledge of waste management methods and understanding linkages between human behavior, waste handling, and health/ sanitation/environment within households	69
Household economics	Individuals' income influencing waste handling behavior (reuse, recycling, illegal dumping), presence of waste collection/ disposal fees, and willingness to pay by residents	22
MSWM administration	Presence and effectiveness of private and/or public management of waste (collection, recovery, disposal)	44
MSWM personnel education	Extent of trained laborers and skilled professionals in MSWM positions	83
MSWM plan	Presence and effectiveness of an integrative, comprehensive, long-term MSWM strategy	50
Local recycled-material market	Existence and profitability of market systems relying on recycled-material throughput, involvement of small businesses, middlemen, and large industries/exporters	36
Technological and human resources	Availability and effective use of technology and/or human workforce and the safety considerations of each	58
Land availability	Land attributes such as terrain, ownership, and development dictating MSWM	0

majority of the world's population can participate in this form of sustainable MSWM. Interestingly, Land Availability was evidenced as an incentive in every case that addressed this as a factor influencing recycling. Sixty-percent of the country case studies revealed a relationship between having a majority of factors acting as incentives and having active recycling efforts. Of the 23 country case studies, 14 actively recycle and 9 do not. Scavengers, low- to no-income citizens that collect materials of value from streets, dumps, and landfills, are present in 16 of the 23 developing countries in the case study review. Troschinetz (2005) details support documentation of each of the 12 factors influencing sustainable recycling of MSW.

4.6. Validation of 12 factors influencing recycling

Other efforts on understanding the various pressures that influence the effectiveness of MSWM in developing countries support the results of this research. Following an assessment of MSWM projects funded by the World Bank, Bartone and Bernstein (1993) proposed that some responsibility should be placed on funding agencies to ensure that MSWM projects include the following aspects: strategic solid waste plans; solid waste collection; transfer, resource recovery, and disposal; hazardous waste management; regulatory framework; institutional arrangements; environmental education and public participation; financing, pricing, and cost recovery; land acquisition; and phasing of MSWM improvements.

Diaz (1998), focusing on Latin America, encourages the following non-technological issues to receive more attention with respect to MSWM: national policy, institutional capacity, regulatory activity, personnel education, and financial stability. Závodská and Knight (2002) developed a 10-point checklist to assist planners and researchers in assessing and improving MSWM in Georgetown, Guyana. Also intending to have broader applicability to most developing countries, it included action items pertaining to the following topics: social factors and education, waste stream information, collection, workforce and productivity, equipment, resource recovery, disposal options, laws and regulations, financial resources, and other issues.

These previous studies raised attention to key topics within MSWM in developing countries similar to this research, but none considered the pressures specifically on material recovery, understood the relationships among factors influencing recycling, nor identified the drivers behind the MSWM institutions. Nevertheless, the consistency among the results of their research and this research strengthen the significance of the 12 factors influencing recycling, a sustainable approach to MSWM, arrived at in this study.

4.7. Relationships among 12 factors and to sustainability

4.7.1. Stakeholder involvement

While identifying each of the 12 factors that influence recycling in developing countries, the literature mentions repeatedly the issue of stakeholder involvement and collaboration as a way to improve the various aspects of MSWM.

The case studies identified collaboration as a catalyst to heighten household awareness about recycling and waste (Wells, 1994; Buenrostro and Bocco, 2003), improve waste handling and disposal operations including characterization and segregation (UNEP, 2001c; Buenrostro and Bocco, 2003), strengthen law enforcement (World Bank, 2003a), utilize scavengers as a legitimate agent of MSWM (UNEP, 2001d), recommend inclusive policy initiatives (UNEP, 2002; Buenrostro and Bocco, 2003), create integrated, sustainable MSWM plans (UNEP, 2001f), and reduce expenses through cost sharing of facilities and equipment between agencies (World Bank, 2001).

Thus, this research recognizes stakeholder involvement as an overarching theme essential to each of the 12 factors, and therefore, additional analysis of it follows.

4.7.2. Collaboration web

The collaboration web shown in Fig. 3 was designed as a result of the reoccurring stakeholder theme highlighted in the case studies. Various institutions represent and govern the issues related to each factor. The functionality of the relationships between factors' institutions, in other words institutional collaboration, greatly influences the success of sustainable MSWM. In Fig. 3, a solid line represents a relationship between institutions necessary for a given factor to contribute to sustainable recycling, whereas a dashed line implies heightened influence on sustainable recycling by a given factor upon institutional interaction. In other words, institutional collaborations shown by solid lines are critical for more sustainable MSWM through recycling, and relationships shown by dashed lines further sustainable MSWM through recycling but are not critical to its presence. Collaboration, in general, demands active participation by all parties working toward a common goal. In this case, the common goal would be striving for more sustainable MSWM through material recovery. The collaboration web in

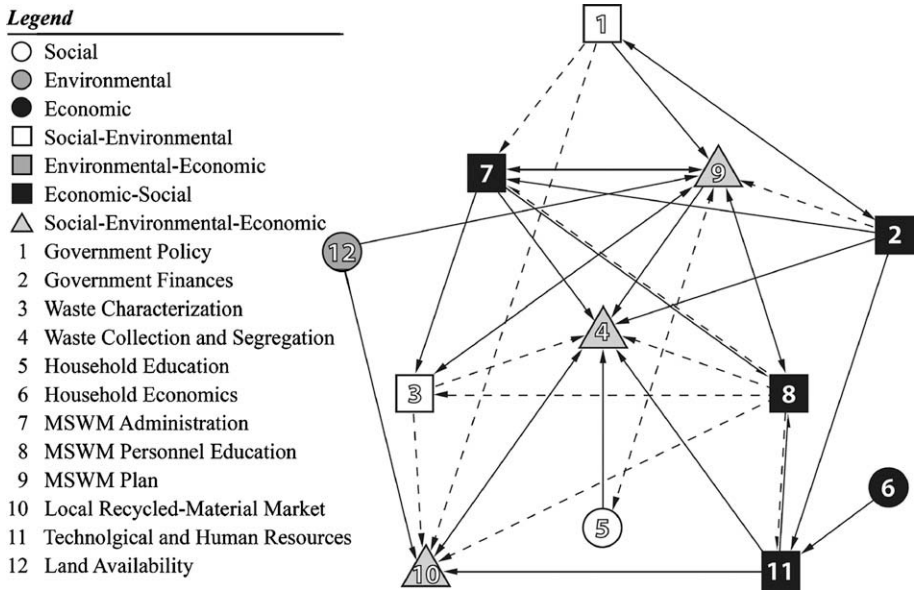

Fig. 3. Collaboration web illustrating relationships among the 12 factors influencing sustainable recycling in developing countries. There are institutions responsible for each factor's activities. A solid line represents necessary collaboration institutions for a given factor to contribute to sustainable recycling, whereas a dashed line implies heightened influence on sustainable recycling by a given factor upon institutional interaction. Arrows show how information flows from one MSWM institution to another; this defines the stakeholder involvement required of each party. Node shading and shape identify the sustainability dimensions governing MSWM institutions' responsibilities based on relationships among factors.

Fig. 3 goes further to illustrate the direction of information flow with arrows (i.e., the giving and receiving parties of information).

For example, waste collection and segregation (#4 in Fig. 3) requires collaborative input from six other factors in order to simply operate, and two additional factors to function efficiently. In order to fulfill the goals of the waste collection and segregation factor, residents need to be educated on how to separate waste properly (#5 in Fig. 3), laborers and equipment are needed for collection and processing of waste (#11), the government needs to manage the finances associated with such operations (#2), and MSWM administrators (#7) need to have a plan (#9) in place from which to gain direction of activities. Educating the MSWM laborers and managers (#8) and understanding the characteristics of the waste stream (#3) will promote efficiency in all of the waste collection and segregation activities. Waste segregation and collection is a factor that receives many inputs from other factors.

In contrast, other factors have institutions that act as suppliers of information and guidance with respect to MSWM. Government finances (#2 in Fig. 3) and government policy (#1 in Fig. 3) are two factors that predominantly provide input to other factors, and actually, the only input for each of these factors is from one another. Government policy provides the regulations needed to formulate the MSWM plan. Government finances cover expenditures on technological and human resources, waste collection and segregation, as well as MSWM administration. Another example of two factors that feed off one another is the relationship between MSWM administration and the MSWM plan. First, administrators create the plan, and then the administrators are required to continually update it and look to it for direction of their responsibilities.

Furthermore, Fig. 3 not only addresses the collaborative nature required of sustainable MSWM, but also how each of the three sustainability dimensions (social, environmental, economic) govern the responsibilities of the institutions associated with the 12e factors influencing recycling in developing countries. The sustainability dimension assignments, as illustrated by shape and shading in Fig. 3, reflect the social, environmental, and/or economic influences on each factor, as well as its relationships to other factors. Sustainability requires de-compartmentalization to better understand the impacts of a given action in pursuit of one goal on the outcome of other goals. Fig. 3 illustrates how certain MSWM activities typically thought of as pertaining to one dimension (e.g., local recycled-material market as economic) has been, under the concept of sustainability, thrust into being multidimensional due to the necessary and beneficial interactions with other activities in order to achieve its goal. In other words, those factors with inputs from various institutions possess greater multidimensionality.

For instance, three factors – waste collection and segregation #4 in Fig. 3), MSWM plan (#9), and local recycled-material market (#10) – require the most collaboration, as illustrated by the large number of arrows pointing toward these three factor nodes in Fig. 3, and also are the only three factors inclusive of all three sustainability dimensions. In contrast, factors demanding less stakeholder involvement in regards to MSWM exude only one or two sustainability dimensions, such as household education and waste characterization. Troschinetz (2005) provides detailed explanations of relationships among factors, direction of informational flow, and factors' connection to sustainability.

Fig. 3 also offers great utility to any stakeholder involved in MSWM in developing countries. It serves to heighten awareness of the relationships involved in sustainable MSWM, as well as the degree to which these relationships affect the institutional activities associated with each factor. Through its use, the institutions associated with each of the 12 factors can achieve a better understanding of the necessary and beneficial collaborations for more sustainable MSWM. Perhaps, a next step could be to identify the institutions associated with each factor node and to detail the interactions among these institutions within the collaboration web that would support sustainable MSWM. Additionally, this collaboration web could be explored for its applicability to other branches of sustainable MSWM such as waste minimization, incineration with energy recovery, and composting. Translating this collaboration web into a useful tool for developed countries' MSWM could also be investigated.

5. Conclusion

This research contributes to an issue on which consensus was reached more than 25 years ago. At the United Nations Conference

on Environment and Development in Rio de Janeiro, Brazil in 1992, 178 governments agreed upon the need for more sustainable municipal solid waste management in both developed and developing nations. Chapter 21 of Agenda 21, the Rio Declaration on Environment and Development, outlines the environmentally sound management of solid wastes, which includes maximizing environmentally sound waste reuse and recycling.

This study quantitatively and qualitatively examined 23 developing country case studies. The average MSW generation rate was 0.77 kg/person/day, with recovery rates varying from 5% to 40%. The waste streams of 19 of these case studies consisted of 0–70% recyclable material and 17–80% organic material.

This research identified the following 12 factors that influence the sustainable recycling of MSWM in developing countries: government policy, government finances, waste characterization, waste collection and segregation, household education, household economics, MSWM administration, MSWM personnel education, MSWM plan, local recycled-material market, technological and human resources, and land availability.

By understanding the relationships among these 12 factors, this study emphasizes the collaborative nature of sustainable MSWM. A correlation between stakeholder involvement and sustainability existed, as supported by the fact that the only three factors driven by all three dimensions of sustainability (waste collection and segregation, MSWM plan, and local recycled-material market) were the three that required the greatest collaboration with other factors. In addition, it was demonstrated how each of the three dimensions of sustainability (social, environmental, economic) govern the responsibilities of the institutions associated with the 12 factors influencing recycling in developing countries.

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