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SEPARATE COLLECTION OF ORGANIC WASTE AND CARDBOARD: ASSESSING THE IMPACT OF A DEVELOPMENT COOPERATION PROJECT IN TULKAREM, WEST BANK

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Abstract

This research aimed to analyze the impact of the introduction of a separate collection system for organic waste and cardboard in the Governorate of Tulkarem, West Bank (Occupied Palestinian Territories). The amount of waste diverted from the final disposal at the landfill of Zahret Al-Finjan was quantified and the quality of separate materials was evaluated. An economic and environmental analysis was performed to quantify the impact of separate collection in terms of greenhouse gas emissions and the costs for the local waste management authority. Different methods for data collection were used, such as meetings, field visits and database analysis, allowing the construction of a scientific-based and coherent descriptive framework for the local solid waste management system. The results of the study demonstrate that the separate collection of organic waste and cardboard is a sustainable solution under the environmental point of view, while criticality has been identified in terms of economic sustainability. The proposed method has led to a proper assessment, allowing the identification of the material collection as the most expensive stage and creating the basis for further intervention on the waste management system.

Key words: composting, lower-middle-income countries, material recovery, municipal solid waste

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1. Introduction

The importance of solid waste management has received more and more acknowledgement in the time due to its nexus with both environment pollution and public health (Wilson et al., 2015). Also Sustainable Development Goals deal with this topic, as a healthy and environmentally sounded waste management system has a direct impact on at least three goals: Clean water and sanitation, Sustainable cities and communities and Responsible consumption and production (UN General Assembly, 2015).

Waste management can affect human population and environment in all its stages, from the collection to the final disposal (Vaccari and Perteghella, 2016). In particular, the final disposal of the waste represents a big issue especially in low- and lower-middle-income countries, where waste is mostly disposed in uncontrolled dumpsites (Caniato et al., 2015; Hoornweg and Bhada-Tata, 2012; Vaccari et al., 2012; Wilson et al., 2015). Uncontrolled dumpsites have environmental and social impacts (Crowley et al., 2003; Damgaard et al., 2011; Di Bella and Vaccari, 2014) on the local (soil, water and air pollution; breeding place for disease vectors; etc.) and on the global level, with reference to greenhouse gases emissions, but they remain a common way to face the problem, above all if waste regulation is lacking (Caniato and Vaccari, 2014).

Waste management has consequently become the object of many projects of development cooperation. Apart from the establishment of sanitary

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landfills, implemented strategies consider also the preferential order of waste treatment options described by the waste hierarchy (Hultman and Corvellec, 2012; Lee et al., 2016), proposing reuse, recycling or recovery alternatives. In some of these projects, attention has been given to the collection stage as well. In fact, between waste management stages, the collection one (from the initial storage at producers' place to the final destination of the waste, whether a treatment plant or a disposal site) has the biggest impact on public budgets and urban living (Coffey and Coad, 2010; Collivignarelli et al., 2011). Moreover, an effort toward separate collection can lead to environmental and economic benefits (Vaccari et al., 2013), and the value of separated waste fractions can be enhanced because source separation leads to a higher level of pureness. Composting requires a pure segregated organic fraction (Perteghella and Vaccari, 2017; Zhao et al., 2016), and so do other organic waste treatments (Lohri et al., 2017); recovered cardboard and paper need a high quality in the collection to be achieved, as well (Miranda et al., 2010; Scott, 2011).

In this framework, it is worth to understand the impact of a development cooperation project targeting waste management, as achieved results influence its sustainability. The importance of a proper assessment for a clear comprehension of points of strength and weakness of the system is recognized (Wilson et al., 2015; Zurbrügg et al., 2014).

In a cooperation project, the assessment should normally be concluded in a short time, while continuous changes occur, making difficult to understand properly the importance of each issue. This study proposes strategies for the assessment of a waste management cooperation project, pointing out some criticality in data collection and case description.

This study has been performed within the "Green Tulkarem Project", implemented by the Italian NGO CESVI and funded by the Italian Agency for Development Cooperation. The project was based in the Governorate of Tulkarem, located in the North of the West Bank (Occupied Palestinian Territories) (Fig. 1) and characterized by a population of 185,314 inhabitants, most living in towns (124,551 inhabitants) (PCBS, 2017). With a GDP (Gross Domestic Product) per capita of 2700 EUR (about 3000 US$), West Bank is considered a lower-middle-income economy (World Bank, 2017). Concerning solid waste management, despite the low generation rate and the high collection service, major issues are related to the widespread waste disposal at landfills, the scarce compliance with the 3Rs principle of waste management (reduce, reuse and recycle), an improper allocation of budgets for solid waste management need and lack of public awareness (Al-Khatib et al., 2007; Al-Khateeb, 2017). Some issues are also related to the political situation of the country and the lack of space for waste treatment and disposal. In fact, West Bank is divided into three areas, namely areas "A", "B" and "C", depending on whom is responsible for the administration and the military control, whether the State of Israel or the Palestinian National Authority (PNA). Even if the Israeli-Palestinian Interim Agreement (also known as OSLO II), in 1995, transferred environmental powers and responsibilities to the PNA in areas defined as areas "A" and "B", the most of facilities need to be located in areas "C" (under the administrative and military control of Israel), with significant administrative delays in their construction (SWEEP-Net, 2014).

Fig. 1. Geographic location of Tulkarem in West Bank (Occupied Palestinian Territories)

2. Material and methods

2.1. Background: MSW management in the Governorate of Tulkarem and the "Green Tulkarem Project"

According to the Environmental Law, the solid waste management system in West Bank is established within the framework of the "National Strategy for Solid Waste Management in the Palestinian Territory 2010-2014" (PNA, 2010), which sets two main actors in charge of waste management: the Municipalities and the Join Service Councils for Solid Waste Management (JSCs-SWM). Those authorities are responsible for the 90.6% of collected waste in the North of the West Bank (PCBS, 2015). In the Governorate of Tulkarem, the collection of Municipal Solid Waste (MSW) is performed by the JSC Wadi Shaer (hereafter indicated simply as JSC), autonomously (e.g. in the case of the village of Deir Al Ghousun) or in collaboration with the Municipalities (e.g in Tulkarem and Anabta). The collected MSW is hauled to the Transfer Station (TS) of Wadi Shaer, managed by the JSC, and then transported and disposed of into the landfill of Zahret Al.Finjan, managed by the JSC Jenin.

The landfill of Zahret Al-Finjan was opened in 2009 and it is 2.9 million m^2 extended. It was designed to receive waste from Jenin and Tubas, but it is receiving also solid waste from Tulkarem, Nablus, Ramallah and Al-Bireh Governorates (El-Kelani et al., 2017). The landfill represents a pollution source because it is not provided with any system of biogas and leachate collection and treatment.

The "Green Tulkarem Project", which was active between April 2014 and March 2017, introduced the Separate Collection (SC) of organic waste and cardboard beside the existing MSW collection. Collected organic waste was destined to an agricultural cooperative (Thinnabeh), where it was composted in aerated turned windrows. Cardboard was collected by the JSC on the behalf of a private enterprise, which covered collection costs; after the storage at the TS, cardboard was sold to a paper factory by the enterprise itself.

A proper understanding of the impact of the project is given by taking into account differences between target subjects and areas involved in the collection of the three different streams of waste (MSW, Organic waste, Cardboard). In fact, MSW collection addressed the whole population through street containers, while cardboard collection focused more on big producers, even if through street containers (steel containers cages), and organic waste collection addressed just big producers (markets, vegetable shops), which were identified and provided with containers of different sizes.

Furthermore, the project went through different stages. In a first phase (Stage 0), several small areas were identified on a morphological basis (i.e. central urban areas; suburbs; rural areas), in order to choose a proper collection model for each of them. In August 2015, the collection was covering the whole city of Tulkarem (Stage 1). The design extension (Tulkarem, 'Attil, Deir Al Ghousun, Qaffin, 'Illar, Al Sharquiywa, Iktaba, Anabta, Kafr Al Labad, Beit Lid and Bal'a) was reached from March to September 2016 (Stage 2). Subsequently, the area of interest was reduced, because covering the farer villages was too expensive. The final area included the city of Tulkarem, Nur Shams Camp and the villages of Deir Al Ghousun and Anabta (Stage 3), with a total population of 86,038 people (PCBS, 2017). The following discussion will not consider the Stage 0, which was characterized by daily changes due to a "trial-and-error" approach, but it will focus on the other three stages.

2.2. Data collection

In order to assess the impact of actions introduced by the "Green Tulkarem Project" both on the local and on the global level, this study is divided into two sections, according to following research questions: (a) Evaluation of the project: which has been the local impact of the project in the area of the Governorate of Tulkarem in terms of quantity and quality of recovered materials? (b) Environmental and economic analyses: which are the environmental and economic consequences of the introduction of SC of organic waste and cardboard, in terms of greenhouses gases emissions and costs?

Data were collected during field visits by:

- meetings with officials and employees of the JSC;
- acquisition, analysis and processing of data included in the database of the JSC (Database JSC-SWM), which included daily logs for waste entering or leaving the TS in the period 01/01/2014 – 13/02/2017 as well as other useful information (e.g. fuel expenses, maintenance costs, distances traveled by the vehicles);
- GPS tracking: routes for organic fraction and cardboard collection were tracked by GPS and analyzed with the software QuantumGIS, together with a mapping of collection points;
- Organic waste composition characterization.

2.3. Evaluation of the project

The implementation of the "Green Tulkarem Project" caused changes in the interested area. It influenced the organization of the SWM system in the Governorate, with the establishment of new collection routes and the involvement of new actors. One of goals of the project was the diminishing of the amount of waste landfilled in Zahret Al-Finjan, together with a different distribution of expenses within the system. This aspect has been analyzed, taking into account the step-by-step development of the new system. Qualitative results of SC were also assessed.

2.3.1. Quantity of waste collected, materials recovered and waste landfilled

The total amount of MSW collected was estimated for the whole Governorate and for the area covered by the project, considering changes occurred during the project. Data on total amounts of MSW were extracted from the Database JSC-SWM or estimated on previously collected aggregated data, when the collection was performed from actors different from the JSC and detailed data were not available. The total amount of collected organic fraction and cardboard was calculated from the Database JSC-SWM, as well. This leads to the evaluation of the impact of the waste diversion from landfill disposal to recycling and composting on the whole waste production in the Governorate.

Potential amounts of the separated fraction in the area were calculated considering the MSW composition in the Governorate of Tulkarem (Hamada, 2011), in order to evaluate the performances of the project. In the starting year of the project (2014), a survey to producers (markets, vegetable shops) within the design area was done to understand the amount of organic waste and cardboard produced by commercial activities targeted by the project. These estimates are resumed in Table 1.

Table 1. MSW daily production in Tulkarem divided for each fraction (2014)

<table>
<tr><td colspan="3">MSW daily production for the Governorate of Tulkarem (2014) (1)</td><td>139.07 t/d</td></tr>
<tr><td colspan="3">MSW daily production for the Municipality of Tulkarem (2014) (1)</td><td>64.11 t/d</td></tr>
<tr><td rowspan="3">Fraction</td><td colspan="3">Estimated daily production for each fraction (t/d)</td></tr>
<tr><td colspan="2">MSW (2)</td><td rowspan="2">Commercial activities (3)</td></tr>
<tr><td>Governorate of Tulkarem</td><td>Municipality of Tulkarem</td></tr>
<tr><td>Organic</td><td>63.97</td><td>29.49</td><td>4.74</td></tr>
<tr><td>Plastic</td><td>16.27</td><td>7.50</td><td></td></tr>
<tr><td>Cardboard</td><td>15.30</td><td>7.05</td><td>3.5</td></tr>
<tr><td>Paper</td><td>5.56</td><td>2.56</td><td></td></tr>
<tr><td>Wood</td><td>6.12</td><td>2.82</td><td></td></tr>
<tr><td>Glass</td><td>5.98</td><td>2.76</td><td></td></tr>
<tr><td>Metals</td><td>7.65</td><td>3.53</td><td></td></tr>
<tr><td>Textile</td><td>12.52</td><td>5.77</td><td></td></tr>
<tr><td colspan="4">(1) Estimate (Database JSC-SWM, 2017; Filippini, 2014)</td></tr>
<tr><td colspan="4">(2) Estimate based on waste composition (Hamada, 2011)</td></tr>
<tr><td colspan="4">(3) Survey performed in 2014 (Vitali, 2014)</td></tr>
</table>

2.3.2. Quality of the collected organic waste

The quality of the collected organic waste was assessed through the characterization of the organic fraction, performed at the composting plant. The waste was sorted manually according to the following categories:

1. organic fraction, subdivided in: vegetable waste from markets, greengrocers and vegetable plants;
2. undesired materials, subdivided in: glass, metal, tissue, cardboard, paper, aluminum, plastic, WEEE (Waste Electrical and Electronic Equipment), construction and demolition waste, health care waste, others.

The whole amount of the organic waste was analyzed during four different days (four samples), which were chosen in order to address possible changes during the time span of a week. The total weight of the organic waste was measured in the Transfer Station by a truck scale (sensitivity = ±10kg), while undesired materials were measured through a digital scale (maximum load = 30 kg; sensitivity = ±0.002 kg).

2.4. Environmental and economic analyses

The environmental and economic analyses were based on the comparison between the previous system (unseparated waste collection and landfilling) and the introduction of SC of organic fraction and cardboard. Environmental impacts and economic costs were calculated with reference to one tonne of material (MSW or separated organic waste or cardboard) (w/w wet weight) because it allows a comparison between different systems (Coffey and Coad, 2010).

Table 2 resumes the management phases of each material collected (i.e. MSW, Organic waste, Cardboard). In order to calculate emissions and costs, fuel consumptions for transport stages (Collection; Transfer to Zahret Al-Finjan) and energy consumptions for treatments were assessed. In particular, concerning fuel consumptions, data came from the Database JSC-SWM. The database was divided into two sections: the first one contained information related to the amount and the origin of the material for each load entering (Collection stage) or leaving (Final disposal stage) the Transfer Station; the second one contained fuel consumptions (L) and costs (EUR-Average change for 2017: 1 EUR = 4.06 NIS (New Israeli Shekel)) and covered kilometers for each vehicle owned by the JSC. Other information available for each vehicle were the plate number and the dimension, but not the model or the car brand. Nonetheless, it was mentioned the kind of fuel (Diesel).

Table 2. Management phases of each material collected

Stream	*Management phases*
MSW	Collection by the Municipality or the JSC; Primary storage at the TS; Transfer and final disposal at Zahret Al-Finjan landfill.
Organic waste	Collection by the JSC; Weighing at the TS; Primary storage at the Thinnabeh cooperative; Treatment (shredding; composting); Sale.
Cardboard	Collection by the JSC; Primary storage at the TS; Treatment (pulper; compacting); Sale.

The two Tables were associated as a function of dates and vehicles identifier. Average characteristics of the collection trip for each stream were calculated from the whole Database JSC-SWM, while it was possible to measure distances covered during organic waste and cardboard collection through GPS Tracking of collection trucks (Table 3). Fuel Consumption for tonne of material collected was calculated using the Eq. (1) ($i = 1,\ldots., N$) where N is the number of recorded trips):

$$Fuel\ Consumption\ \ for\ Tonne\ of\ Waste(L/t) = \tag{2}$$

$$= \frac{1}{N}\sum_{i=1}^{N}\frac{Trip\ Length_i(km) * Fuel\ Consumption_i(L/km)}{Load\ Weight_i(t)} \tag{1}$$

Table 3. Average characteristics of the collection trip for each stream (MSW, Organic, Cardboard)

	Collection stage			*Final disposal at the landfill of Zahret Al-Finjan*
Average characteristics	*MSW*	*Organic fraction*	*Cardboard*	
Length of the collection trip (km)	58.96	49.9 *	36.9 *	67.30
Load weight of waste (t)	5.45	1.02	1.42	28.84
Length of the trip per load weight of waste (km/t)	10.81	48.92	25.99	2.33
Fuel consumption (L/km)			1.33	1.77
Cost of fuel (EUR/L)			1.38	1.39

** Measured values*

Energy consumptions were also calculated. The organic fraction was treated with a shredding machine before being composted in turned windrows: the shredding machine for organic waste was composed by two engines with a nominal power of 5.3 kW for conveyor belts and one engine with a nominal power of 22 kW for the shredder and it treated 2 tonnes of organic waste per hour. Cardboard was processed in the TS by a compactor (nominal power of 11.2 kW, 1.75 tonnes for hour) before selling.

2.4.1. Greenhouse gases emissions

A comparison between MSW, organic waste and cardboard management procedures (Table 2), concerning greenhouse gases emission, has been done. Greenhouse gases emission in terms of carbon dioxide equivalent (CO_2eq) considering a time span of 100 years has been calculated using simplified mass balances, resumed as follows:

- Fuel consumption - Collection and transfer to the landfill implicate fuel consumption for operating trucks. Fuel consumption (diesel, with a density of 0.832 kg/L) for collecting and transferring one tonnes of waste was calculated for each stream (MSW, organic waste, cardboard). The stoichiometric equation Eq. (2) was used for combustion in order to calculate the pure CO_2 emissions:

The contribution of CH_4 and N_2O (then transformed in CO_2 equivalent) was calculated using the emission factors provided by EPA (2018). More precisely, we used an average value between “Diesel Light duty vehicles” and “Diesel medium and heavy-duty vehicles” values for collection stages (0.01616 gCH_4/km; 0.00196 gN_2O/km) and the "Diesel medium and heavy-duty vehicles" values for transport from TS to landfill stage (0.03169 gCH_4/km; 0.00298 gN_2O/km).

Power consumption for electromechanical equipments - Nominal power for the shredding machine and the compactor was known, and operating hours were calculated considering the load capacity of each of equipments. CO_2eq emissions for electric kWh depend on the energy mix: for the Middle East this value is assumed to be 205.76 gCO_2/kWh (IEA, 2017);

Composting - CH_4 and N_2O emissions from the biological treatment of 1 kg of wet waste were assumed to be 4 g CH_4/kg and 0.24 g N_2O/kg (IPCC, 2006). GWP100 (Global Warming Potential over 100 years) used for the conversion to CO_2eq emissions is 25 for methane and 298 for nitrous oxide;

Landfill disposal - The volume production of biogas per tonne of waste was calculated from literature values (Sirini et al., 2010): 0.75 m^3/kg_{VS} (VS = Volatile Solids), considering that for MSW from households, VS constitute the 52% w/w of the waste. It has been assumed that 100% of the biogas produced is emitted into the atmosphere (since there is no biogas collection system in the Zahret Al-Finjan landfill). In order to calculate, from the volume of the produced biogas, the mass of CH_4 and CO_2 emitted, it was considered that biogas is composed of 50% CH_4 (density 0.7168 kg / m^3) and 50% CO_2 (density 1.9768 kg / m^3) (De Feo et al., 2012). Finally, through the GWP100 methane index, everything has been transformed into terms of CO_2eq.

2.4.2. Economic analysis

Operational costs for each management procedure (Table 2) was assessed considering personnel costs, fuel and energy consumptions, maintenance costs, administrative expenses and disposal fees (only for MSW). While fuel consumptions were estimated using daily logs from the Database JSC-SWM, other data were obtained from meetings. Check lists were compiled together with local partners, leading to the construction of the economic framework. In fact, personnel costs were calculated on the basis of data provided by the JSC. The JSC provided also its budget for the year 2015 (the last one available), on which maintenance (4.5 EUR/t) and administration costs (7.4% of total collection costs) were deduced. Concerning treatment costs, the average energy cost for the shredding machine (19.7 EUR/month) was provided by the director of the compost station, while no data were available about the operation of the compactor machine for cardboard.

3. Results and discussion

3.1 Evaluation of the project

3.1.1 Quantity of waste collected, materials recovered and waste landfilled

The impact of the "Green Tulkarem Project" on the SWM system of the Governorate of Tulkarem was calculated with respect to three different levels.

First, the impact of SC on the total amount of MSW collected in the whole Governorate was calculated. As shown in Table 4, the percentage of organic waste and cardboard diverted from the landfill reached 2.58% of MSW collected during the first period of 2017.

Subsequently, the impact of SC was calculated with respect to the area actually interested by the project (hereafter mentioned as "real area"). Concerning the organic waste, the involved area went through the three stages explained in Materials and methods. On the other hand, cardboard SC started in September 2016, covering Tulkarem, Deir Al Ghousun, Anabta and Kafr Al Labad. Fig. 2 shows the amount of MSW, organic waste and cardboard collected in the "real area" on a monthly basis (t/month) in comparison with the amount of collected MSW in the "design area". In Table 5 performances of the SC are shown as a percentage of the daily amount of collected waste in the "real area" (average on monthly basis), giving the magnitude of the amount of material which needs to be managed daily.

Continuous changes in the set-up of the project affected its performances and made difficult the analysis. For example, variations of the project area were supposed to influence the amount of organic waste collected. Nonetheless, the Stage 2, coinciding with the widest area covered by the project, did not correspond to larger amounts of collected organic waste (Fig. 2), and was also characterized by the lowest efficiency with reference to MSW collected in the project area (Table 5). Even after the resizing of the area (Stage 3), the efficiency did not reach the level reached during Stage 1. It is not clear whether the efficiency would have been influenced by other variables, such as the seasonal variability, the organization of the collection or the level of involvement of organic waste producers. A possible reason can be found in the drop out of the project of some merchants, which were not satisfied with the timing of the collection, or were disappointed because during the transition period the collection service was not guaranteed. Anyway, this information was collected during informal dialogues and not cross-checked in a systematic way. On the contrary, performances of the SC of cardboard, started in September 2016, were increasing during all the period of study.

Finally, the performances of the project were evaluated comparing collected amounts to the expected production of each fraction in the target area or population. As previously mentioned (Section 2.3.1), the survey to producers involved in the project resulted in 4.74 t/d of organic waste, of which 1.85 t/d of animal origin (bones, meat, chicken skin) which could not be composted due to safety reasons (De Nardo, 2017). An unknown amount of organic waste was destined to direct animal feed as well.

Cardboard was collected through street collection, so an estimate of 15.75 t/d for January 2017 was calculated on the whole MSW production, assuming an incidence of cardboard of 15% (Hamada, 2011). With reference to these values, the project reached in January 2017 about 45% (1.31 t/d) of the amount of organic waste produced by target users, and about 21% (3.36 t/d) of the amount of cardboard produced in the target area.

Table 4. MSW collected in the Governorate of Tulkarem (t/year): 2014-2017

Year	***2014***	***2015***	***2016***	***2017 (3)***
MSW managed by the JSC through the Transfer Station (1)	41,400	42,553	43,969	5,531
* MSW destined for disposal in landfill (collected by the JSC)	13,634	13,179	12,680	2,116
* MSW destined for disposal in landfill (collected by Municipalities)	27,766	29,285	30,937	3,232
* SC of organic waste	0	89	306	45
* SC of cardboard	0	0	46	138
MSW managed by other actors	9,360	11,552	12,760	1,575
* Villages in the project (Attil, Illar, Baqa Al Sharqiywa, Qaffin) (2)	9,360	11,552	12,760	1,575
* Other villages	n.a.	n.a.	n.a.	n.a.
Total	50,760	54,104	56,729	7,106
* Rate of SC of organic waste on MSW collected in the Governorate of Tulkarem	-	0.16%	0.54%	0.63%
* Rate of SC of cardboard on MSW collected in the Governorate of Tulkarem	-	-	0.08%	1.94%
* Rate of SC on MSW collected in the Governorate of Tulkarem	-	0.16%	0.62%	2.58%
(1) Database JSC-SWM (2) Estimation on 2014 values (Filippini, 2014) (3) Period: 1st January - 12th February 2017 (not annualized)				

Table 5. Performances of SC of organic waste and cardboard (%)

Stage	Month	MSW (t/d)	SC on MSW Collected in the real area (%)		
			Cardboard	Organic waste	Separate Collection (SC)
1	2015-08	71	-	0.74	0.74
	2015-09	63	-	0.65	0.65
	2015-10	64	-	0.75	0.75
	2015-11	69	-	1.32	1.32
	2015-12	65	-	1.94	1.94
	2016-01	67	-	1.73	1.73
	2016-02	65	-	1.71	1.71
2	2016-03	142	-	0.86	0.86
	2016-04	139	-	0.80	0.80
	2016-05	155	-	0.58	0.58
	2016-06	155	-	0.41	0.41
	2016-07	154	-	0.63	0.63
	2016-08	147	-	0.69	0.69
	2016-09	137	1.35	0.77	2.12
3	2016-10	101	1.23	1.14	2.37
	2016-11	97	1.79	1.33	3.12
	2016-12	107	1.84	1.27	3.11
	2017-01	105	3.20	1.25	4.44

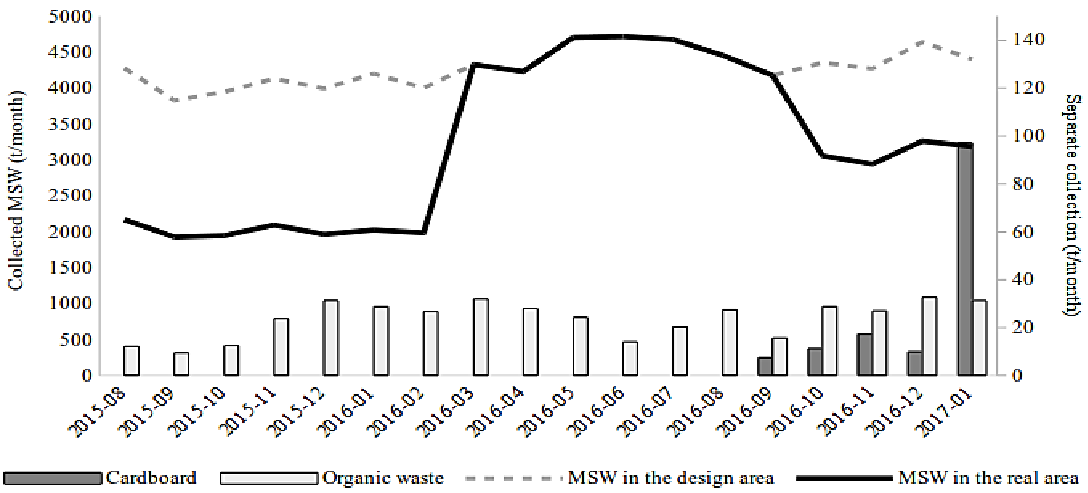

Fig. 2. Comparison between SC of organic waste and cardboard with MSW Collection in the design area and in the real area (t/month)

3.1.2 Quality of the collected organic waste

The characterization of the collected organic waste resulted in an average percentage of contaminants of 0.223 ± 0.001 % out of four samples analyzed. The organic fraction (99.777 ± 0.001 %) was composed mainly of discarded vegetables, with a considerable amount of wood coming from a canning industry working with banana fruits. Even if wet cardboard and tissues could be composted, they were considered as undesired materials because these fractions are supposed to be collected separately. Plastic is the most relevant fraction among undesired materials (ranging from 30% to 73% w/w); it includes several types of polymers, which were separately weighted: MDPE (films) was predominant, followed by HDPE (hard containers), polypropylene (wires), PET (soft plastic bottles), polylaminate (snack packaging) and latex (gloves) (Fig. 3). Other undesired materials were mostly glass bottles (0-18% w/w) and aluminum cans (0-2% w/w), while the presence of other objects (toys, nappies, medicine packs) occurred randomly.

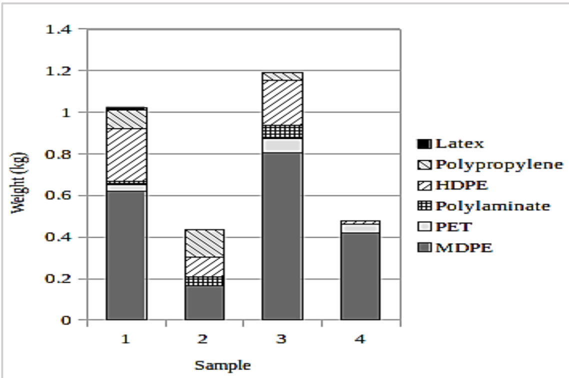

Fig. 3. Amount and kind of plastic present in the organic waste collected

3.2. Environmental and economic analysis

3.2.1 Greenhouse gases emissions

Analyzing the Database JSC-SWM, the average fuel consumption for tonne of waste was calculated: for the collection stage it resulted in 7.20 L/t for MSW, 36.52 L/t for organic waste, 22.46 L/t for cardboard; for the transport of MSW from the TS to the landfill it resulted in 2.58 L/t. Greenhouse gases emissions in terms of carbon dioxide equivalent (CO_2eq) were calculated: they account for 3,905,569 g CO_2eq/t for MSW, 270,747 gCO_2eq/t for organic waste, 60,760 g CO_2eq/t for cardboard. Detailed results are resumed in Table 6.

In terms of carbon dioxide equivalent, emissions from the landfill have a magnitude higher than other considered emissions (Fig. 4a). In order to allow the comparison between other emissions, results are shown in Fig. 4b without taking into account emissions generated by waste landfilling. Comparing emissions in the collection stage, the transport of one tonne of organic waste leads to more emissions than transport of both cardboard and MSW. This is because a collection trip for organic waste is longer than other collection trips, and the amount of transported waste is lower on average, not exploiting the entire load capacity of the truck.

Comparing emissions of SC of organic waste and cardboard, therefore taking into account the whole procedure, the management of organic waste results as the most impacting, due also to emissions in the composting process. It has to be pointed out that the lack of information related to the treatment and subsequent transport of the cardboard is likely to lead to an underestimate of emissions. At the same time, the lack of information about the location of the paper plant and production processes did not consent to calculate the amount of avoided emissions due to the use of recycled cardboard in substitution to the primary raw material. This aspect would have influenced the balance in positive terms, diminishing the amount of estimated emissions.

Finally, it is worth to mention that the contribution of CH_4 and N_2O from the fuel combustion, which was calculated on the basis of the length of the trip, may be eventually neglected in a more semplified approach as it accounts for less than 1% on total GHG emissions.

Table 6. Greenhouse gases emission in terms of gCO_2eq for tonne of waste calculated for each waste stream (MSW, organic waste, cardboard)

Stream: MSW	***GHG emissions (g CO_2eq/ t)***
Collection stage (fuel consumption)	18,915
Primary storage at the Transfer Station	neglected
Transfer from the TS to the landfill (fuel consumption)	6,778
Final disposal (emissions from the landfill)	3,879,876
Total emissions	3,905,569
Stream: Organic waste	***GHG emissions (g CO_2eq/ t)***
Collection stage (fuel consumption)	95,935
Treatment:	
Shredder (energy consumption)	2,263
Conveyor belts (energy consumption)	1,029
Composting process (emissions)	171,520
Transfer to the final user (fuel consumption)	N.A.
Total emissions	270,747
Stream: Cardboard	***GHG emissions (g CO_2eq/ t)***
Collection stage (fuel consumption)	58,997
Treatment:	
Compactor (energy consumption)	1,764
Transfer from the TS to the paper mill	N.A.
Avoided emissions due to the use of secondary raw material in the production of cardboard and paper	N.A.
Total emissions	60,760

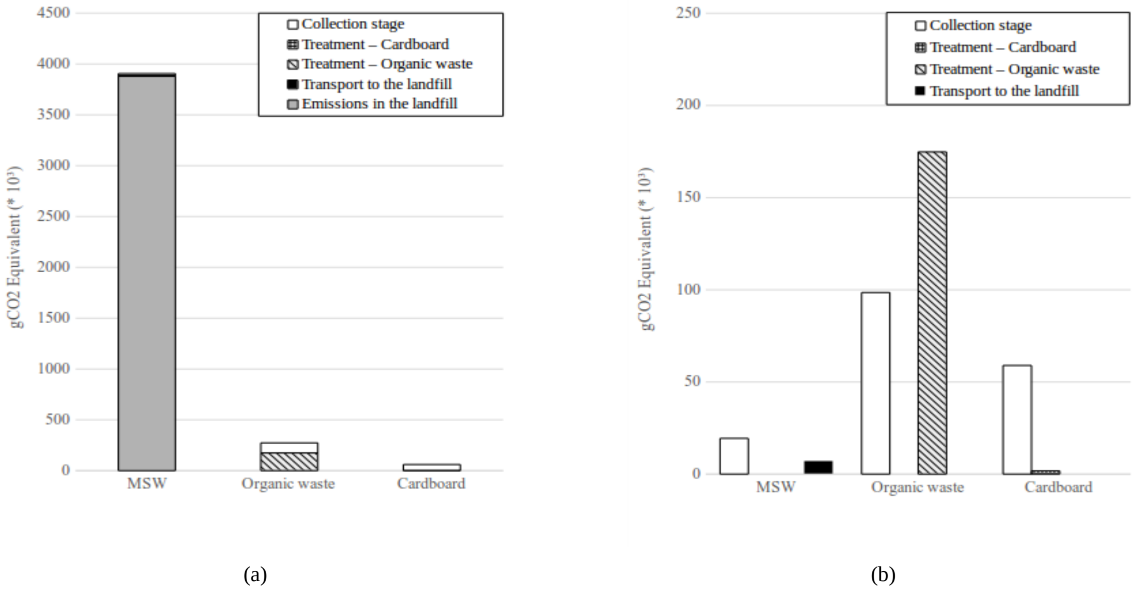

Fig. 4. Greenhouse gases emission in terms of gCO_2 for tonne of waste calculated for each waste stream

(MSW, organic waste, cardboard) with (a) or without (b) emissions generate by waste landfilling

3.2.2 Economic analysis

Average costs for managing one tonne of MSW (collected and transferred to Zahret Al-Finjan – CT; simply transferred - T), organic waste or cardboard have been calculated. Concerning transport stage (collection and transfer to the landfill), daily logs contained in the Database JSC-SWM allowed the calculation of costs referred the collection of one single tonne of waste. Management costs covered by the JSC and its partners (Thinnabeh and the private enterprise charged with the cardboard collection) are included in the calculation. Collection costs for MSW collected by Municipalities and transferred to the landfill by the JSC (MSW-T) are not available. Nonetheless, the total cost for MSW-T has been calculated considering the storage in the TS and final disposal costs. These costs are in fact covered by the JSC and they are necessary to calculate the total cost of the SWM system. The results are shown in Table 7.

Total management costs for cardboard (54.17 EUR/t) and organic waste (79.54 EUR/t) are higher than total MSW management costs (45.89 EUR/t). Total MSW management costs are comparable with literature data for the West Bank: for the city of Qalqilia the estimate ranged from 46 to 63 EUR/t (Hinde, 2010), for the city of Nablus costs were estimate in 47 EUR/t in 2005 (Al-Khatib et al., 2010), while for the Governorate of Jenin they were calculated in 25 EUR/t (Sweep-Net, 2014). In a study of UN-Habitat on twenty cities in the world, total MSW management costs ranges from 10 to 128 EUR/t (UN-HABITAT, 2010).

In this study, collection results as the most expensive phase, with costs influenced by collection duration, distance covered by trucks and waste collected amount.

Concerning organic waste, collection costs are higher because the compactor truck covers a higher distance to collect less waste if compared with MSW and cardboard routes. Possible solutions to minimize organic waste collection costs can include the selection of a smaller and more efficient truck, the increment of the number of user involved in the collection (maintaining the same area), or a further resizing of the collection area. On the contrary, collection costs for cardboard are covered almost entirely by the private enterprise. This represents a saving of 14 EUR/t (MSW-T) to 43 EUR/t (MSW-CT) for the JSC, which should have otherwise paid these collection costs. Earnings of the private enterprise from the sale of cardboard to the paper factory are not known. Treatment costs, with reference to the organic waste and to cardboard, have a little influence on total costs. Transfer and disposal costs of MSW affect only MSW management and can be consequently considered as "avoided costs" for both organic waste and cardboard. Annual costs for waste management calculated on the amount of waste managed by the JSC are resumed in Table 8, including costs covered by the private enterprise and not those covered by Municipalities. Table 8 shows an economic impact of organic waste SC of about 2% of the annual budget.

The results of both environmental and economic analysis are resumed in Fig. 5. For each type of waste stream (MSW, organic waste or cardboard) every phase is described, with corresponding management costs in EUR/t and greenhouse gases emissions in kg CO_2eq/t.

Table 7. Waste management costs (EUR/t) covered by the JSC and other partners

	Organic waste (EUR/t)	***Cardboard (EUR/t)***	***MSW-CT (EUR/t)***	***MSW-T (EUR/t)***
Management costs, of which	79.54	54.17	45.89	17.00
- covered by the JSC	78.77	2.96	45.89	17.00
- covered by other partners	0.77	51.22	-	-
Collection	72.93	47.43	26.76	n.a.
* Personnel (drivers, workers)	18.04 (1)	11.92 (1)	12.29 (1)	n.a.
* Fuel	50.36 (2)	30.97 (2)	9.94 (2)	n.a.
* Maintenance	4.53 (1)	4.53 (1)	4.53 (1)	n.a.
Administrative expenses	5.83	3.79	2.14 (1)	n.a.
Storage in the Transfer Station (cardboard, MSW)	-	2.96 (1)	2.96 (1)	2.96 (1)
Treatment (organic waste, cardboard)	0.77	n.a.	-	-
* Energy consumption (shredding machine for organic waste)	0.77 (1)	-	-	-
* Energy consumption (pulper for cardboard)	-	n.a	-	-
* Energy consumption (compactor for cardboard)	-	n.a	-	-
* Management costs for Thinnabeh (organic waste)	n.a.	-	-	-
Transfer to Zahret Al-Finjan (MSW)	-	-	14.04	14.04
* Fuel (MSW)	-	-	3.58 (3)	3.58 (3)
* Truck maintenance and driver (MSW)	-	-	2.33 (1)	2.33 (1)
* Disposal fee (MSW)	-	-	8.13 (1)	8.13 (1)
(1) Based on interview results				
(2) Based on Database JSC-SWM (average fuel price: 1.38 NIS/L)				
(3) Based on Database JSC-SWM (average fuel price: 1.39 NIS/L)				

Table 8. Annual costs for waste management (EUR/year)

	2014	*2015*	*2016*	*2017 (1)*
Collection and transfer (MSW-CT)	625,647	604,761	581,898	97,123
Transfer (MSW-T)	471,848	497,656	525,728	54,922
Organic waste	0	7,101	24,333	3,575
Cardboard (of which covered by JSC)	0	0	2,477 (135)	7,482 (408)
Total	**1,097,494**	**1,109,518**	**1,134,436**	**163,102**
(1) Period: 1st January - 12th February 2017 (not annualized)				

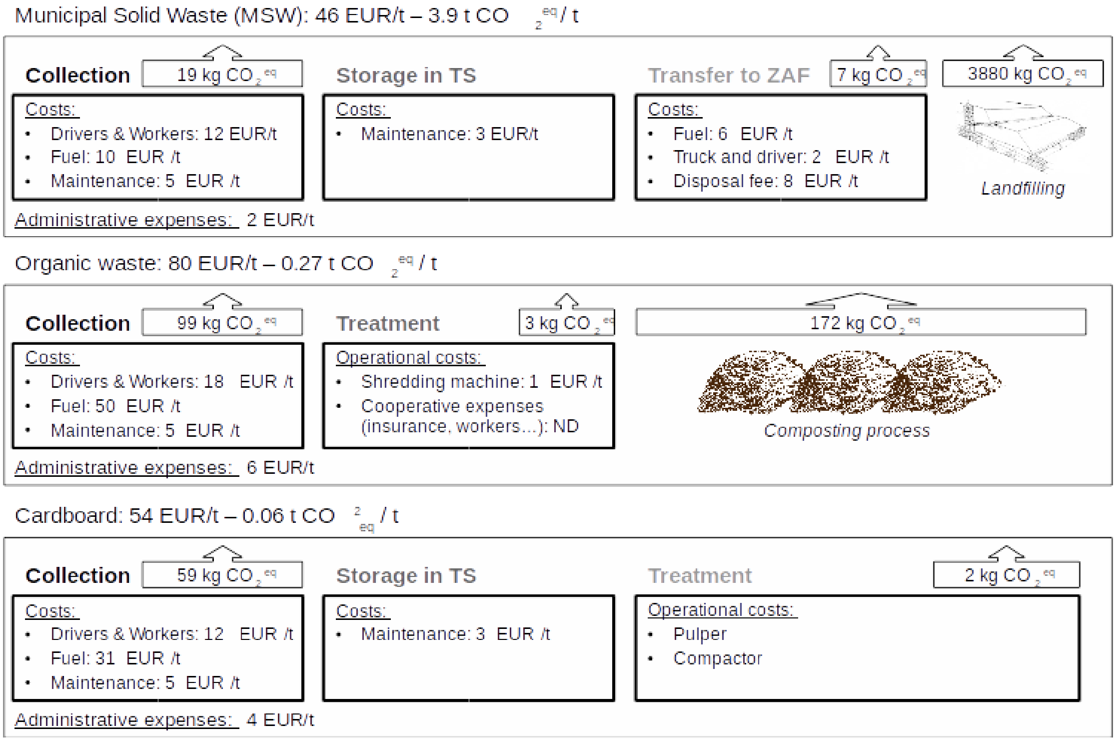

Fig. 5. Overview of the waste management system: stages, processes, greenhouse gases emissions and management costs

4. Conclusions

This study has the purpose of assessing the environmental and economic impact of the SC system introduced by a development project in a city of the West Bank.

In the target area, the introduction of the SC has led to the separation of a satisfactory amount of the expected production of the organic waste (45%) and cardboard (21%), characterized by a high levels of quality. These results were due to the awareness activities addressing shop keepers and merchants and the engagement of collection workers, which actively contribute to a good collection. Considering the whole Governorate of Tulkarem, a small impact on the whole SWM was reached as well, with the 2.58% of waste diverted from the landfill.

On the side of the environmental assessment, the SC has led to lower GHG emissions in comparison with the previous system: in fact, the complete management of one tonne of organic waste (0.27 tCO_2eq) and cardboard (0.06 tCO_2eq) is far less impactful of the disposal of one tonne of MSW in the landfill (3.9 tCO_2eq), even considering the impact of the collection phase.

From the economic point of view, higher costs for SC have been observed, balanced out by revenues only in the case of the cardboard. The relevance of the collection stage in this sense has been confirmed, as it accounts for 92% (organic waste stream), 88% (cardboard stream) and 58% (MSW stream) of waste management costs.

These results confirm the feasibility of the SC of organic waste and cardboard with reference to attitudes of the population but point out a criticality on the economic side. In fact, the lack of economic sustainability led to the suspension of the SC of organic waste at the end of the project, when the international funding finished.

From the methodological point of view, the analysis was affected by the lack of data, which is common in developing context (*inter alia*) (Di Bella et al., 2012; Domini et al., 2017). Moreover, the several changes which occurs within the project prevent analysis to be done on a long term period characterized by stable boundary conditions. Those obstacles have been tackled with the adoption of simplified models for both environmental and economic assessment. This choice has revealed itself suitable for the context, leading to representative results.

Overall, the "Green Tulkarem Project" should be considered as the first tentative to establish SC in the area. It did not reach a final efficient set up, but the cost of organic waste SC in this phase was not exceeding the 2% of the annual budget of the JSC for SWM, and it could have been eventually balanced out by savings originated by cardboard SC. Consequently, such a project can have a positive impact, whether considered as a first step of warming-up toward a more efficient management system.

Furthermore, an improvement of the system may arise from the use of available data, which were collected by the JSC but roughly analyzed. In fact, more detailed analysis can support the choice of cheaper solutions, intervening on the collection stage and maintaining the separation at source, which is known to be a pre-requisite for sustainable recycling of cardboard (Miranda et al., 2013) and valorization of the organic waste. Solutions to minimize the cost of SC should be identified, for example through the optimization of transports or the local and decentralized treatment of organic waste. A final aspect which should be targeted in further studies is the existence of local practices, such as the direct animal feed, often overlooked. Located at the apex of the food waste hierarchy (Papargyropoulou et al, 2014), such a practice might lead to positive impact whether considered in the whole waste management system.

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