Pilot monitoring of three (3) waste streams of municipal solid waste (MSW) produced at household level in Northern Greece

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Abstract

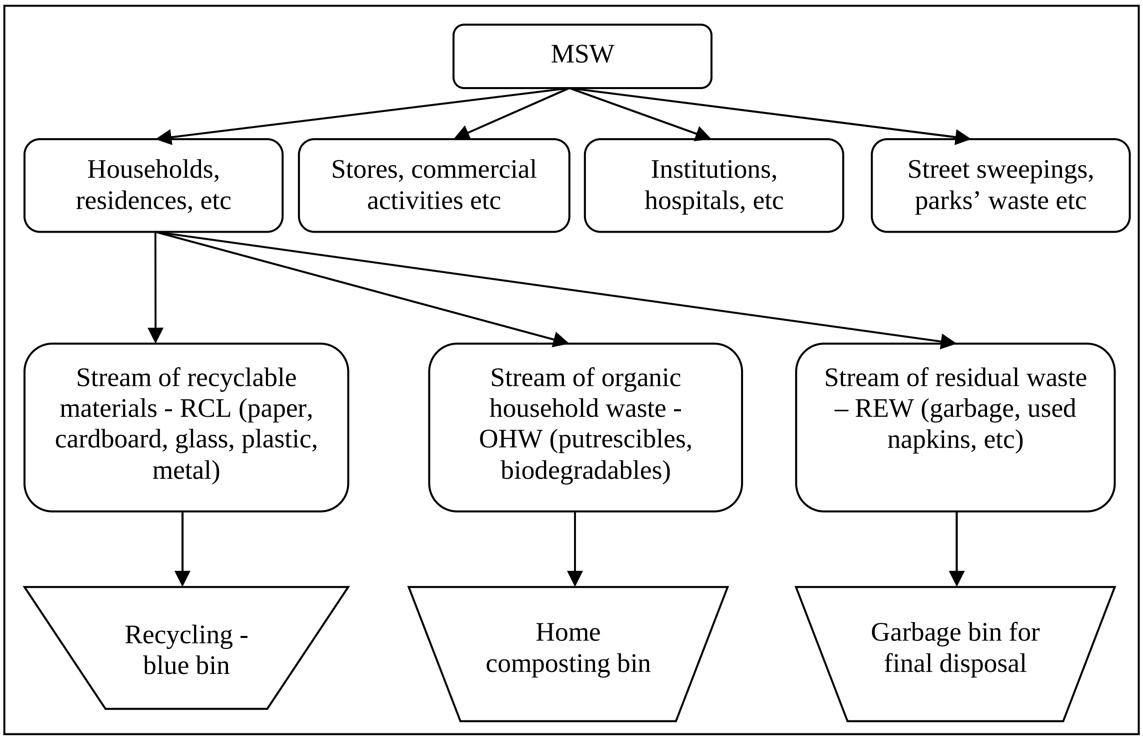
Nowadays, the daily management of Municipal Solid Waste (MSW) generated in Greece remains a problem. A great percentage of MSW is coming from household activities. By sorting MSW at household level a first step for sustainable recycling of resources has been done. A pilot monitoring program of MSW production at household level was planned and implemented in the framework of Waste-C-Control project (LIFE09 ENV/GR/294). The production of three (3) waste streams (recyclable packaging material, biodegradable and residual waste) was monitored and recorded by a number of households in a city in Northern Greece, for a period of five (5) months. The recyclable packaging materials were directed to package recycling (blue bin), biodegradable to home composting, while residual waste to final disposal. Weighing data of the three waste streams were recorded regularly in households. Based on average results of this pilot program, a 67% w/w of a household's MSW can be recycled and composted, (20% and 47%, respectively), while only 33% w/w can be directed to other treatment or disposal. During the summer months, the biodegradable fraction showed an increase in its recorded weight. Based on average results, a production rate of 0,425kg per capita per day of MSW at household level can be assumed. As a conclusion, better management of households' MSW, via sorting at source, may have twofold benefit with fewer waste disposed to landfills together with reduced emissions of greenhouse gases.

Keywords: Municipal solid waste (MSW), household waste, Green House Gases (GHG), home composting, organic household waste, recycling

Introduction

Sustainable management of Municipal Solid Waste (MSW) remains a problem in Greece. MSW are generated from various activities like household activities, commercial activities, street sweepings, institutes, schools, businesses, etc (Panagiotakopoulos, 2007). The main sources and activities generating MSW are presented in Figure 1.

Figure 1. MSW main generation sources with three main household waste streams and possible management practices.



A great percentage of MSW is coming from households activities and the sorting of MSW at household level comprises a first, crucial step for the sustainable recycling of resources (EPA 2011). For example, the sorting of recyclable materials (e.g. glass, paper, plastic, metal) can divert these materials from landfills to Material Recycling Facilities (MRFs), saving in this way natural resources and energy. At the same time, by diverting materials from landfills, for example by sorting biodegradable waste (organic waste) at household level and implementing home-composting, the emitted amount of green house gases

(GHG), like methane, carbon dioxide etc, is reduced. Thus, better management of MSW, through home-composting and recycling, can reduce GHG emissions and at the same time recycling targets, set by the European Waste Framework directive 2008/98/EC or Landfill Directive, can be achieved.

Three main fractions of waste produced at household level can be distinguished as follows. Firstly, recyclable materials (RCL) that include paper, cardboard, plastic, metal and glass. These materials can be separately sorted and collected in commingled bins (blue bins) and directed to MRFs. Secondly, organic household waste (OHW) that include food-preparing waste, fruits, vegetables, putrescibles and biodegradable waste. This waste fraction may be directed in a home-composting bin. Thirdly, residual waste (REW) that include garbage, used napkins, inert material, etc. This waste fraction after collection in garbage bins, if there is no other treatment, is directed for final disposal to Sanitary Landfill (SL).

Other waste generated at household level, like special waste of electronic and electrical equipment (WEEE), batteries or other hazardous waste (like used paint, etc), were not taken into consideration in this work. According to other studies found in the literature this fraction is a very small percentage of the total weight of household waste (Dahlen et al. 2009, Bernstad et al. 2012). Nonetheless, in Greece, this special waste (WEEE, batteries etc) is appropriately managed by specific collection systems that have been established and operate according to the waste Producer's Responsibility.

Objective of this work was, through continuous weighing and monitoring of three waste streams generated at household level, to estimate waste generation rates and to investigate the recycling behaviour of households in a city in Northern Greece. In this way, the importance of household waste fraction with regard to the total MSW can be investigated and conclusions can be drawn, contributing on better management of MSW.

The paper presents the results of the pilot action of monitoring MSW production at household level that was planned and implemented in the framework of the Local Action Plan in the Region of Eastern Macedonia Thrace of the project "Waste Management Options for Greenhouse Gases Emissions

Control” (WASTE-C-CONTROL - LIFE09 ENV/GR/294). Waste-C-Control consisted of a joint project between EPEM SA and three Greek Waste Management Authorities: the Waste Management Authority of Eastern Macedonia and Thrace (DIAAMATH), the Waste Management System of the Region of Western Macedonia (DIADYMA) and the Trans-Municipal Enterprise of Solid Waste Management of the Regional Union of Chania, Crete (DEDISA). The WASTE-C-CONTROL project was co-financed by the EU LIFE+ 2009 Program and lasted for 36 months (10/2010 to 9/2013). During the project, the Waste-C-Control software Tool was developed that provides decision-support for the optimization of the solid waste management system in terms of GHG emissions and financial data. Also, during the project dissemination and public awareness actions took place regarding different waste management options with respective GHG emissions reductions.

Short review

In Northern European countries (Scandinavia) there is extensive literature about studies regarding the monitoring, recording and analysis of household waste streams (Dahlen and Lagerkvist 2008, Dahlen et al. 2009, Boer et al. 2010, Bernstad et al. 2012). A number of articles regarding household waste generation can be found in countries of Asia and Africa (Sha’Ato et al. 2007, Bolaane and Ali 2004). Dangi et al. (2008) estimated MSW generation at household level in the capital city of Nepal by taking samples of MSW from households for 2 weeks. The average household MSW generation was 161,2g/capita/day. Organic waste presented the highest percentage of MSW. According to Phuntsho et al. (2010), that investigated MSW generation rates in Bhutan, the MSW generation rate in the urban centres was 0,53 kg/capita/day. The per capita household waste generation was 0,25 kg/day, so the domestic waste from the households accounted for 47% of the total MSW generated. Ogwueleka (2013) surveyed waste quantities and composition of 74 households in Abuja, Nigeria and found an average daily per capita waste generation of 0,634kg/capita/day. Qu et al. (2009) surveyed the generation rate and composition of household wastes in Beijing, China and found a generation rate of household wastes was 0,23 kg/person/day. In Greece there are few monitoring and recording studies focusing on household waste.

With sound management of MSW through home-composting of biodegradable waste and recycling or reuse of recyclable packaging material (paper and cardboard, glass, plastic, metal) there can be a reduction of the emissions of GHG since less waste is disposed into landfills. Home composting of the organic household waste is characterized as best available practice. According to Barrena et al. (2014) home composting, when properly conducted, can provide excellent levels of stability with negligible impurities compared to compost produced in industrial facilities. According to Andersen et al. (2012), that conducted a Life Cycle Analysis of the management of the organic household waste in Denmark, it was concluded that home composting is a suitable waste management option for OHW. The environmental impacts of home composting are generally quite low, since despite the emissions of GHGs (CH_4 and N_2O) from the composting process there are environmental savings from substituting fertilizer with compost in hobby gardening. Another potential benefit is the avoidance of collection and transportation of biowaste.

According to a study from European Environment Agency (EEA 2011) regarding GHG emissions per tonne of biowaste subjected to different treatments, it was evident that home composting and anaerobic digestion have small net emissions savings. Direct emissions from home composting are negligible (very little methane is emitted), and there is no transportation involved. A (net) reduction of GHG emissions was calculated, when home composting, instead of landfilling, was implemented for one tone of biowaste. Home composting is also favoured against anaerobic digestion, since there is no need for transporting biowaste to a central instalment. Moreover, home-composting can be used as a recycling practice in the framework of sorting at source.

Similar to home composting, the recycling of recyclable materials can provide net GHG emissions savings, as well. Paper and cardboard are the greatest fraction (w/w) of packaging recyclables. By introducing them back to production process, there are savings of volume in landfills, reduction of the need for cutting trees and reduction of energy and water demands. In Table 1 there are values of equivalent CO_2-eq saved by recycling of one tone of recyclable MSW.

Table 1. Recyclables as present in typical Northern European MSW and approximate CO_2-eq saved when recycling materials as opposed to use of virgin raw materials for production of the same amount of recycled material (ISWA 2009).

Material	kg recyclable per 1000 kg MSW	kg recovered per 1000 kg	kg CO_2-eq. saved per 1000 kg Material	kg CO_2-eq. saved per 1000 kg MSW
Paper	200	140	2.500-600	350-85
Aluminium	10	6	10.000	60
Steel	25	15	2.000	30
Glass	50	30	500	15
Plastic	80	50	1.000-0	50-0
Total	365	241		505-190

Materials and methods

In the Regional Unit of Rodopi, Greece, in the framework of the project LIFE 09 ENV GR 294 / WASTE-C-CONTROL, the waste management Authority of Eastern Macedonia Thrace, (DIAAMATH), designed and implemented the project "Integrated Management of MSW at household level with recycling of packaging material and home composting." The basic principal of the project was that participating households should weigh the amount of waste they produce and record this using diaries and feedback sheets.

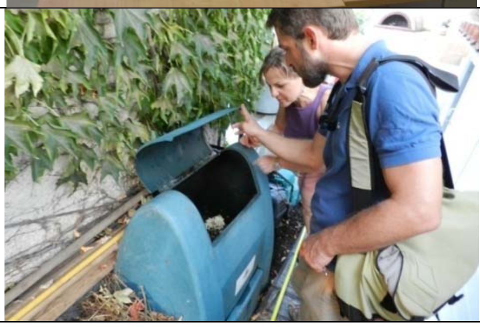
The production of three (3) different solid waste streams were weighted, recorded and monitored by a number of ten (10) households in the city of Komotini, in Northern Greece, for a period of five (5) months, from April to August 2013. The systematic recording of the weight of waste streams concerned quantities of i) recyclable packaging material (RCL), ii) organic household waste (OHW) and iii) residual waste (REW), by using appropriate equipment (electronic weight scales and plastic bins). RCL was directed to package recycling (blue bin), OHW was directed to home composting bins, while REW was directed to garbage bins for final disposal. Weighing data of the three fractions of waste were recorded regularly by volunteers in the households. Zorpas and Lasaridi (2013) reported that the engagement of volunteers in waste management, amplifies the information dissemination. In the same study, it is reported that self-weighing and monitoring by small groups of volunteers is also a means of measuring the prevention of waste. Collaboration with the Ecological Group of Rodopi (EGR) was not only essential for selection of participating households, distribution of equipment and guidelines, personal interviews with participants but also for data monitoring and processing. The participating households in the pilot action were selected among a number of households that responded in a call of interest of DIAAMATH and EGR. The main parameter for the selection of the households was to be familiar with the use of a home composting bin. EGR also contributed in the communication with the households, the preparation of questionnaires and calendar/recording sheets, and the digitization of records as well in the assistance of the participants throughout the pilot action.

Households used the following equipment during the implementation of the project:

1. Digital weighing scales with a max weight limit of 3 kg and a sensitivity of 0,001 kg. All digital scales were new and were checked for accuracy before use.
2. Plastic bin with a volume of approximately 30 litres, for the collection of recyclable material of MSW (paper and cardboard, glass, plastic, metals).
3. Plastic bin with a volume of approximately 3,2 litres for the collection of putrescibles kitchen waste.
4. Calendars for recording the weights of the three waste streams of households' MSW.
5. Questionnaires for the participants.

On March 2013, in the premises of DIAAMATH an information meeting took place with the participants. The aforementioned equipment was distributed during this meeting. The implementation of weighing, monitoring and recording started on April 1st and lasted until 31st of August 2013. The participating households recorded the weighted amounts of the three separate waste streams (RCL, OHW, and REW). During the implementation of the project, two out of ten households did not weigh the fraction of OHW. The results presented in this work derive from the eight (8) households that recorded all waste streams. In Table 2 photos of the implementation stage of the pilot action are presented.

Table 2. Photos of equipment, weighing of materials and household interview.

A questionnaire was filled by the participating households with open questions and closed questions in three parts. In the first part general information of the household profile was recorded (number of the household's members, age groups of the members, educational level). In the second part of the questionnaire, there were questions, about the household's information and opinion on Green house effect and the relation between waste management and GHG emissions. In the third part, there were questions about the impressions of the participants in this pilot action, possible difficulties encountered or other suggestions for future efforts. During the project, interviews of the participating households took place. Oral communications for clarifications were given to the participants when needed. The recorded data were processed in spreadsheets and results were produced regarding the total weight and average weight per waste stream for each household. Finally, data about gender, age, education level etc of the participants were also collected.

Results and discussion

According to the collected data, the total number of participants (members of the households) was 24 persons of which 42% were female and 58% male. The average size of household (number of members per household) was 3 members. The main age group of the participants was between the ages of 41 and 60 years (54%) while the 83% of the respondents attained a secondary school. Table 3 presents the profile of the members of the participating households.

Table 3. Profile of the members of the participating households.

N. of household	**Members**	**Sex**		**Age profile (years)**				**Education level**		
		M	F	0-20	21-40	41-60	60<	Elementary	Secondary	Higher
1	2	1	1	0	0	2	0	0	2	0
2	4	2	2	0	2	2	0	0	1	3
3	6	5	1	1	2	2	1	2	4	0
4	1	1	0	0	1	0	0	0	0	1
5	2	0	2	1	0	1	0	0	1	1
6	3	2	1	0	1	2	0	0	0	3
7	2	1	1	0	0	2	0	0	1	1
8	4	2	2	2	0	2	0	2	1	1
Total	24	14	10	4	6	13	1	4	10	10
Percentage	100%	58%	42%	17%	25%	54%	4%	17%	41,5%	41,5%

Results regarding the total weight of waste, for the duration of the pilot action, for each waste stream and each household are presented in Table 4. Regarding total weight one can observe a variation of the RCL fraction with a minimum amount of 10,352 kg (Household 3) and a maximum of 69,681 kg (Household 6). The respective values of OHW fraction are: a minimum of 12,600 kg (Household 4) and a maximum of 215,253 kg (Household 6). Denominated in percentage (%) of total MSW, the above figures are as follows: for the RCL fraction a minimum of 9% and a maximum of 30%, while for the OHW fraction, a minimum of 20% and a maximum of 61%. Household 2 presents the greatest weight of REW with a value of 268,065 kg. This can be mainly attributed to the presence of a baby in the household. According to NEARTA (2009) a child using disposable diapers is responsible for solid waste with a minimum of 0,685kg/day. Households 6 and 7 present high values of OHW total weight 215,253kg and 183,914kg respectively. This can be attributed to the living standards and consumption habits of these households like eating great amounts of vegetables and fruits, preparing food in house, hosting guests etc.

In Table 4 also, the calculations of average values of weight of each waste stream generated in terms of kg per capita per day and kg per capita per year are presented. Regarding the fraction of RCL an average production rate of 31kg/capita/year is estimated, while a production rate of 73kg/capita/year of OHW. Concerning the total production rate of household waste during a year there is a minimum of 45 kg/capita/year and a maximum rate of 289 kg/capita/year. The average production rate of household waste is estimated 155kg/capita/year.

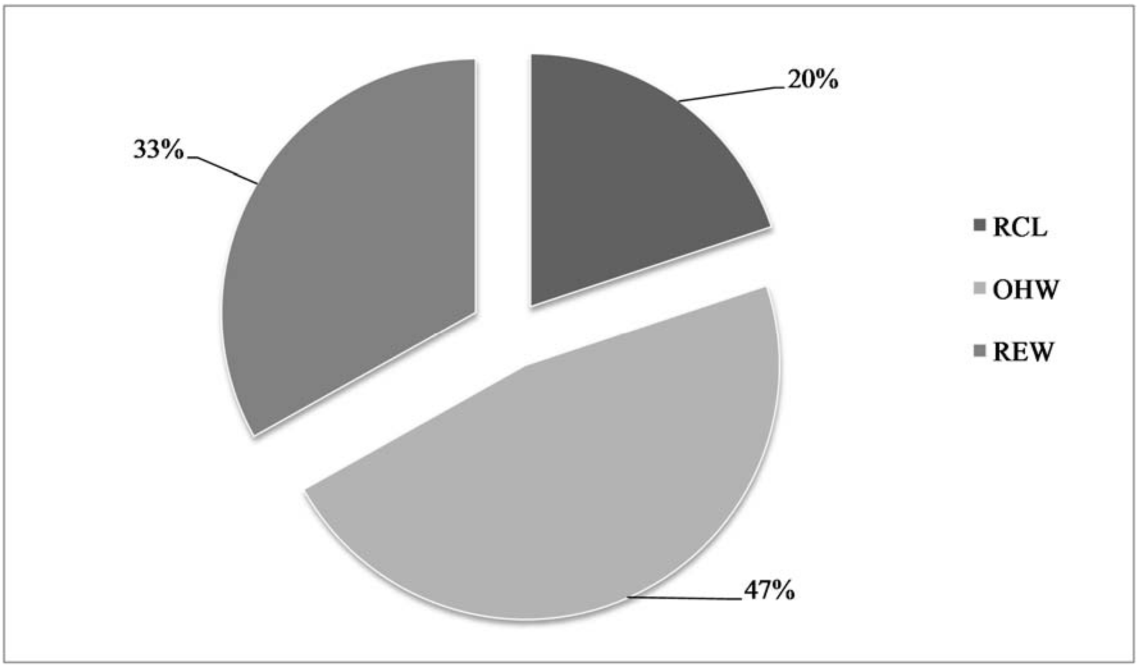
Table 4. Weight of produced household waste streams for 5 months and average values.

Household	Household's members	Waste stream*	Data of Weight (kg)	Calculation of average weight kg/cap/day	Calculation of average weight kg/cap/year	Calculation of total household waste weight kg/cap/year
No1	2	RCL	26,700	0,088	32	113
		OHW	34,240	0,113	41	
		REW	33,370	0,110	40	
No2	4	RCL	69,520	0,114	42	284
		OHW	134,945	0,222	81	
		REW	268,605	0,442	161	
No3	6	RCL	10,352	0,011	4	45
		OHW	52,029	0,057	21	
		REW	49,268	0,054	20	
No4	1	RCL	29,310	0,193	70	126
		OHW	12,600	0,083	30	
		REW	10,925	0,072	26	
No5	2	RCL	23,438	0,077	28	105
		OHW	30,338	0,100	36	
		REW	34,450	0,113	41	
No6	3	RCL	69,681	0,153	56	282
		OHW	215,253	0,472	172	
		REW	67,177	0,147	54	
No7	2	RCL	35,605	0,117	43	290
		OHW	183,914	0,605	221	
		REW	21,535	0,071	26	
No8	4	RCL	43,592	0,072	26	82
		OHW	64,670	0,106	39	
		REW	27,990	0,046	17	
Total of 8 Households	**Total members**	**Waste stream**	**Weight (kg)**	**Average weight kg/cap/day**	**Average weight kg/cap/year**	**Percentage (%)**
	24	RCL	308,198	0,084	**31**	**20%**
		OHW	727,989	0,200	**73**	**47%**
		REW	513,320	0,141	**51**	**33%**
	Total			**0,425**	**155**	**100%**

*RCL: recyclable material, OHW: Organic Household Waste, REW: Residual Waste

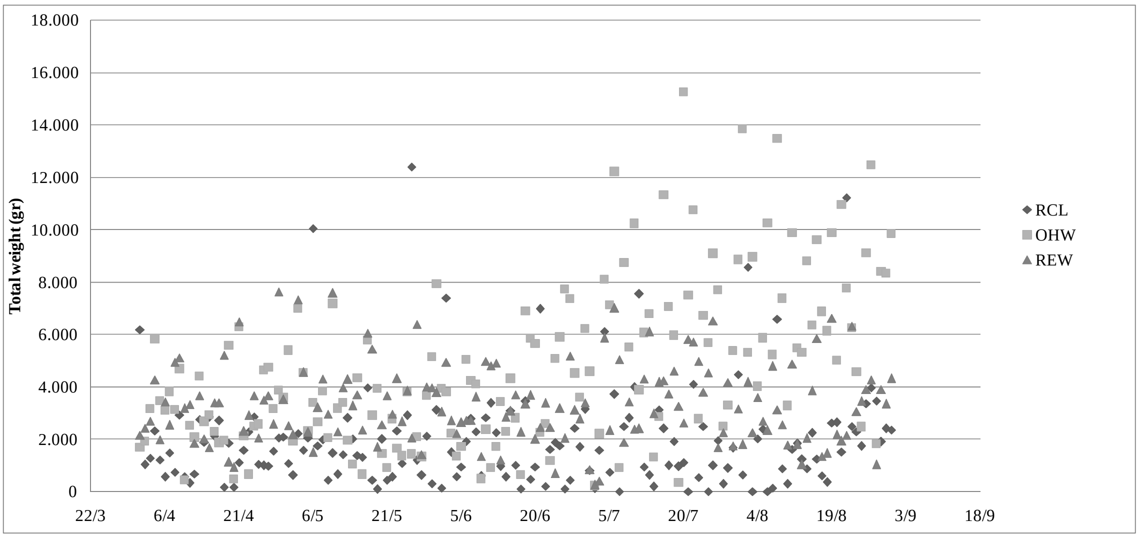
In Figure 2 the percentage (%) of RCL, OHW and REW fractions is presented. More specifically, the RCL fraction accounted for 20% (w/w) of the total waste, the OHW fraction accounted for 47% (w/w) of the total waste, while REW fraction, that was disposed in the garbage bin, accounted for the 33% (w/w) of the total waste.

Figure 2. Percentage of three waste streams produced at household level in Komotini.



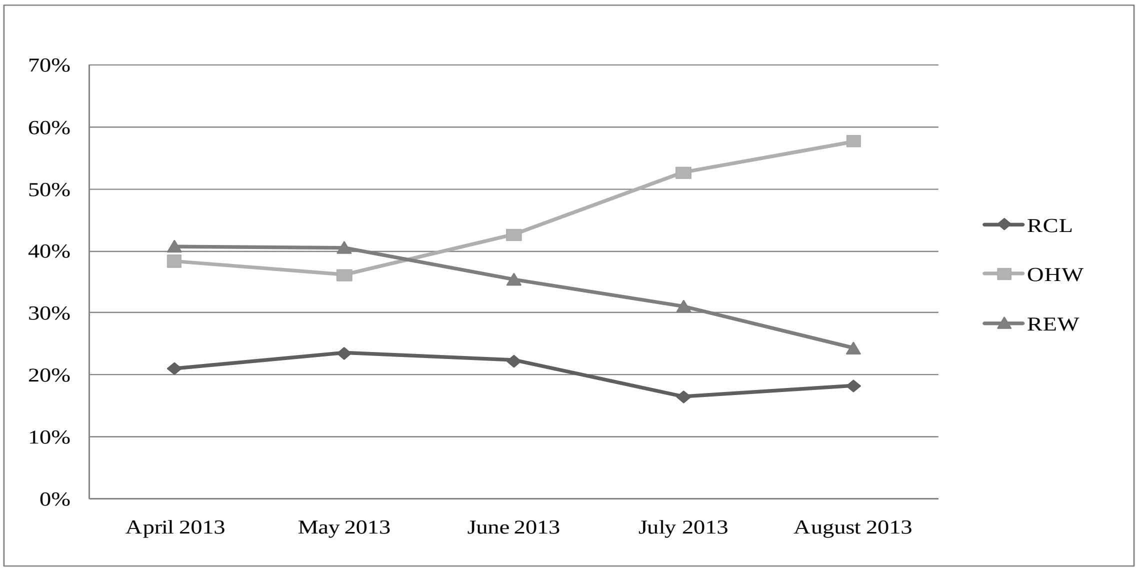
Consequently, based on the results of this pilot program, 67% (w/w) of a household's MSW can be recycled or composted. Data showed that 33% (w/w) of waste by weight cannot be recycled at source and is directed to garbage for final disposal. A 20% (w/w) of waste by weight can be recycled while a 47% (w/w) of waste can be composted. By extrapolating average results production rates of MSW at household level can be calculated with a total of 0,425kg/capita/day or 155kg/capita/year. The production rates for the three waste streams are as follows: 0,084kg/capita/day or 31kg/capita/year of RCL, 0,200kg/capita/day or 73kg/capita/year of OHW and 0,141kg/capita/day or 51kg/capita/year of REW. These production rates should be treated with caution and taking in consideration the context of this pilot action. The results are based on household level measurements and not on municipality level. This pilot action took place in a city of approximately ~55.000 inhabitants in Northern Greece and during a spring/summer period of five months. In Figure 3 a time series of the total weight of three waste streams for the five months is presented. An increase in the weight of the OHW over the period of summer (June onwards) is recorded. The increase in OHW fraction is clearly witnessed in Figure 4 where the monthly average percentages of the waste streams are presented.

Figure 3. Time series of total weight of three waste streams at household level.



As it can be seen in Figure 4, the fraction of OHW is steadily increasing during summer months from approximately 35% on May 2013 to about 60% on August 2013. The fraction of recyclables (RCL) is more or less steady at 20% with a slight decrease during summer months, while the residual waste shows also a decrease during summer months.

Figure 4. Average monthly weight (%) of three waste streams of 8 households.

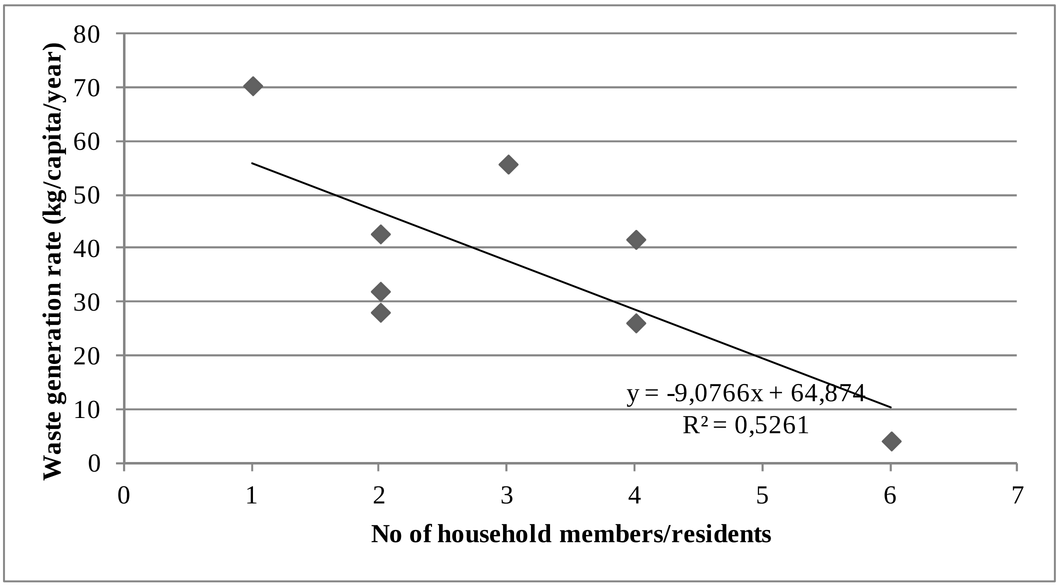


Regarding the household size and the generation of RCL fraction, an interesting correlation is evident. Some researchers have found a negative impact of household size on per capita quantities (Bolaane and Ali 2004, Qu et al. 2009, Ogwueleka 2013). In this work, taking into account all 8 monitored households, there is a negative correlation between the household size (number of households members) and the per capita household recyclable (RCL) waste generation rate. This effect can be seen in Figure 5. More specifically, the household with only one member-person (household No 4) is the one with the greatest per capita production rate of recyclable materials (0,193kg/capita/day). The household No 3 with six (6) members-persons presents the smallest production rate of 0,011kg/capita/day of RCL. However, no significant correlation was observed regarding the other waste fractions of OHW or REW against the size of the household.

According to weighbridge data of the total MSW generated in the municipality of Komotini and the respective population (population census 2011) a yearly MSW generation rate of 323kg/capita/year is estimated. In line with the results of this study the household waste generation rate is 155 kg/capita/year. As a result, household waste is approximately 48% of total MSW in the city of Komotini and it is inferred that 52% of MSW must be generated by commercial and other activities (stores, supermarkets, hotels, restaurants-cafes, schools, institutions, etc).

The results of this work regarding the recyclables collected at household level are on average 31kg per capita per year. According to operational data of the Alexandroupolis MRF a rate of 27kg per capita per year of recyclable material was recovered for the year of 2012 (HERRCO 2014). Comparing the two figures a slight difference is noticeable. This is explained mainly by the fact that participating households implemented more rigorously the method of sorting materials at source. Additionally, there are implications that there is room for improvement on recycling in the municipality of Komotini.

Figure 5. Effect of household size on per capita household RCL waste generation rate.



By improving household solid waste management, through home composting and recycling of recyclable materials, there are possible savings and reduction of GHG emissions (ISWA 2009, EEA 2011). On the basis of the results of this pilot action and the specific amount of waste monitored, by using the assumptions set in the documented work of ISWA (2009) and EEA (2011), some calculations of possible savings of equivalent Carbon Dioxide (CO_2-eq) can be made. These calculations and results are presented in Table 5. Calculations are based on data in Table 4 for emissions CO_2-eq (kg) saved from better management of RCL and OHW fractions of the 8 households for the duration period of the pilot monitoring. Hence, GHG reduction with a unit rate of 54,2(=1.307,4/24) kg CO_2-eq per person for the 5 months of the pilot monitoring is estimated. In a yearly basis, the estimation is 131 kg CO_2-eq per person. This result is comparable with values that other authors provide. Kenny and Gray (2009) in a survey of household and personal carbon dioxide emission in Ireland conclude that household waste disposal represented a rate of 117kg CO_2-eq per person per year.

As a result, with sound management of MSW produced at household level in REMTH, by utilizing home-composting and recycling of recyclable packaging materials, a saving of approximately 131kg eq-CO_2 per capita per year might be possible. By using this result and extrapolating to the whole population of Region of Eastern Macedonia and Thrace (608.182 residents according to 2011 population census) there is an estimation of 79.512 t CO_2-eq per year possible saved for REMTH.

Table 5. Calculations of saving CO_2-eq (kg) for 5 months of the pilot action.

Household	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
Number of persons	2	4	6	1	2	3	2	4	**24**
Total amount of recyclable materials (kg)	26,70	69,52	10,35	29,31	23,44	69,68	35,61	43,59	**308,20**
Estimated amount of individual materials (kg)									
Paper/cardboard	20,025	52,140	7,764	21,983	17,579	52,261	26,704	32,694	**231,149**
Aluminium	0,267	0,695	0,104	0,293	0,234	0,697	0,356	0,436	**3,082**
Metal	0,534	1,390	0,207	0,586	0,469	1,394	0,712	0,872	**6,164**
Glass	1,602	4,171	0,621	1,759	1,406	4,181	2,136	2,616	**18,492**
Plastic	4,005	10,428	1,553	4,397	3,516	10,452	5,341	6,539	**46,230**
Amount of CO_2-eq saved (kg) by recycling recyclable materials	*37,580*	*97,849*	*14,570*	*41,254*	*32,989*	*98,076*	*50,114*	*61,356*	**433,789**
Amount of putrescibles (gr)	34,240	134,945	52,029	12,600	30,338	215,253	183,914	64,670	**727,989**
Amount of CO_2-eq saved (kg) by home-composting of putrescibles	*41,088*	*161,934*	*62,435*	*15,120*	*36,406*	*258,304*	*220,697*	*77,604*	**873,587**
Total amount of CO_2-eq saved (kg)	**78,668**	**259,783**	**77,005**	**56,374**	**69,395**	**356,380**	**270,811**	**138,960**	**1.307,375**

Conclusions

In this work a pilot monitoring action of three waste streams at household level was designed and implemented for 5 months in the city of Komotini in Northern Greece. The results illustrate the twofold benefit that may occur from the contribution of citizens and households in sustainable waste management. Through home-composting and recycling, waste amounts that are disposed to sanitary landfill, can be reduced together with GHG emissions.

Based on the results of this pilot action on household level and taking into account data of the MSW management system in the Municipality of Komotini, the following more specific conclusions can be drawn:

- It is estimated that on average 67% w/w of households MSW can avoid final disposal through recycling (20%) and home composting (47%). Only 33% w/w can be directed to other treatment or final disposal.
- Household waste is estimated as 48% of MSW generated in the city of Komotini. So it can be inferred that 52% of MSW must be generated by commercial and other activities (waste by stores, supermarkets, hotels, restaurants-cafes, schools, institutions, etc).
- Recyclables collected at household level are on average 31kg per capita per year. Comparing with results of the local MRF is concluded that there are margins of improving the recycling levels by households as well by commercial activities in the city of Komotini.
- An increase in the weight of OHW stream is observed during summer months.

These conclusions can help planning better waste management systems and taking actions for improving sorting MSW at source.

Future work may include a greater period of study (a whole year study) and participation of more households, since MSW generation and composition depends on seasonal effects. Future work may also incorporate a more analytical methodology so that, other waste generated in a household, like

WEEE, batteries, etc, can be included.

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