Waste Recycling in a Developing Context: Economic Implications of an EU-Separate Collection Scheme

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Abstract This study assesses the economic viability of implementing a successful developed economy-based separate collection scheme in a developing economy test area while taking into consideration different influential factors. Two scenarios with different intensities of source segregated (SS) materials were simulated to compare the overall collection cost in developing versus developed economies while considering the variation in waste composition. The SS efficiencies were calculated based on a successful source separation scheme implemented in a developed economy. Scenario S1 reflects a policy towards separation of paper and packaging waste with an overall SS intensity of 13% in the test area in comparison with 25% in the developed economy. Scenario S2 considered an increase in the overall SS intensity that reached 68% in the test area in comparison with 48% in developed economy, when considering the separation of organic waste. The results showed that in the test area, an increase in SS intensity from 13% up to 68% caused a significant reduction in residual municipal solid waste but a consequent increase in the overall collection cost reaching up to ~44%. The developing economy exhibited significantly lower (63–84%) collection costs in comparison with developed economy, mainly due to significantly lower personnel cost. Variation in waste composition caused a major difference in the overall collection cost between developing and developed economies, depending on waste density, collection vehicles load, and compaction ratio. For instance, the collection of low-density waste (e.g. light packaging) resulted in lower fuel consumption and collection cost (up to 83%) in developing economies in comparison with higher fractions in developed economies.

Keywords Waste separation · Waste collection · 3R concept · Economic assessment · Developing context

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1 Introduction

Worldwide, nearly more than 2 billion tonnes of solid waste are generated annually, with projections to reach 3.4 billion tonnes by 2050 (Kaza et al. 2018). Population growth, development, and urbanization have increased the quantities of municipal solid waste generation to levels raising considerable management challenges (Gundupalli et al. 2017). The 3R (reuse, recycle, and recovery) concept has been evolving to become most effective in partially facing these challenges. This concept is extrapolated from the waste management hierarchy, which was developed by the European Commission and was long recognized in the EU legislation as a fundamental component of integrated waste management (Council Directive 1991). In this context, separation of waste material at source is a critical factor influencing the successful implementation of this concept. Several studies (Boonrod et al. 2015; Sukholthaman and Sharp 2016) have also demonstrated the effectiveness of waste separation at source in reducing the amount of waste to be landfilled and increasing the amount of recyclable materials. Accordingly, it has been widely applied in developed economies (Rousta et al. 2015; Di Maria and Micale 2014) towards a sustainable integrated waste management system. Developing economies have witnessed a lack of public participation in waste separation at source with limited applications in pilot cities (Kaza et al. 2018; Tai et al. 2011). This can be attributed to several factors such as the lack of awareness about the importance of waste separation at source (Kaza et al. 2018; Boonrod et al. 2015), outdated legislation or lack of services and infrastructure (Sukholthaman et al. 2017), unavailability of market for recyclables (Belton et al. 1994), and inconsistent waste separation campaigns (Miller Associates 1999). In turn, waste collection of source-separated material can affect its quality and consequently can impact the effectiveness and efficiency of the 3R process. The waste collection process in developing economies shares the highest cost among the other urban services whereby local authorities spend between 20 and 50% of their budget on this service (UN Habitat 2010).

Past efforts evaluated the impact of source separation on waste collection and identified influencing factors affecting the application of this concept (Sukholthaman and Sharp 2016; Vassanadumrongdee and Kittipongvises 2018; Boonrod et al. 2015). Other studies examined aspects related to source segregation intensity, fuel consumption, as well as economic and environmental impacts (De Oliveiera and Borenstein 2007; Di Maria et al. 2013; Everett et al. 1998a, b; Iriarte et al. 2009; Johansson 2006). For instance, Sukholthaman and Sharp (2016) demonstrated that the higher source separation rate, the less amount of waste left to be landfilled, the less the total management cost waste to be collected, and eventually the higher the efficiency of the waste collection service. However, the authors did not consider additional costs from collecting source-separated waste.

While economic implications of implementing separate waste collection schemes have been recognized particularly in developed economies (Di Maria and Micale 2013), limited to no study identified the differentiating factors influencing the practical implementation of this concept in a developing context. These factors may include the amount and quality of the waste, its composition and fraction of recyclable materials, available recycling industries and market for recyclable material, public awareness and attitude, as well as the economic, legal, and institutional support to the 3R concept. In this study, we aim to assess the economic viability of implementing a successful developed economy-based separate collection scheme in a developing economy context, while considering those influential factors. The ultimate objective is to support the development of an economically viable separate collection system while quantifying advantages and disadvantages towards decision making and policy planning.

2 Materials and Methods

2.1 Test Area

The test area (Beirut, Lebanon) has a population >2 M inhabitants and encompasses mostly medium to high-rise apartment buildings. Table 1 presents its average waste composition in comparison with a medium-sized Italian city with characteristics similar to the test area. Generally, developing economies are characterized by a higher fraction of organic waste (53.4%) in comparison with developed economies (20.3%). Papers (15.6%) in developing economies are lower than those encountered in developed economies of 35.5% (Table 1).

The management system in the test area consists of commingled MSW collection, sorting and recycling, composting, and landfilling. Waste is collected at a cost of 26 €/tonne (CDR 2010) and transferred into two material recovery facilities (MRFs) where it is sorted into bulky items, inerts, biodegradable organics, and recyclables. The biodegradable fraction is sent for open windrow composting with relatively

Table 1 Average MSW composition (% w/w)

Waste category	Test area[a]	Developed economy[b]
Organic	53.4	20.3
Glass	3.4	7
Metals	2	6.5
Papers	15.6	35.5
Plastics	13.8	12.6
Textiles	2.8	1.5
Wood	0.8	3.6
Others	8.2	12.7
Total	100	100

[a]Laceco/Ramboll (2012); Maalouf and El-Fadel (2019a)
[b]Data retrieved from Di Maria and Micale (2013) for a typical Italian city

low-quality compost often rejected by farmers (Maalouf and El-Fadel 2019b). Waste management activities concerning the collected waste after being unloaded at the MRFs were not been included in the present study.

2.2 Scenario Definition: Policy Management and Economic Analysis

In this study, a simulation model (Di Maria and Micale 2013) was used to calculate associated costs of adopting a separate waste collection system. The model runs giving to space/time correlation and is able to estimate the quantity of collected waste (tonnes), the amount of fuel consumed (L), and the time (s) required to cover a given collection route (km). Input data are presented in Table 2.

Two scenarios with different intensities of source segregated (SS) materials were simulated to compare overall collection cost with respect to a developed economy-based separate collection scheme while considering the difference in waste composition (Table 3). The SS efficiencies were calculated based on a successful source separation scheme implemented in a developed economy (Di Maria and Micale 2013). The segregation efficiency by individual waste component adopted for all scenarios is displayed in Table 4 Scenario S1 reflects a policy towards separation of paper and packaging waste with an overall SS intensity of 13% in the test area in comparison with 25% in a developed economy. The latter is about double the overall SS intensity in the test area due to the higher fraction of recyclable materials (Table 1). An increase in SS intensity was achieved by increasing the amount of source-separated materials. For instance, scenario S2 reached an overall SS intensity of 68% in the test area when considering the organic waste fraction, which is higher

Table 2 Model input data

Type of data	Value	Reference
Vehicle acceleration (km/h/s)	2.8	Wang (2001)
Pickup time (s)	60	Di Maria and Micale (2013)
Average speed (km/h) depending on waste collection vehicle (WCV) size (m3)	WCV (22–24 m^3): 16 WCV (18 m^3): 16 WCV (6 m^3): 16 WCV (3 m^3): 16	
Average fuel consumption (L/km) depending on WCV size (m^3)	WCV (22–24 m^3): 0.84 WCV (18 m^3): 0.70 WCV (6 m^3): 0.15 WCV (3 m^3): 0.17	
Vehicle purchase cost (€) depending on WCV size (m^3)	WCV (22–24 m^3): 18,000 WCV (18 m^3): 98,000 WCV (6 m^3): 29,000 WCV (3 m^3): 18,000	

Table 3 Description of source segregation efficiencies of tested scenarios

Scenario	Location	Description	Material (% w/w)	Overall SS efficiency (%)
S1	Test area-LB	Separation of paper and packaging (plastic, metals, and glass)	RMSW (86.9) Paper (8.3) Packaging (4.7)	13
	Italian city-IT[a]		RMSW (74.6) Paper (19.0) Packaging (6.40)	25
S2	Test area-LB	Separation of paper, light packaging (plastic), organic, glass, and metals	RMSW (32) Paper (5.1) Light packaging (13.3) Organic (47.1) Glass (1.6) Metals (1)	68
	Italian city-IT[a]		RMSW (51.9) Paper (11.6) Light packaging (12.1) Organic (17.9) Glass (3.3) Metals (3.2)	48

RMSW Residual municipal solid waste; *SS* source segregation; *LB* Lebanon; *IT* Italy
[a]Data retrieved from Di Maria and Micale (2013) for a typical Italian city

Table 4 Source segregation efficiency by individual waste component for tested scenarios

	Waste component	Source segregation efficiency (%)
S1	Paper	53.23
	Light packaging + glass	24.50
S2	Paper	32.70
	Light packaging	96.00
	Organic	88.20
	Glass	47.10
	Metal	49.20

than at the developed economy (Table 1). Therefore, the latter resulted in a lower SS intensity of 48% in S2 (Table 3). The waste collection vehicles (WCV) are equipped with rear loaders and powered by diesel fuel oil at an average cost of about 0.55 €/L. Larger WCV (i.e. 18–24 m^3) operate with a 2-person crew, while 6 and 3 m^3 WCV operate with 1-person crew.

Data retrieved from Di Maria and Micale (2013) for a typical Italian city

In all scenarios, the simulations used similar assumptions for a separate collection scheme in a developed economy, which include:

- Maximum length of a work shift is 6 h per day;
- Two work shifts per day;
- WCV operating on daily basis with full-day use;
- Vehicle mortgage around 5 years;
- Minimizing number of different size WCV (m^3) depending on SS intensity of each scenario. The lower SS intensity scenario S1 requires fewer large-sized WCVs whereby higher SS intensity (S2) requires more small-sized vehicles.

The economic analysis included personnel and vehicle purchasing costs (see Table 2). Vehicle operating and maintenance costs were not considered in this study because they are very similar for the different SS scenarios. The average gross cost per crew member in the test area was assumed at 4500 €/year.

3 Results and Discussion

Figure 1 depicts collection costs by waste component for the simulated SS intensity scenarios under developing (LB) versus developed (IT) economies while considering the same amount of waste and variation in waste composition. Collection costs of individual waste components were categorized based on WCV, fuel consumption, and personnel costs.

As expected, the increase in SS intensity up to 68 and 48% in developing and developed economies, respectively, caused a significant reduction in residual MSW (RMSW) but an increase in the collection cost (Fig. 1). For instance, the overall collection cost increased from 9 €/tonne for 13% SS intensity scenario (S1) to 13 €/tonne for 68% SS intensity scenario (S2) (Fig. 1). This can be attributed to the increase in the collection points and total distances travelled on a daily basis by the WCVs. Consequently, this requires an increase in the number of vehicles and personnel involved in the collection activity contributing to the increase in corresponding costs.

Di Maria and Micale (2013) examined the average fuel consumption for 25 and 48% SS intensity scenarios and showed that the fuel consumed per tonne of waste collected increased with SS intensity. The average fuel consumption for the different scenarios ranged from 3.3 to 3.8 L/Ton, respectively, for the 25 and 48% SS intensity. Similarly, the collection costs increased from about 40 to about 70 €/tonne in a typical Italian city characterized by apartment buildings and a high-density population.

Moreover, results showed that for all scenarios, developing economy (LB) resulted in lower collections costs (63–84%) in comparison with developed (IT) economy (Fig. 1). This can be mainly attributed to the personnel cost, which is around 4500 €/year in a developing economy in comparison with 40,000 €/year under

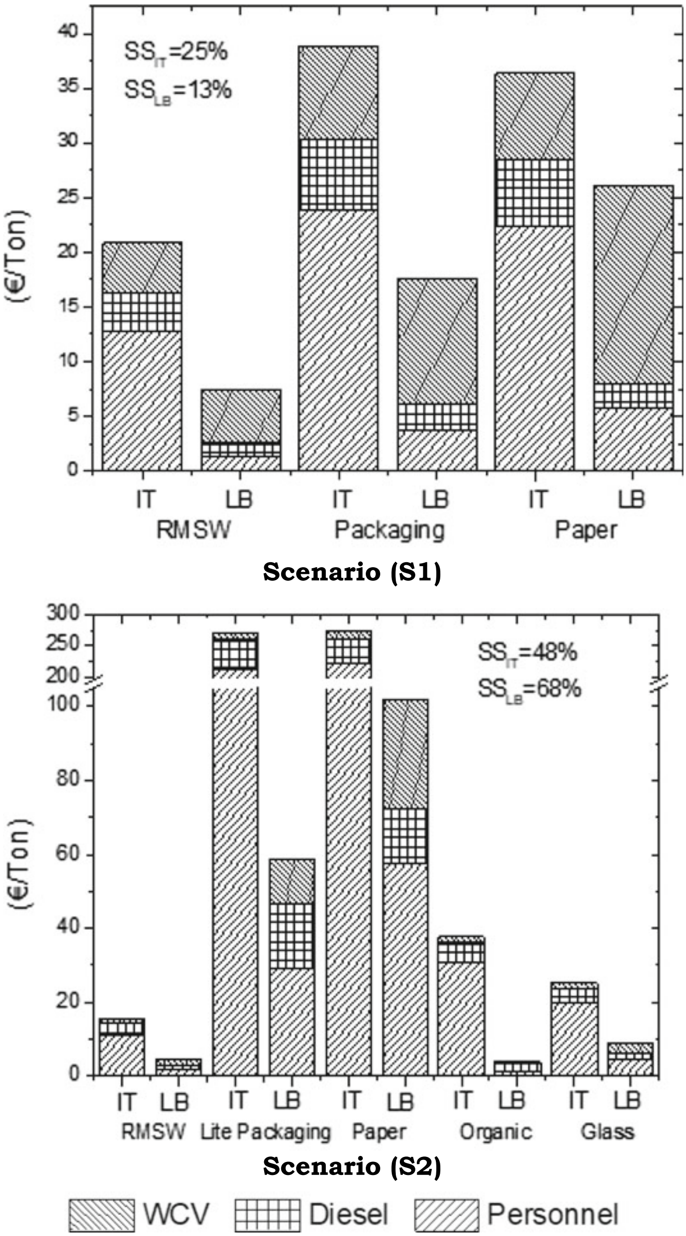

Fig. 1 Specific collection cost by waste component for different SS intensity scenarios in developed versus developing economies categorized by WCV, diesel, and personnel costs

a developed one. The latter was the major contributor (up to 82%) to the overall collection cost in a developed economy (Fig. 1).

Another aspect that can influence the collection cost is the WCV purchasing cost. In a developing economy, for instance, the WCV purchasing cost was the significant contributor (~67%) to the overall collection cost for the 13% SS scenario (S1), followed by personnel (~20%) and diesel fuel consumption (~13%) costs (Fig. 1). The number of personnel was about 10 at a cost of about 45,000 €/year, operating on two large-sized WCVs (corresponding purchasing cost of about 52,000 €/year). In contrast, the overall collection cost in 68% SS scenario (S2) was influenced mainly by the increase in the number of crew needed (~17 workers at cost of 77,000 €/year) rather than the number of purchased WCVs (one large-sized and five small-sized WCVs for a total of about 58,000 €/year).

Equally important is the impact of waste composition that may vary with location and is noticeably different between developed and developing economies (Table 1). For instance, the collection of low-density waste such as light packaging and RMSW resulted in higher fuel consumption and collection cost in developed economies in comparison with lower fractions under a developing economy (Fig. 1). In particular, the collection of low-density waste performed in high SS intensity scenario (S2) resulted in high collection costs due to the low weight transported by the WCVs. In contrast, the collection of source segregated organic waste in scenario S2 resulted in lower collection cost in comparison with other waste components as a consequence of the lower fuel consumption, which is greatly affected by the lower compaction ratio of the large-sized WCVs with respect to the low-sized WCVs in S1.

4 Conclusion

Waste collection of source-separated waste is an essential component of an integrated waste management system whereby it can affect its quality and consequently can impact the effectiveness and efficiency of the 3R process. This study assessed the economic viability of implementing a successful developed economy-based separate collection scheme in a developing economy test area while taking into consideration different influential factors and variation in waste composition. The results showed that the increase in SS intensity from 13% up to 68% caused a significant reduction in residual municipal solid waste but a consequent increase in the overall collection cost reaching up to ~44%. Note that for all tested scenarios, developing economy exhibited lower collections costs (63–84%) in comparison with developed economy, mainly due to significantly lower personnel cost. Moreover, a comparison of average reported data showed that the collection cost is affected mainly by the increase in purchasing waste collection vehicles and personnel costs rather than fuel consumption cost. Differences in waste composition between developed and developing economies also played a significant role in affecting the overall collection cost, depending on waste density, collection vehicles load, and compaction ratio. For instance, the collection of low-density waste (e.g. light packaging) resulted in lower fuel consumption and collection cost (up to 83%) in developing economies in comparison with higher fractions in developed economies.

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