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▶ **To cite this version:**

Benu Adhikari, A. Trémier, José Martinez, S. Barrington. Home and community composting for on-site treatment of urban organic waste : perspective for Europe and Canada. Waste Management and Research, 2010, 28 (11), p. 1039 - p. 1053. 10.1177/0734242X10373801 . hal-00677364

**HAL Id: hal-00677364**
**https://hal.science/hal-00677364**

Submitted on 8 Mar 2012

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Author-produced version of the article published in Waste Management & Research, 2010, 28, 11. 1039-1053.
Original publication available at http://www.uk.sagepub.com/home.nav – doi:10.1177/0734242X10373801

# Home and community composting for on-site treatment of urban organic waste: perspective for Europe and Canada

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Presented to the journal of: Waste Management & Research

**Abstract**

Management of municipal solid waste (MSW) is a challenge faced by urban centres worldwide, including the European Union (EU) and Canada, as a result of urbanization and economic prosperity accelerating the generation of municipal solid wastes (MSW) along with its organic fraction. Within a concept of waste recovery, source separation and on-site treatment of urban organic waste (UOW) can resolve major economic issues and faced by urban centres along with environmental and social issues associated with landfilling. In this context and as compared to the traditional landfilling practice (Base Sce), this paper examines on-site UOW composting strategies using a combination of centralized composting facilities (CCF), community composting centres (CCC) and home composting (HC) (Sce 1, 2 and 3). This study consists of a feasibility and economic study based on available data and waste management costs. This study indicates that on-site treatment of UOW using practices such as home and community composting can lower management costs by 50, 37 and 34 % for the rich European countries (annual GDP over $25000 US), the poorer European countries (annual GDP under $25000 US), and Canada, respectively. Furthermore, on-site composting can reduce greenhouse gas (GHG) emissions by 40 % for Europe and Canada, despite gas capture practices on landfill sites. However, the performance of home composters and the quality of the compost products are issues to be further addressed for the successful implementation of UOW on-site composting.

**Keywords:** municipal solid waste, urban organic waste, greenhouse gas, landfill, composting

## Introduction

Depending on the country's economic activity, organics represent 20 to 80 % of the municipal solid waste (MSW) main stream and therefore constitute one of its major fractions (Adhikari et al. 2009; Adhikari et al. 2006; EEA & ETC-WMF 2002; Papadopoulos et al. 2009 ). The improper disposal of urban organic wastes (UOW), composed mostly of food and green wastes, results in well-known health and environmental issues: attraction of insects and rodents; development sites for parasites, pathogens and viruses; contamination of drainage waters, and; emissions of unpleasant odours and greenhouse gases (Kumar et al. 2009; Moghadam et al. 2009; Rasapoor et al. 2009; Turan et al. 2009).

All countries worldwide can benefit from reducing the generation of MSW through recycling and reusing. In Asian countries, the expansion of urban centres and their economic growth have exponentially increased the production of MSW along with the mass of UOW (Adhikari et al. 2009). Since several major cities in Asia can only afford to collect 30 % of their MSW, their growth has further stressed issues associated with collection and disposal (Guermoud et al. 2008; Harjula et al. 2001; Parrot et al. 2009; Troschinetz & Michelcic 2009; Vehlow et al. 2007). In industrialized countries of Europe and North America, landfilling is still the most common practice for the disposal of MSW along with UOW although social pressures are making it harder to find proper sites (De Baere 2000; Environment Canada 2009; Messineo & Panno 2008). Furthermore, landfilled organic wastes (OW) emit greenhouse gases which can be recovered at a cost, generate leachate which requires treatment and remove land which otherwise could be used for agriculture (Machado et al. 2009; Official Journal 2000; Wagner & Arnold 2008). In an attempt to reduce the number of landfills along with their social and environmental impacts, European and North American countries have adopted policies aimed at reducing the generation of wastes through for example recycling and reuse (Landfill Directive 1999; CCEM 1989).

To be diverted from landfills, OW must be stabilized with the objective among others of producing a soil amendment. In North Canada, composting to produce a soil amendment is likely the most popular treatment, while in Europe, countries such as Germany and the Netherlands have encouraged source separation for composting and biogas production through anaerobic digestion (Table 1). Other European countries such as Spain and France, allow the stabilization of the OW fraction by composting the entire MSW mainstream before landfilling; these countries also mechanically and source separate the OW to produce soil amendments (Kelleher 2007). Although the source separated OW produces a compost of higher quality and value, this management option through centralized composting facilities increases the collection and transportation costs, besides that of the disposal method. Source separation of UOW for its composting or anaerobic digestion requires a separate collection increasing transportation cost. Cities have generally coped with this issue by collecting UOW weekly and the rest of MSW twice monthly. In terms of treating source separated UOW and as compared to landfilling costs of \$30 to 50 US $ton^{-1}$ of MSW including greenhouse gas capture, composting and anaerobic digestion cost from \$50 to 400 US $ton^{-1}$, with an end product not even meeting the recycling cost at \$5 to 10 US $ton^{-1}$ wholesale.

**Table 1**

Therefore, the recycling of OW into a high quality soil amendment requires additional investments as compared to the traditional method of landfilling even where greenhouse gases are captured and treated (Burnley 2007; Dunne et al. 2008; Hazra & Goel 2009). This additional investment is an economic burden for developed as well as developing countries. As an alternative method of reducing if not eliminating collection and transport costs to compensate for the treatment cost, community composting centres (CCC) and home composting systems (HC) are proposed. Nevertheless, such systems have not yet been demonstrated as sanitary, and economically and environmentally advantageous.

Within the recycling legislative framework of Europe and North America, the aim of this study was to investigate the economical and environmental advantages of the on-site treatment of UOW by community or individual household composters. The present feasibility and economic study is based on available waste management costs and environmental knowledge. In this study, food and garden wastes generated from households, institutions and businesses make up the UOW fraction of MSW.

## The European and Canadian UOW generation and management

In this study, the 27 member states of the European Union (EU) will be split into groups 1 and 2 (EUG1 and EUG2) consisting of countries with a gross domestic product (GDP) in excess of and under \$25000 US capita$^{-1}$ year$^{-1}$ (Table 2), respectively. Canada and the EU are similar in economy but differ in their landmass and population density. The EUG1 and EUG2 have population densities of 136 and 92 persons km$^{-2}$ whereas Canada has a population density of only 4 persons km$^{-2}$ (World population prospects, 2007). Nevertheless, the Canadian population is mainly concentrated along its southern border, for a more representative density of 20 person km$^{-2}$. To consider the different contexts of economy, urbanization and population density, the following sections separately discuss the MSW generation and management for the EU, the EUG1, the EUG2 and Canada.

### *MSW and UOW generation*

The MSW and UOW generated by the EUG1, the EUG2 and Canada are presented in Table 2. For Canada, the quantities of MSW and UOW correspond only to household waste whereas for the EU, the quantities correspond to household, institutions and commercial wastes (OECD 2006-2007). In 2005, the EUG1 generated 207 million tonnes of MSW or 2.0 kg person$^{-1}$ day$^{-1}$, representing 82 % of total MSW generated by the EU. The OW fraction represented 32 % of the

121 total MSW main stream and amounted to 0.63 kg person$^{-1}$ day$^{-1}$. Also in 2005, the EUG2
122 generated 44 million tonnes of MSW or 1.56 kg person$^{-1}$ day$^{-1}$ representing 18 % of the total
123 MSW generated by the EU. The generated OW fraction amounted to 25 % of the MSW
124 production for the EUG2. With an average gross domestic product (GDP) of $35000 US capita$^{-1}$,
125 the EUG1 produced 28 % more MSW per person than the EUG2 with half the GDP of $17000
126 US capita$^{-1}$.

127 In North America and for 2005, the Canadian urban population of 25.8 million produced
128 13.4 million tonnes of MSW or 1.42 kg person$^{-1}$ day$^{-1}$ for a GDP of $33400 US capita$^{-1}$. In
129 comparison, the US and Mexican urban populations of 242.3 and 79.6 million, respectively,
130 produced 180.1 and 27.5 million tonnes of MSW or 2.5 and 1.2 kg person$^{-1}$ day$^{-1}$, for a GDP of
131 $41400 and $10700 US capita$^{-1}$. Accordingly, the calculated UOW generation for Canada, the
132 US and Mexico was 0.43, 0.63 and 0.63 kg person$^{-1}$ day$^{-1}$, respectively.

133 For the EU and Canada, UOW is one of the major fractions of the MSW main stream
134 (Table 3) representing in 2005, 30 and 25 % of the MSW main stream, respectively. Other
135 reported components of the MSW main stream were paper and paperboard, glass, metal, plastics
136 and textile.

137 **Insert Table 2 & Table 3**

138

139 ***European and Canadian UOW management practices***

140 Landfilling is still the most common MSW disposal method in both the European Union and
141 Canada. In 2005, the EUG1 and EUG2 landfilled 36 and 82 % of the total MSW main stream,
142 whereas Canada landfilled 60 % (Table 2). Diversion of MSW from landfilling practices vary
143 widely among the EUG1 countries with Germany and the Netherlands reaching over 98% as
144 compared to the UK still at 22 % (Table 1). In Malta, Greece and the Czech Republic, more than
145 80 % of all MSW was still being landfilled in 2005 (EEA 2009).

The low landfill diversion rate for most European Countries and Canada is far from meeting environmental policy expectations. In 1999 and for the biodegradable fraction of MSW, the EU Landfill Directive 99 (Article 5) set diversion objectives of 25 % by 2006, 50 % by 2009, and 65 % by 2016, based on 1995 levels. Similarly in Canada, the Canadian Council of Ministers of the Environment (CCME) proposed a national diversion goal of 50 % of all MSW by 2000 based on that disposed in 1989, without specifically targeting the organic fraction (Wagner & Arnold 2008).

Individual country policies have influenced the level of diversion and the technology preferred for this diversion. Incineration is not widely used because of issues of atmospheric emissions and the fact that the high moisture content of UOW reduces the caloric value of the process (Zsigraiová et al. 2005; El Asri & Baxter 2004; Marton & Alwast 2002; Environment Canada, 2009). While in the EUG1 countries, 21 % of all MSW was incinerated in 2005, less than 6 % was treated by this process in the EUG2 and Canada (EEA, 2009). The high EUG1 incineration level results in part from countries such as France, Germany and The Netherlands using this technology to divert over 30 % of their MSW while generating energy. In 2007 and within the EUG1, Germany and The Netherlands were diverting 98 to 99 % of their MSW (Table 1), respectively, because of strict and costly landfilling and incineration regulations encouraging composting, and a subsidy on biogas production from the anaerobic digestion of organic wastes. In Canada since 2000, only the province of Nova Scotia succeeded in composting 60 % of its OW (Wagner & Arnold 2008), through strict regulations prohibiting among others, the disposal of OW through landfills. However, recycling dropped to 41 % in 2006 because of a higher level of waste generation as a result of economic growth and changes in consumer habits. British Columbia is second in Canada with 32 % diversion from landfill through recycling mainly because of a bylaw requiring manufacturers to recover packaging (Table 1). With voluntary recycling policies for the rest of the Canadian provinces, less than 20 % of all MSW is diverted

171 from landfills excess for Quebec thanks to its public organization Recy-Quebec managing the
172 recycling of metals, paper and glass (Environment Canada 2009).

173 Composting and anaerobic digestion are commonly used to treat and recycle the organic
174 fraction of MSW. In 2006 and for the EU, 124 central composting facilities were treating 4
175 million tonnes of MSW annually (Kelleher 2007). In 2005, France, Spain and The Netherlands
176 were composting 14, 33 and 24 % of all MSW, respectively (Table 4), while in Canada, 12 %
177 was composted. In the past, centralized mixed MSW composting facilities were built and
178 operated, while at present, the composting of source separated OW facilities are preferred to
179 assure the quality and value of the finished product. In Germany, source separation of the
180 organic fraction of MSW is mandatory in many municipalities and at present, 700 to 900
181 composting facilities are in operation (Table 5). In France, amongst 119 composting facilities
182 treating MSW, 54 use source separated UOW. In Canada, 54 facilities compost source separated
183 food waste generated from residences, industries, businesses and institutions (Table 5). The
184 construction of a centralized composting facility can easily cost $7 million US, for a UOW
185 processing cost of at least $140 US $ton^{-1}$.

186 Anaerobic digestion is another technology used to divert UOW from landfill sites and
187 produce energy, but its application is generally accompanied by an incentive to generate energy
188 (Table 1). The highest mass of organic waste diverted using this technology is found in Germany
189 and the United Kingdom with 2000 kilo tonne of oil equivalent (ktoe) $yr^{-1}$ followed by Italy and
190 Spain with 300 ktoe $yr^{-1}$ and the France, Austria and The Netherlands with 100 ktoe $yr^{-1}$
191 (European Biomass Industry Association 2006). To encourage such source of green energy, EU
192 countries must generally offer a subsidy equivalent to the cost of electricity produced by
193 conventional technologies. At a crude oil price of $100 US $barrel^{-1}$, such a green energy policy
194 costs the EU some $4 billion US $year^{-1}$.

195 **Insert Table 4 & Table 5**

196 In order to reduce the cost of treating and recycling UOW, a more interesting diversion
197 method is needed. Within this objective, the on-site treatment of source separated UOW was
198 proposed to produces a dry, stabilized and volume reduced soil amendment (Adhikari et al.
199 2009) readily available for urban gardens. Nevertheless, the real economical impacts are issues
200 to be addressed before recommending the wide use of home and community composting centres.
201 Within this context, the following sections formulate and compare strategies for on-site
202 composting of UOW in the EUG1, EUG2, and Canada.
203
204 **Comparison of on-site UOW composting scenarios diverting MSW from landfills**
205 The following sections examine the growth of MSW and UOW over the upcoming 15 years and
206 then, predict the economic and environmental advantages associated with on-site composting to
207 divert the UOW fraction from the MSW mainstream and landfilling operations.
208
209 ***Estimated growth in MSW and UOW production***
210 The Adhikari et al. (2006) study is updated study by including rather than estimating the 2005
211 urban population (UP) and gross domestic product (GDP) data according to UNPD (2007) and
212 UNSD (2008). The growth of MSW and UOW was estimated by correlating the 2005 urban
213 population of each country (UNPD 2007) with its 2005 GDP (UNSD 2008) (Figure 1a & b).
214 Similarly, MSW and UOW generation rates were correlated with GDP (Figure 1c) according to
215 Adhikari et al. (2006). Estimating urban population expansion based on future economic
216 improvement and population growth, MSW and UOW production were computed from the
217 following equations for 2009, 2016, 2020 and 2025:

218 $$(MSW)_{CRY} = 3.65 \times 10^{-9} \times (UP)_{CRY} \times (MSWR)_{CRY} \times (TP)_{CRY} \quad (1)$$

219 $$(UOW)_{CRY} = 3.65 \times 10^{-9} \times (UP)_{CRY} \times (UOWPR)_{CRY} \times (TP)_{CRY} \quad (2)$$

where, $(MSW)_{CRY}$ is the MSW production (million tonne $yr^{-1}$); $(UP)_{CRY}$ is the urban population (%); $(TP)_{CRY}$ is the total population; $(MSWR)_{CRY}$ is the MSW production rate (kg $capita^{-1}day^{-1}$); $(UOW)_{CRY}$ is the UOW production (million tonne $yr^{-1}$); $(UOWPR)_{CRY}$ is the UOW production rate (kg $capita^{-1}day^{-1}$), and; in the subscripts *CRY*, *C* refers to the country, R to the continents of Europe and North America and Y to the year.

**Insert Figure 1**

The short term global economic recession was assumed to have a negligible impact on MSW generation and management systems. From Equations (1) and (2) and for 2009 to 2025, the estimated growth in MSW and UOW in the EU, the EUG1, the EUG2 and Canada are presented in Figure 2. With the largest population, the EUG1 is expected to increase its MSW production from 202 to 263 million tonnes $yr^{-1}$, over the next 15 years (2009 to 2025), resulting in an UOW production increasing from 75 to 92 million tonnes $yr^{-1}$. Over the same period, the EUG2 with the second largest population is expected to increase its UOW production from 11 to 13 million tonnes $yr^{-1}$. The UOW production is expected to increase by 23 % and 18 % in the EUG1 and the EUG2 respectively. With 8 million tonnes $yr^{-1}$ of UOW in 2009, Canada's production is expected to reach 10 million tonnes $yr^{-1}$ in 2025 representing an increase of 25 %.

**Insert Figure 2**

***Scenarios for UOW treatment strategies***

The economic and environmental impacts of the proposed scenarios are evaluated in this section for the upcoming decades. The Base Scenario (Base Sce) assumes that all UOW will continue to be landfilled, but that 80% of their biogas generation will be captured; Scenario one (Sce 1)

considers the practices of diverting 57, 16, and 44 % of all UOW from landfilling for the EUG1, the EUG2 and Canada respectively, and treating the diverted waste through a centralized composting facility (CCF) except for 1 % which would be treated through home composter (HC); Scenario two (Sce 2) assumes that UOW diversion from landfill increases from 25 % in 2006 to 65 % in 2016 and 80 % in 2025 and the diverted UOW is composted at centralized composting facilities (CCF), and; scenario three (Sce 3) considers zero landfilling with 10, 60, and 30 % of UOW treated using CCF, HC and community composting centres (CCC) respectively by 2025 (Table 6). Community composting centres (CCC) are considered to be on-site treatment systems because of their close proximity to producers who can drop off the waste on their way to work or during other activities.

**Insert Table 6**

***Economical assumptions***

Table 7 compares the cost of various composting strategies to that of landfilling UOW. Disposal of UOW through landfilling requires: land acquisition; capital, operating and closure costs, and; collection and transportation of UOW to landfill sites generally located at some distance from the city (Adhikari et al. 2009). Besides the collection and transportation costs estimated at $115 US tonne$^{-1}$, a landfill-dumping fee of $50 US tonne$^{-1}$ is quite common in Europe and America, for a total landfilling costs $165 US tonne$^{-1}$ of MSW (Eunomia 2002). The cost of capturing landfill biogases of $1.50 US tonne$^{-1}$ was added to represent more current practices. Centralized composting facilities (CCF) were assumed to cost 33 % more in collection and transportation as compared to landfilling because of the double collection required, but at a less frequent interval for MSW other than UOW, and the location of CCF within the urban perimeter. With a capacity of $20 \times 10^3$ tonne yr$^{-1}$ and at 7 % interest rate, CCF can compost UOW at a cost of $241 US tonne$^{-1}$. Community composting centres (CCC) are estimated to treat UOW at a lower cost of

271 $118 US tonne$^{-1}$ (Table 7) because of the time volunteered to operate the centre. Community
272 composters with a 11.5 m$^3$ capacity were presumed to cost $30000 US, if not automated and
273 built of polyethylene (Eco-quartier, 2009). As compared to CCC, HC can cost in the range of
274 $31 US tonne$^{-1}$ of capacity and are expected to have a 10 yr life. For HC, no collection and
275 transportation costs are involved and the time required to manage the system is free. Purchasing
276 the composter, promoting the use of HC and training the community, are the only costs
277 amounting to $42 US tonne$^{-1}$. The cost of bulking agent is considered negligible when food
278 waste is composted along with yard trimmings.
279
280 **Insert Table 7**
281
282 ***Environmental assumptions***
283 For all management methods, UOW generated $CH_4$. Landfilled UOW contribute to global
284 warming by generating potentially 204 kg $CH_4$, 500 kg $CO_2$ and 0.13 kg $N_2O$ tonne$^{-1}$ wet OW
285 (Barton & Atwater 2002; Pettus 2009; SITA Australia Pty Ltd 2008; US CESLG 2008; Wang et
286 al. 1997), where modern technology can capture and oxidize up to 80 % of the $CH_4$ generated
287 (SITA Australia Pty Ltd 2008). In addition, the garbage trucks collecting and transporting the
288 MSW generate some 25 kg $CO_2$ tonne$^{-1}$ wet UOW (Clean Energy 2007), assuming that UOW
289 constitute 46 % of the volume handled.
290 According to IPCC (2006), CCF generate 4 kg $CH_4$ and 0.3 kg $N_2O$ tonne$^{-1}$ wet organic
291 waste and the transportation contribution was presumed increased by 33% as compared to
292 landfilling. This compares favourably with Amlinger et al. (2008) reporting that HC generates
293 0.8 to 2.2 kg $CH_4$, 139 to 215 kg $CO_2$ and 0.076 to 0.186 kg $N_2O$ tonne$^{-1}$ of OW. Although
294 composting is an aerobic process, some $CH_4$ is formed by anaerobic pockets within the mass,
295 when initiating the process because microbes can consume $O_2$ faster than it can be transferred. In

296 the present analysis, $CH_4$, $CO_2$ and $N_2O$ emissions from CCC and HC were assumed to respect
297 the upper limits found by Amlinger et al. (2008), because of limited data on CCC emissions. The
298 GHG ($CO_2$, $CH_4$ and $N_2O$) emissions were expressed as units of $CO_2$ equivalent based on the
299 global warming potential (GWP) of $CH_4$ and $N_2O$ valued at 21 and 310 times that of $CO_2$,
300 respectively (US EPA 2005).
301
302 **Comparison of the results for the different scenarios**
303 ***Economic implications of various scenarios from 2009 to 2025***
304 Considering the Base Sce, the cost of UOW landfilling in the EUG1 will increase from $12300
305 to $15100 million US from 2009 to 2025, an increase of 23 % based on 2009 values (Figure 3a).
306 Compared to the base scenario and for 2025, Sce 1 & 2 will increase the cost of handling and
307 treating UOW by 25 & 37 %, respectively, whereas Sce 3 will lower the cost by 49%.
308 Accordingly from 2009 to 2025 and for Sce 1, 2 and 3, the cost of treating UOW will increase
309 from $15400 to $18900 million US, $15100 to $20700 million US and $6300 to $7800 million
310 US, respectively.
311 In the EUG2, the landfilling cost for UOW will increase by 14 % from $1800 to $2100
312 million US. Over the same period, Sce 1, 2 and 3 could increase the cost of handling and treating
313 UOW from $1950 to $2225 million US, $2250 to $2850 million US and $935 to $1070 million
314 US, respectively (Figure 3b). In comparison to landfilling, adopting CCF (Sce 2) will increase
315 the cost by 57 % in 2025 while adopting HC (Sce 3) will drop the cost by 41 %.
316 In the EU27, the cost of UOW landfilling is expected to increase from $14100 to $17200
317 million US, if the Base Sce is maintained, an increase of 22 % (Figure 3c), whereas Sce 1 & 2
318 will increase this cost by 50 and 67 %, respectively and Sce 3 can drop this cost by 37 %.
319 For Canada, maintaining the Base Sce will increase UOW handling and treatment costs
320 by 29 %, in 2025 as compared to 2009. If Sce-3 is adopted, the cost will increase from $660 to

321 $850 million US over the same period. By adopting Sce 3, the cost can be lowered by 34% as
322 compared to the Base Sce (Figure 3d). Accordingly, Sce 3 appears to be the most feasible option
323 from an economic point of view for the on-site treatment of UOW over the next 15 years.
324
325 **Insert Figure 3**
326
327 ***GHG ($CO_2$, $N_2O$ and $CH_4$) emissions under the various scenarios for 2025***
328 From 2009 to 2025, UOW management can increase GHG emission if the Base Sce, mainly
329 landfilling, is maintained along with its fossil fuels consumption for waste collecting and
330 transportation. Considering Base Sce for the EUG1, GHG emission from landfilled UOW will
331 grow from 37 to 45 million tonne $CO_2$-eq (Figure 4a), whereas Sce 1 and 3 could emit 34 and 27
332 million tonne $CO_2$-eq, respectively by 2025, representing a drop of 25 and 40 %. The Sce 2 is
333 will increases emissions by 7 % in 2025, because non $CH_4$ capture is assumed from 2016
334 onwards with the assumption that less UOW landfilling makes $CH_4$ capture uneconomical.
335 Similarly for the EUG2 by 2025, the GHG emissions for the Base Sce could increase from 5 to 6
336 million tonne $CO_2$-eq whereas Sce 1, 2 and 3 could limit GHG emissions to 6, 7 and 3 million
337 tonne $CO_2$-eq, respectively (Figure 4b). Again with the Base Sce, GHG emissions by the EU27
338 could increase from 42 to 51 million tonne $CO_2$-eq (Figure 4c) whereas Sce 1, 2 and 3 could
339 limit GHG emissions to 40, 55 and 31 million tonne $CO_2$-eq. Compared with 2005 emissions
340 (Table 4), the Base Sce, and Sce 1, 2 and 3 will contribute 1.4, 1.1, 1.5 and 0.8 % of the EUG1
341 anthropogenic GHG emissions respectively in 2025.
342 Similarly in Canada, GHG emission from landfilled UOW or the Base Sce is expected to
343 increase from 4 to 5 million tonne $CO_2$-eq from 2009 to 2025 (Figure 4d), but to drop to 4 and 3
344 million tonne $CO_2$-eq, if Sce-1 and 3 are adopted and increases to 5 % if Sce 2 is implemented.

345 Therefore, in the EU and Canada, the implementation of Sce-3 will reduce GHG emissions
346 remarkably in upcoming years.
347
348 **Insert Figure 4**
349 ***Land used for UOW landfilling from 2006 to 2025***
350 Landfilling requires 33 ha of tillable land per million tonne of UOW (Adhikari et al. 2009).
351 Accordingly and from 2009 to 2025, maintaining the Base Sce in the EUG1 will waste 32%
352 more land annually for landfilling (Figure 5a) which is equivalent to twice the Luxemburg
353 permanent crop area of 1780 ha (CIA 2009). Similarly, the EUG2 will require 21% more land
354 (Figure 5b) which is equivalent to twice the Malta permanent crop area of 990 ha (CIA 2009). In
355 Canada, maintaining the Base Sce will increase the annual land usage for landfilling by 38 %
356 (Figure 5d).
357
358 **Insert Figure 5**
359
360 By 2025 in the EUG1, implementing Sce 1, 2 and 3 will reduce the annual land
361 requirements for UOW landfilling by 56, 80 and 100 % as compared to the Base Sce, while for
362 the EUG2, land use will be reduced by 15, 80 and 100 %, respectively (Figure 5b). Similarly, in
363 Canada, Sce 1, 2 and 3 will reduce land use by 41, 80 and 100 %, respectively.
364
365 **Proposed CCC and HC in Paris, France and Toronto, Canada**
366 The cities of Paris in France, and Toronto in Canada, are large cities with a respective
367 population density of 3400 and 2500 $km^{-2}$ (Table 9) where the residential, commercial and
368 institutional generation of UOW amounts to 0.63 kg $person^{-1}$ $day^{-1}$ (OECD 2006/2007). In this
369 projection, it is proposed to use for Paris, 2 CCC $km^{-2}$ with 3 - 15 $m^3$ in-vessel composters and

438 individual home 400 L composting bins $km^{-2}$, and for Toronto, 1 CCC $km^{-2}$ with 2 - 15 $m^3$ in-vessel composters and 255 individual home 400 L compost bins $km^{-2}$ (Table 8).

**Insert Table 8**

Compared to landfilling, CCC and HC can save annual UOW treatment cost by $25760 and $28900 US $km^{-2}$ in Paris while Toronto can benefit from annual savings of $8150 and $49570 US $km^{-2}$, respectively. Furthermore, GHG emissions will drop drastically and urban air quality can benefit from less garbage collection and transportation (Adhikari et al. 2009). Therefore, the on-site composting of source separated UOW can offer interesting environmental and economic benefits for the years to come. However, the successful implementation of on-site composting offers some challenges.

To recycle a high fraction of the UOW, the implementation challenge for CCC and HC are numerous. The first prerequisite is the participation and involvement of waste producers (urban residents), because most need as stimulus, tax incentives or legislative pressures, besides education on the benefits of compost as soil amendment. Finding space for CCC in highly populated cities such as Paris and Toronto is another challenge, although the Montreal City Tournesol Centre owes its success to its location on the edge of the impressive Jeanne Mance park. The compost produced from CCC and not used by the UOW producers will have to be transported to city gardens.

## Conclusion and recommendations

The production of municipal solid waste (MSW) and its urban organic waste (UOW) fraction is expected to increase exponentially over the next 15 years, as a result of economic growth and urban expansion. If landfilling is maintained as the main treatment option, such growth will further add to already existing waste management issues and resource shortages. To divert the

organic fraction from landfills, the European Union (EU) and Canada have promulgated and implemented waste management legislations with emphasis on reduction, reuse and recycling.

The economic and environmental impact of promoting community composting centres (CCC) and home composters (HC) to recycle UOW was investigated in this project as an alternative to landfilling. By 2025, such on-site practices could reduce costs and greenhouse gas emissions by 34 to 50 and 40 %, respectively, as compared to maintaining landfilling practices. Furthermore and annually, some 3440 and 330 ha of agricultural land could be saved for the generation of food in the EU and Canada. By eliminating collection, transport and labour costs, HC are an interesting solution to the recycling of UOW. However, the shift of MSW management systems from landfill disposal to resource recovery requires technological input, population participation, compost quality assurance and sufficient urban gardens to divert the mass produced (Burnley 2007; Hargreaves et al. 2008). In this context, the performance of HC is an issue to be addressed for its successful implementation as on-site treatment system.

**Acknowledgement**

The authors gratefully acknowledge the financial and all necessary logistics supported by the Regional Council of Brittany, France, Cemagref Rennes, France, and the Natural Science and Engineering Research Council of Canada.

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**List of symbols and acronyms**

| | | |
|---|---|---|
| Base Sce | – | base scenario |
| CCC | – | community composting centres |
| CCF | – | centralized composting facility |
| $CH_4$ | – | methane |
| $CO_2$-eq | – | carbon dioxide equivalent |
| $CO_2$ | – | carbon dioxide |
| EU | – | european union |
| EUG1 | – | european union group one |
| EUG2 | – | european union group two |
| GDP | – | gross domestic product |
| GHG | – | greenhouse gas |
| GMP | – | glass, metal and plastics |
| HC | – | home composter |
| IC & I | – | institutions, commercials and industries |
| LF $CH_4$ | – | landfill methane |
| LF | – | landfilling |
| MSW | – | municipal solid waste |
| NUP | – | national urban population |
| OW | – | organic waste |
| P&PB | – | paper & paperboard |
| Sce 1 | – | scenario one |
| Sce 2 | – | scenario two |
| Sce 3 | – | scenario three |
| TA $CH_4$ | – | total anthropogenic methane |
| TA GHG | – | total anthropogenic greenhouse gas |
| TMSWG | – | total municipal solid waste generated |
| T&O | – | textile & others |
| TP | – | total population |
| UOW | – | urban organic waste |
| UOWPR | – | urban organic waste production rate |
| UP | – | urban population |

Table 1: Legislation to divert MSW from landfill in some EU countries and provinces of Canada in 2006.

| Country | Diversion | Legislation for diversion |
|---|---|---|
| Germany | 99 % | - Waste Disposal Act (1972): closure of uncontrolled landfills and introduction of strict and costly regulations for new and larger landfills.<br>- Waste Avoidance and Management Act (1986) and German Packaging Ordinance (1991): obligatory packaging recovery by producers and users.<br>- Technical Guidelines for Hazardous Wastes (1991) and Solid Household Wastes and Wastes Similar to Household Wastes (1993): more stringent and costly regulations on landfills and incinerators; realisation that organic wastes create most leachate and gas issues.<br>- Ordinance on Biowaste (1998): control for the sanitary treatment of organic wastes.<br>- Renewable Energy Law (2000): subsidizing of biogas production from organic wastes and municipal support for home composting. |
| The Netherlands | 98 % | - National Environmental Policy (1988): brought awareness for recycling with slow progress in terms of mass recycled.<br>- Regulation Air Emissions on Incineration (1989): strict and costly regulations imposed on incinerators.<br>- Regulation on the anaerobic digestion of UOW: subsidization of OW to produce electricity. |
| France | 56 % | - Directive aimed at MSW (2005): has producers share the cost of waste management.<br>- Action Plan for 2009-2012: aims at increasing recycling, by applying a higher tax on waste management and requiring manufacturers to help finance packaging management.<br>- Incineration: air quality policies improved from 1995 to 2006; early softer policies allowing the incineration of 47% of all MSW to generally produce energy. |
| United Kingdom | 22 % | - Hazardous Waste Directive (1991), Packaging Waste Directive (1994), White paper *Making Waste Work* (1995), Landfill Directive (1999): UK fails to draw 1999 waste management plan.<br>- Waste Strategy for England and Whales (2000): making local authorities responsible for waste management has limited impact on landfilled MSW.<br>- Renewable Obligation Order (2002): sets a 2010 target for the UK to generate 10 % of its electricity from renewable sources with power to be purchased by the Non-Fossil Purchasing Agency (NFPA). |
| **Canada** British Columbia | 32% | - Emission Criteria for Municipal Solid Waste Incinerators (1991): imposed emission standards and gives all incinerators 5 years to comply.<br>- Landfill Criteria for Municipal Solid Wastes (1993) and Guidelines for Environmental Monitoring (1996): controls and sets standards for the management of landfills; landfill operators have to show that they meet performance criteria.<br>- Regional District Solid Waste Management plan Guidelines (1994): each district sets its plan and several have banned the disposal by landfill of recyclable, hazardous and organic materials.<br>- Recycling Regulation - Product Stewardship (revised 2009): industry and the consumer are responsible for the disposal of packaging and containers. |
| Nova Scotia | 41 % | - Nova Scotia Environment Act (1994): proposed to develop a Solid Waste Resource Development Strategy with the 55 municipalities, introduced strict regulations on new landfills and required existing landfills to conform by 2006.<br>- Environment Goals and Sustainable Prosperity Act (1996): committed to recycling 50% of all municipal solid wastes; ban on disposal of all containers and packaging, refillable or recyclable beverage containers, and all organics which can be composted. |
| Ontario | 19 % | - Waste Diversion Act (2002) giving Board the responsibility to develop and implement waste diversion programs: reviewed by public consultation to recommend path towards zero waste. |
| Quebec | 27 % | - Bylaw on landfill tax (2006): a landfill tax of \$10 $ton^{-1}$.<br>- Bylaw on the disposal by landfill and incineration of municipal solid wastes (2006): revision with strict environmental requirements whereas before, in many instances a landfill liner was not even required.<br>- Law and several bylaws on recovery and recycling (1990): creation of Recy-Quebec to manage the recycling of glass, paper and metal. |

Note: regulations on compost quality are excluded. References : Eurostat (2009); Statistics Canada (2008); CCC (2010); MEEDDM (2009); LAP (2003); Zhang et al. (2009); Schnurer (2000); Bergs (2005); van der Sloot (1996); Gervais (2002).

Table 2: Population and waste generation for countries categorized by GDP per capita (US$) in 2005.

| Category | Countries | GDP[a] per capita US$ | TP[b] ('1000) | UP[b] ('1000) | UP % | MSW[c] generated million tonne | UOW[d] generated million tonne | MSW[c] landfilled million tonne |
|---|---|---|---|---|---|---|---|---|
| EU Group 1 | Luxembourg | 64102 | 457 | 378 | 82.8 | 0.32 | 0.14 | 0.06 |
| (EUG1) | Ireland | 39040 | 4143 | 2507 | 60.5 | 3.07 | 0.77 | 1.84 |
| GDP> | Denmark | 34298 | 5417 | 4653 | 85.9 | 3.99 | 1.16 | 0.21 |
| 25000 | Netherlands | 34289 | 16328 | 13095 | 80.2 | 10.19 | 3.57 | 0.18 |
| | Austria | 33299 | 8292 | 5514 | 66.5 | 5.13 | 1.80 | 0.66 |
| | UK | 33125 | 60245 | 54040 | 89.7 | 35.18 | 13.13* | 22.65 |
| | Belgium | 32955 | 10398 | 10117 | 97.3 | 4.95 | 1.93 | 0.38 |
| | Sweden | 32750 | 9038 | 7619 | 84.3 | 4.36 | 2.12* | 0.21 |
| | Finland | 32467 | 5246 | 3274 | 62.4 | 2.49 | 1.13* | 1.48 |
| | France | 31846 | 60991 | 46780 | 76.7 | 33.06 | 10.58 | 11.89 |
| | Germany | 29913 | 82652 | 60667 | 73.4 | 46.62 | 6.53 | 3.97 |
| | Italy | 29189 | 58646 | 39645 | 67.6 | 31.79 | 9.22 | 17.30 |
| | Spain | 26792 | 43397 | 33285 | 76.7 | 25.91 | 12.69 | 12.67 |
| **Total/Average** | | **34928** | **365250** | **281574** | **77** | **207** | **65** | **74** |
| EU Group 2 | Greece | 23386 | 11100 | 6704 | 60.4 | 4.86 | 1.40* | 4.30 |
| (EUG2) | Slovenia | 22294 | 1999 | 990 | 49.5 | 0.85 | 0.24* | 0.66 |
| GDP | Portugal | 21168 | 10528 | 6064 | 57.6 | 4.70 | 1.60 | 2.93 |
| <25000 | Czech Republic | 20931 | 10192 | 7491 | 73.5 | 2.95 | 0.90* | 2.13 |
| | Cyprus | 19724 | 836 | 579 | 69.3 | 0.62 | 0.11* | 0.55 |
| | Malta | 19239 | 403 | 377 | 93.6 | 0.25 | 0.05* | 0.22 |
| | Hungary | 18257 | 10086 | 6687 | 66.3 | 4.64 | 1.35 | 3.85 |
| | Slovakia | 15991 | 5387 | 3027 | 56.2 | 1.56 | 0.44* | 1.23 |
| | Estonia | 15990 | 1344 | 933 | 69.4 | 0.59 | 0.10* | 0.37 |
| | Lithuania | 14538 | 3425 | 2281 | 66.6 | 1.29 | 0.21* | 1.17 |
| | Poland | 14156 | 38196 | 23491 | 61.5 | 9.36 | 3.08* | 8.63 |
| | Latvia | 13692 | 2302 | 1565 | 68 | 0.71 | 0.15* | 0.56 |
| | Bulgaria | 9220 | 7745 | 5437 | 70.2 | 3.68 | 0.42* | 3.14 |
| | Romania | 9067 | 21628 | 11614 | 53.7 | 8.15 | 1.17* | 6.40 |
| **Total/Average** | | **16975** | **125171** | **77241** | **65** | **44** | **11** | **36** |
| North Americas | US | 41410 | 299846 | 242276 | 80.8 | 222.90 | 55.73 | 121.03 |
| | Canada | 33400 | 32271 | 25849 | 80.1 | 13.40 | 3.22 | 8.05[e] |
| | Mexico | 10689 | 104266 | 79555 | 76.3 | 36.00 | 18.36 | 34.81[f] |

GDP - Gross domestic product; UP - Urban population; TP - Total population; MSW - Municipal solid waste; OW - Organic waste; [a]UN (2007); [b]World Population Prospects (2007); [c]Eurostat (2008); [d]OECD (2006/2007); *Estimated from Adhikari et al. (2006) with 2005 UOW and GDP data; [e]2004; [f]2006; MSW generated and landfilled data for North America from OECD (2006/2007).

Table 3: Municipal solid waste (MSW) composition for the EU and North America in 2005.

| Country | TMSWG million tonne | OW % | P&PB % | T&O % | GMP % | OW million tonne | P&PB million tonne | T&O million tonne | GMP million tonne |
|---|---|---|---|---|---|---|---|---|---|
| Luxembourg | 0.32 | 45 | 22 | 16 | 16.8 | 0.14 | 0.07 | 0.05 | 0.05 |
| Ireland | 3.07 | 25 | 31 | 23 | 20 | 0.77 | 0.95 | 0.71 | 0.61 |
| Denmark | 3.99 | 29 | 27 | 32 | 11.8 | 1.16 | 1.08 | 1.28 | 0.47 |
| Netherlands | 10.19 | 35 | 26 | 12 | 27 | 3.57 | 2.65 | 1.22 | 2.75 |
| Austria | 5.13 | 35 | 22 | 19 | 24 | 1.80 | 1.13 | 0.98 | 1.23 |
| Belgium | 4.95 | 39 | 17 | 29 | 15 | 1.93 | 0.84 | 1.44 | 0.74 |
| France | 33.06 | 32 | 20 | 26 | 22 | 10.58 | 6.61 | 8.59 | 7.27 |
| Germany | 46.62 | 14 | 34 | 12 | 39 | 6.53 | 15.85 | 5.59 | 18.18 |
| Italy | 31.79 | 29 | 28 | 22 | 20 | 9.22 | 8.90 | 6.99 | 6.36 |
| Spain | 25.91 | 49 | 21 | 7 | 24 | 12.69 | 5.44 | 1.81 | 6.22 |
| Hungary | 4.64 | 29 | 15 | 35 | 21 | 1.35 | 0.70 | 1.62 | 0.97 |
| Portugal | 4.70 | 34 | 21 | 23 | 22 | 1.60 | 0.99 | 1.08 | 1.03 |
| Slovakia | 1.56 | 38 | 13 | 31 | 18 | 0.59 | 0.20 | 0.48 | 0.28 |
| USA | 222.90 | 25 | 34 | 16 | 25 | 55.73 | 75.79 | 35.66 | 55.73 |
| Canada | 13.40 | 24 | 47 | 8 | 22 | 3.22 | 6.30 | 1.07 | 2.95 |
| Mexico | 36.00 | 51 | 15 | 16 | 15 | 18.36 | 5.40 | 5.76 | 5.40 |

Source: OECD (2006/2007); Eurostat (2008)

TMSWG - Total municipal solid waste generated; OW - Organic waste;

P&PB - Paper and cardboard; T&O - Textile and others; GMP - Glass, metal and plastics.

Table 4: Composting of urban organic waste (UOW) in some of the EU countries and Canada.

| Country | Composting million tonne | Composting % | Composting million tonne | Composting % |
|---|---|---|---|---|
| | 1995 | | 2005 | |
| Luxembourg | 0.02 | 7.04 | 0.06[b] | 19.28[b] |
| Ireland | - | - | 0.03[a] | 1.25[a] |
| Denmark | 0.32 | 10.69 | 0.55[b] | 15.28[b] |
| Netherlands | 2.01 | 23.72 | 2.38[c] | 23.49[c] |
| Austria | 0.94 | 26.56 | 2.06[c] | 44.7[c] |
| Belgium | 0.27 | 5.95 | 1.05[b] | 22.76[b] |
| France | 2.53 | 9.14 | 4.87 | 14.33 |
| Germany | 5.59 | 10.96 | 8.30[c] | 17.14[c] |
| Italy | 0.12 | 0.45 | 10.55 | 33.30 |
| Spain | 2.09 | 10.38 | 7.43[c] | 32.69[c] |
| Slovenia | 0.00 | 0.00 | 0.01[a] | 1.15[a] |
| Portugal | 0.50 | 12.90 | 0.31 | 6.26 |
| Hungary | - | - | 0.05[b] | 1.07[b] |
| Canada | - | - | 1.66[c] | 12.50[c] |

Source: OECD (2006/2007); Eurostat (2008)
UOW - Urban organic waste
[a]2002; [b]2003; [c]2004.

Table 5: Municipal Solid Waste (MSW) composting facilities in some EU countries and Canada.

| Country | No of composting facilities | Description | References |
|---|---|---|---|
| France | 119 | 65 mixed MSW and 54 source-separated urban organic waste (UOW) composting facilities. | ECN (2009) |
| Germany | 700-900 | Source separated UOW composting is the main focus in Germany for quality assurance. | ECN (2009) |
| Finland | 20 | In-vessel composting facilities with a capacity ranging from 5 to 35 million kg. | ECN (2009) |
| Canada | 54 | Composting of food waste from institutions, commercials & industries (IC&I) and residential sectors | Antler (2009) |

Table 6: Various scenarios for Urban Organic Waste (UOW) treatment strategies.

| Scenarios | LF % | CCF % | CCC % | HC % |
|---|---|---|---|---|
| **Base Scenario (Base Sce)** | 100 | 0 | 0 | 0 |
| **Scenario one (Sce 1)** | | | | |
| EUG1 | 42 | 57 | 0 | 1 |
| EUG2 | 84 | 15 | 0 | 1 |
| Canada | 56 | 43 | 0 | 1 |
| **Scenario two (Sce 2)** | | | | |
| **Year** | | | | |
| 2006 | 75 | 25 | 0 | 0 |
| 2009 | 50 | 50 | 0 | 0 |
| 2016 | 35 | 65 | 0 | 0 |
| 2020 | 25 | 75 | 0 | 0 |
| 2025 | 20 | 80 | 0 | 0 |
| **Scenario three (Sce 3)** | 0 | 10 | 30 | 60 |

LF - Landfilling; CCF - Centralized composting facility; CCC - Community composting Centre; HC - Home composters.

Table 7: Cost of landfilling and composting systems for urban organic waste (UOW).

| Costs ($ US tonne$^{-1}$ wet UOW) | LF[a] | CCF[b] | CCC | HC |
|---|---|---|---|---|
| **Collection** | **115** | **153** | 0 | 0 |
| **Capital costs** | | | | |
| Land acquisition | 2 | 4 | 0 | 0 |
| [h]Civil works | 19 | 17 | 20[c] | 0 |
| Equipments | 0 | 18 | 64[d] | 0 |
| Site assessment/restoration | 2 | 0 | 0 | 0 |
| After care | 7 | 0 | 0 | 0 |
| Compost bin | 0 | 0 | 0 | 31[f] |
| **Sub-total** | **30** | **39** | **84** | **31** |
| **Variable costs** | | | | |
| Annual maintenance | 0 | 7 | 0 | 0 |
| [i]Manpower/operation | 18 | 23 | 28[e] | 0 |
| Fuel and disposal of rejects | 0 | 19 | 0 | 0 |
| Training/Promotion | 0 | 0 | 6 | 11[g] |
| [j]Gas capturing | 2 | 0 | | |
| **Sub-total** | **20** | **49** | **34** | **11** |
| **Total** | **165** | **241** | **118** | **42** |

LF - Landfilling; CCF - Centralized Composting Facility; CCC - Community Composting Center; HC - Home Composter; UOW - Urban Organic Waste;

[a&b] values adjusted using an annual inflation rate of 2.5% from 2002 to 2009 and an exchange of $1.00 US = 0.72 € mid-month average for 2009 (Eunomia 2002; Bank of Canada 1995-2010); for EU, collection cost averaged from a range of $50 to $210 US tonne$^{-1}$ ; CCF increased by 33 % because of double collection at a lower frequency for MSW other than UOW; other costs for LF and CCF were based on UK and Italian values;

[c] Site preparation and installation costs for CCC of $40000 US (Eco- Quartier 2009);

[d] CCC costing $30000 US for 11.5 m$^3$ total capacity (Eco-Quartier 2009) serving 360 persons generating 0.63 kg UOW person$^{-1}$day$^{-1}$ (OECD 2006/2007);

[e] Annual management cost of $5700 US;

[f] Wooden 400L composting bin at $200 US (Recycle works Ltd 2010) serving 4 persons per household generating 0.63 kg UOW person$^{-1}$day$^{-1}$ (OECD 2006/2007);

[g] Promotion of bins and education of producer (Nash 1992);

[h] Civil works for LF including capital investment and interest;

[i] Manpower/operation for labour, power and equipment maintenance;

[j] Gas capturing cost consisting of vertical extraction wells at $246 US m$^{-1}$ drilling and installation cost with a 25 m influence radius, and at $525 US per wellhead assembly with piping and valves (CIWMB 2008), based on a landfill 15 m deep with an average waste density of 380 kg m$^{-3}$ (Peavy et al. 1985; Bhide 1994).

Table 8: Proposed community and home composting in Paris, France and Toronto, Canada.

| Description | Paris | | Toronto | |
|---|---|---|---|---|
| | [a]TP million(2005): | 10.4 | [a]TP million(2006): | 5.671 |
| | [a]Total area ($km^2$): | 3043 | [a]Total area ($km^2$): | 2279 |
| | % NUP: | 22 | % NUP: | 22 |
| | Population $km^{-2}$: | 3400 | Population $km^{-2}$: | 2500 |
| | [b]UOW$person^{-1}day^{-1}$: | 0.63 | UOW$person^{-1}day^{-1}$: | 0.63 |
| | CCC | HC | CCC | HC |
| [c] composting centre $km^{-2}$ | 2 | - | 1 | - |
| In-vessel composters $centre^{-1}$ | 3 | - | 2 | - |
| In-vessel composter size | 6 m long x 1.8 m diameter | - | 6 m long x 1.8 m diameter | - |
| [d] Compost bins $km^{-2}$ | - | 255 | - | 438 |
| Capacity of home composter $bin^{-1}$ | - | 400L | - | 400L |
| Composting costs | \$118 US $tonne^{-1}$ | \$42 US $tonne^{-1}$ | \$118 US $tonne^{-1}$ | \$42 US $tonne^{-1}$ |
| Total UOW composted $yr^{-1}$ $km^{-2}$ | 548 tonne | 235 tonne | 173 tonne | 403 tonne |
| Cost saving compared to landfilling | \$47 US $tonne^{-1}$ | \$123 US $tonne^{-1}$ | \$47 US $tonne^{-1}$ | \$123 US $tonne^{-1}$ |
| Cost saving compared to CCF | \$123 US $tonne^{-1}$ | \$199 US $tonne^{-1}$ | \$123 US $tonne^{-1}$ | \$199 US $tonne^{-1}$ |

TP - Total population; NUP - National urban population; UOW - Urban Organic Waste;
CCC - Community composting centre; HC - Home composter;
The density and capacity of CCC and HC corresponds to the waste generated by the population.
[a] Demographia (2009);
[b] OECD (2006/2007) and assuming same for Toronto;
[c] Assuming 70 % and 30 % population live in multi-storey buildings in Paris and Toronto, respectively; [d] Assuming 30 % and 70 % people live in single unit house in Paris and Toronto, respectively with 4 persons $household^{-1}$.

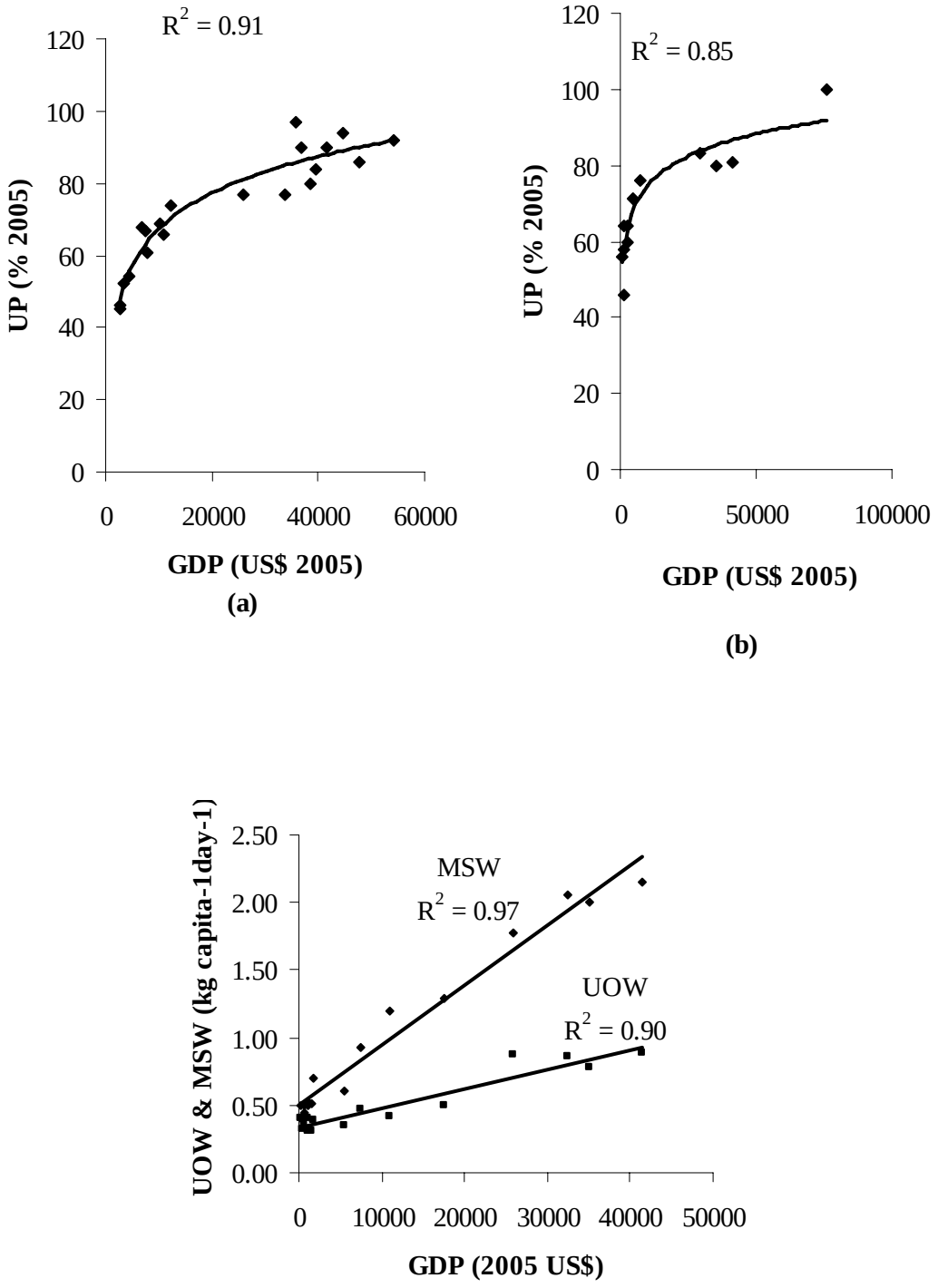
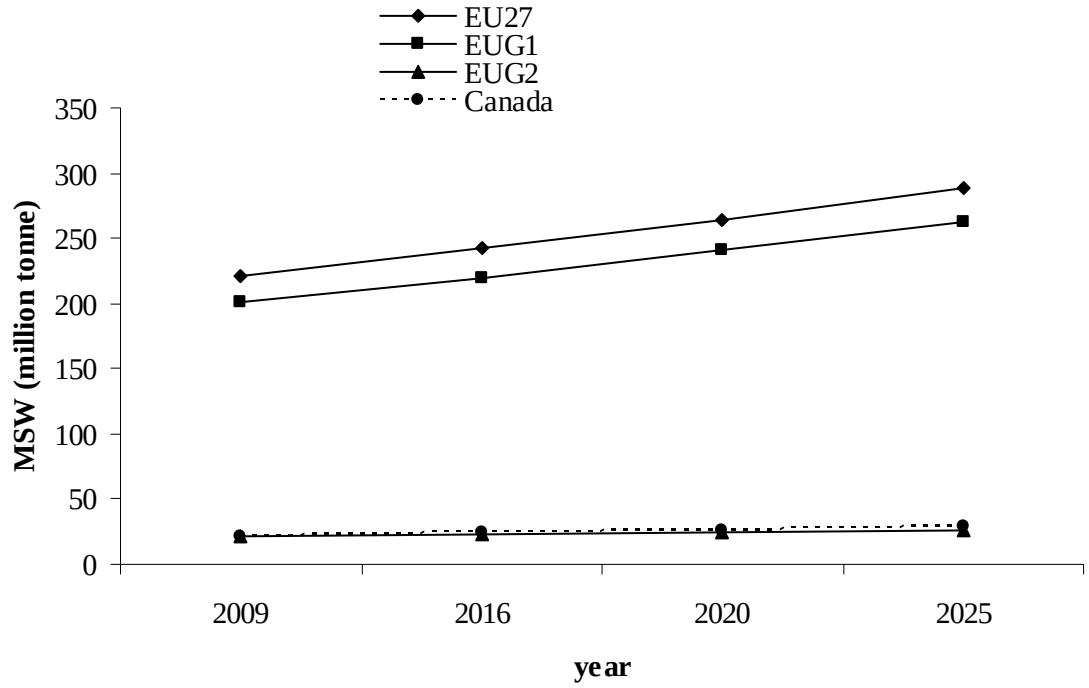
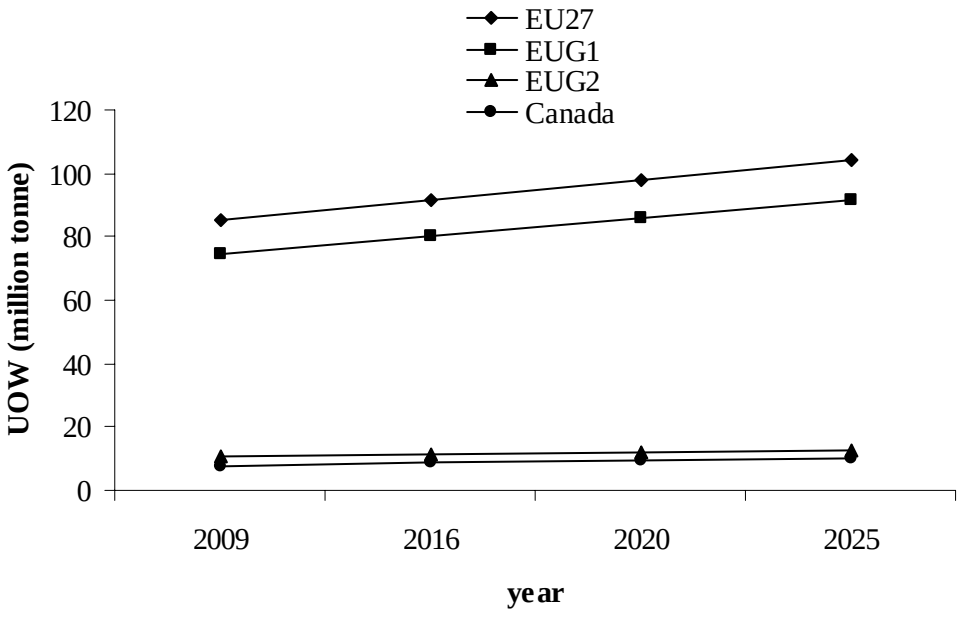



Fig. 1: Correlation of urban population (% UP) with per capita gross domestic product (GDP) according to UNPD (2007) and UNSD (2008) for (a) Europe; and (b) The Americas. (c) correlation of per capita urban organic waste (UOW) and municipal solid waste (MSW) production with per capita gross domestic production (GDP) according to OECD (2006-2007); Eurostat (2008); Sufian & Bala (2007); Government of India (2008); Kanbour (1997); WHO (1995); Al-Yousfi (2003); Alamgir & Ahsan (2007); and World Resources (1998-99).




**(a)**




**(b)**

Fig. 2: Urban solid waste generation in the European Union (EU) and Canada on an annual basis (a) Municipal Solid Waste (MSW); and (b) Urban Organic Waste (UOW).

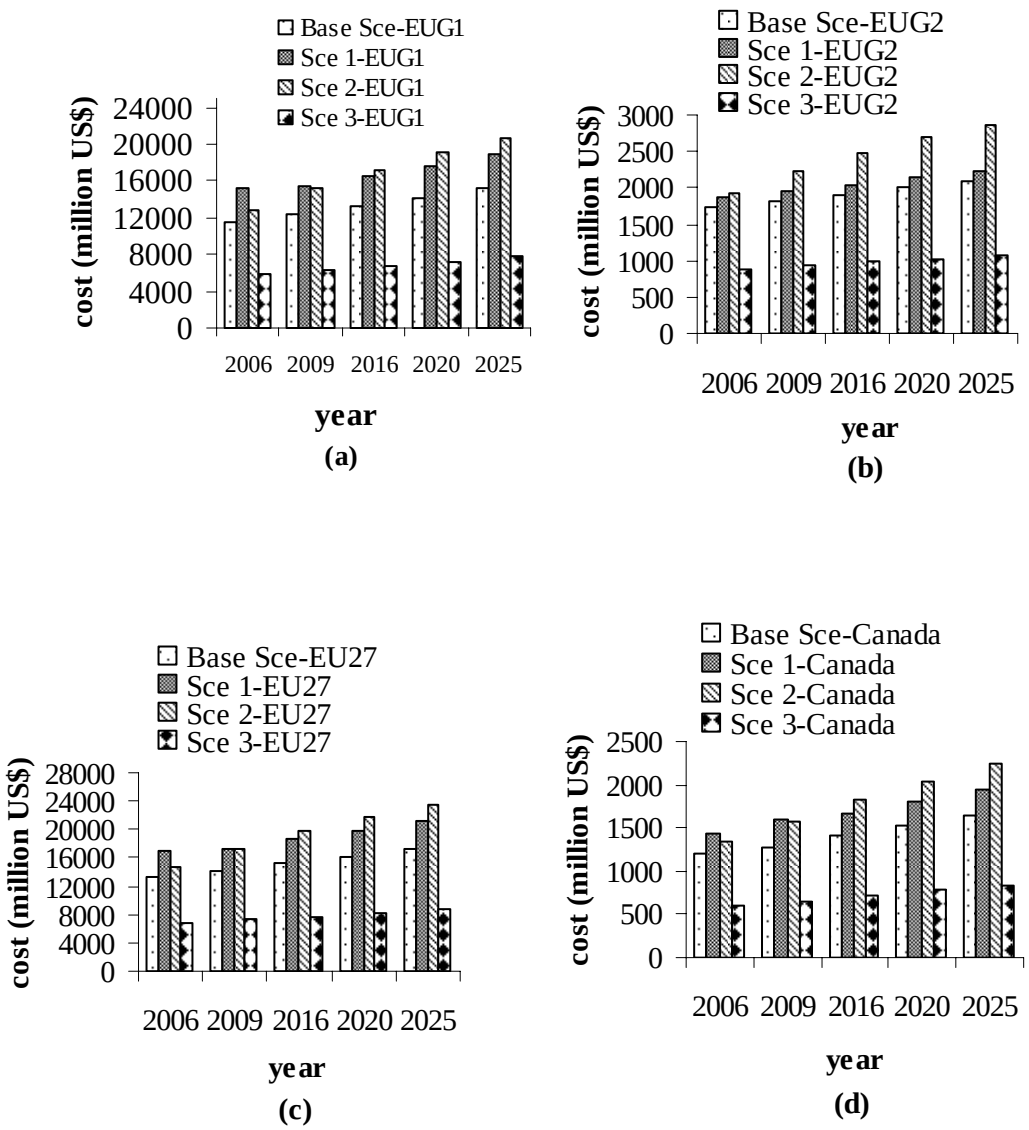



Fig. 3: Cost of urban organic waste (UOW) handling and treatment in consideration of various scenarios for (a) The European Union Group one (EUG1 with annual GDP over $25000 US); (b) The European Union Group two (EUG2 with annual GDP under $25000 US); (c) 27 countries of The European Union (EU27 or EUG1 + EUG2); and (d) Canada.

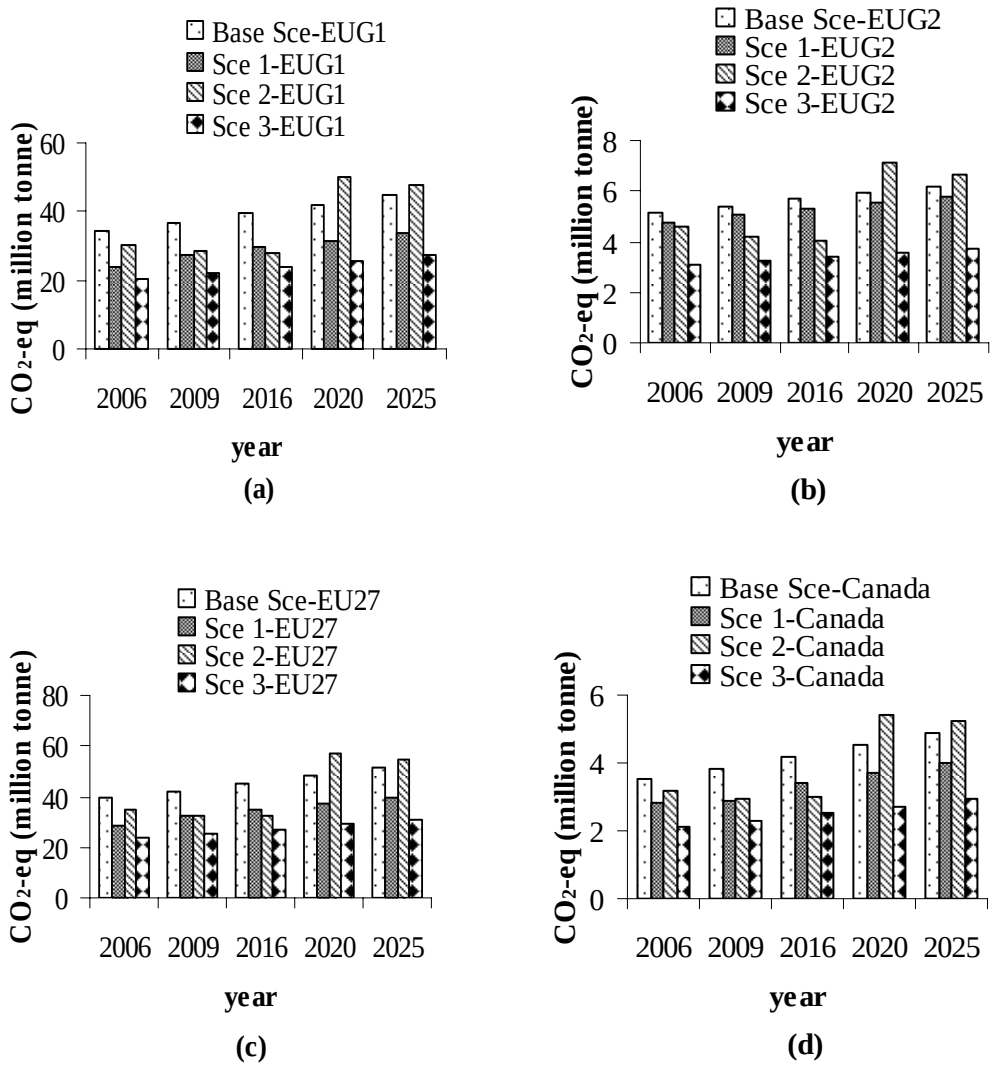



Fig. 4: Computed Greenhouse Gases ($CH_4$, $CO_2$ & $N_2O$) emissions from UOW treatment in consideration of various scenarios for (a) The European Union Group one (EUG1 with annual GDP over $25000 US); (b) The European Union Group two (EUG2 with annual GDP under $25000 US); (c) 27 countries of The European Union (EU27 or EUG1 + EUG2); and (d) Canada.

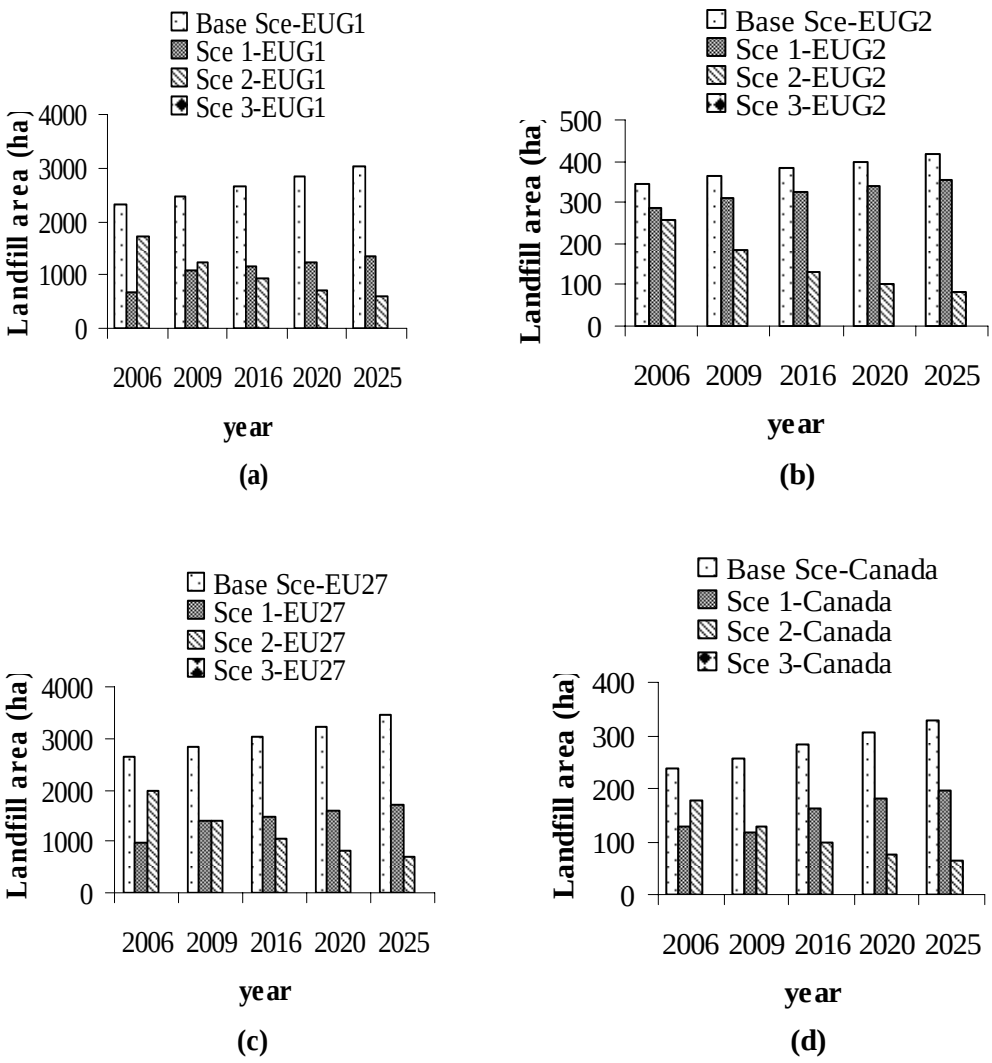
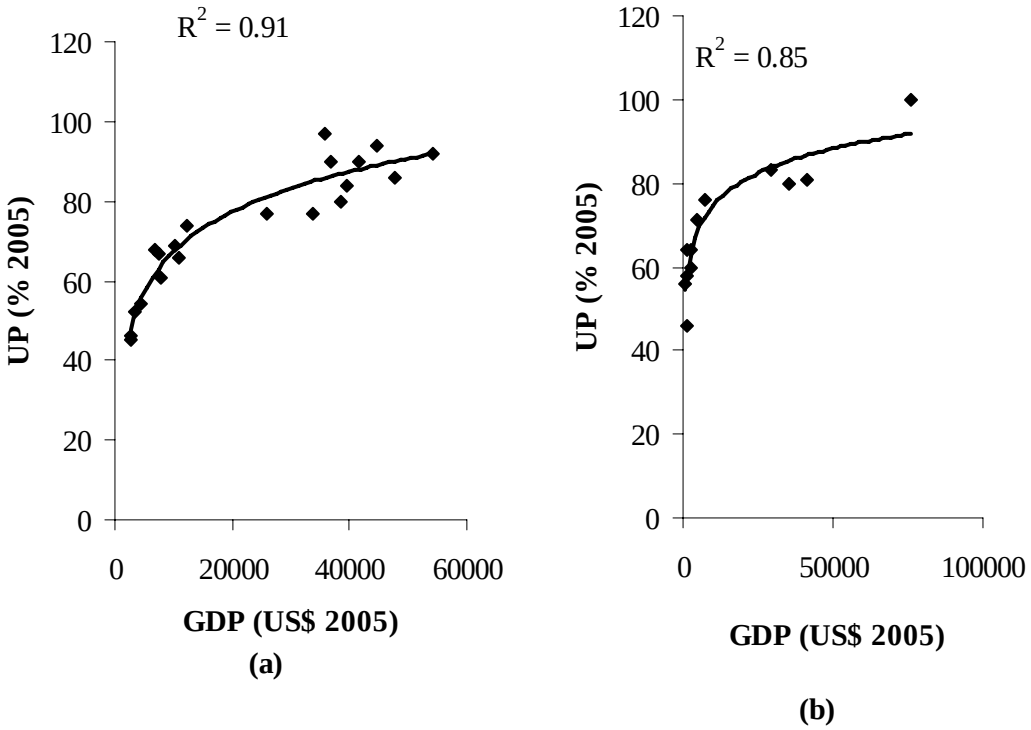



Fig. 5: Computed landfill area required for urban organic waste (UOW) landfilling in consideration of various scenarios for (a) The European Union Group one (EUG1 with annual GDP over $25000 US); (b) The European Union Group two (EUG2 with annual GDP under $25000 US); (c) 27 countries of The European Union (EU27 or EUG1 + EUG2); and (d) Canada.



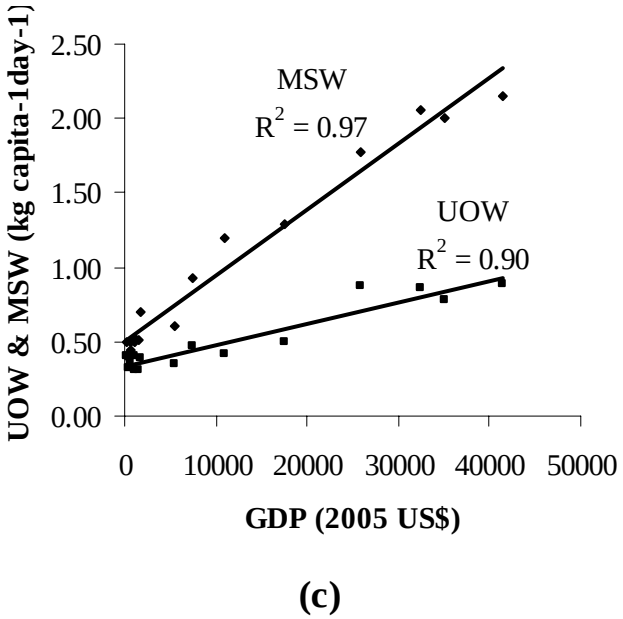




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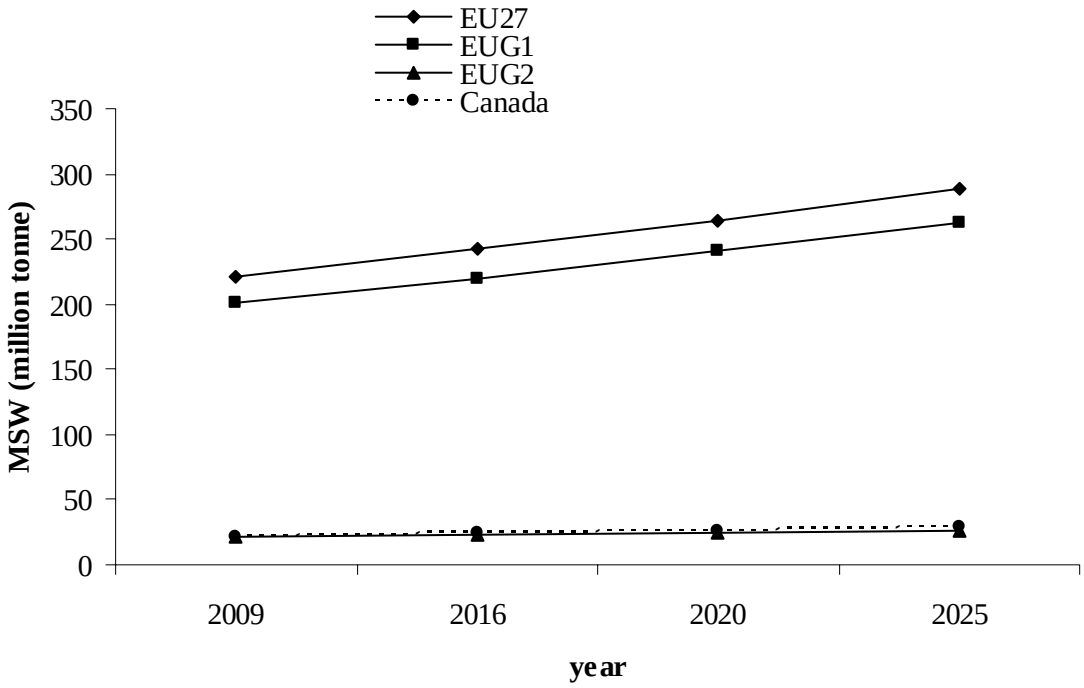
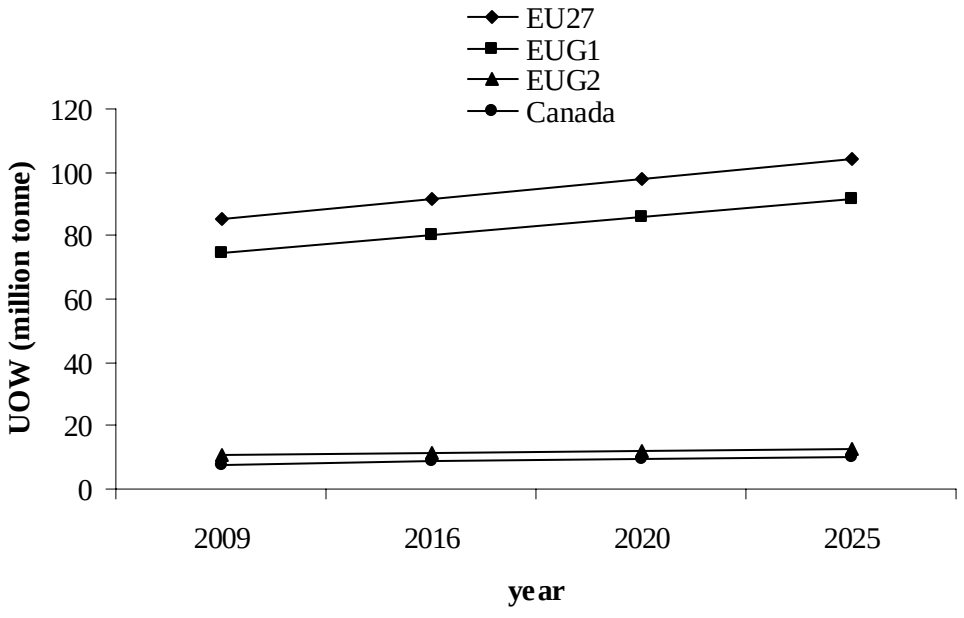
Fig. 1: Correlation of urban population (% UP) with per capita gross domestic product (GDP) according to UNPD (2007) and UNSD (2008) for (a) Europe; and (b) The Americas. (c) correlation of per capita urban organic waste (UOW) and municipal solid waste (MSW) production with per capita gross domestic production (GDP) according to OECD (2006-2007); Eurostat (2008); Sufian & Bala (2007); Government of India (2008); Kanbour (1997); WHO (1995); Al-Yousfi (2003); Alamgir & Ahsan (2007); and World Resources (1998-99).




**(a)**




**(b)**

Fig. 2: Urban solid waste generation in the European Union (EU) and Canada on an annual basis (a) Municipal Solid Waste (MSW); and (b) Urban Organic Waste (UOW).

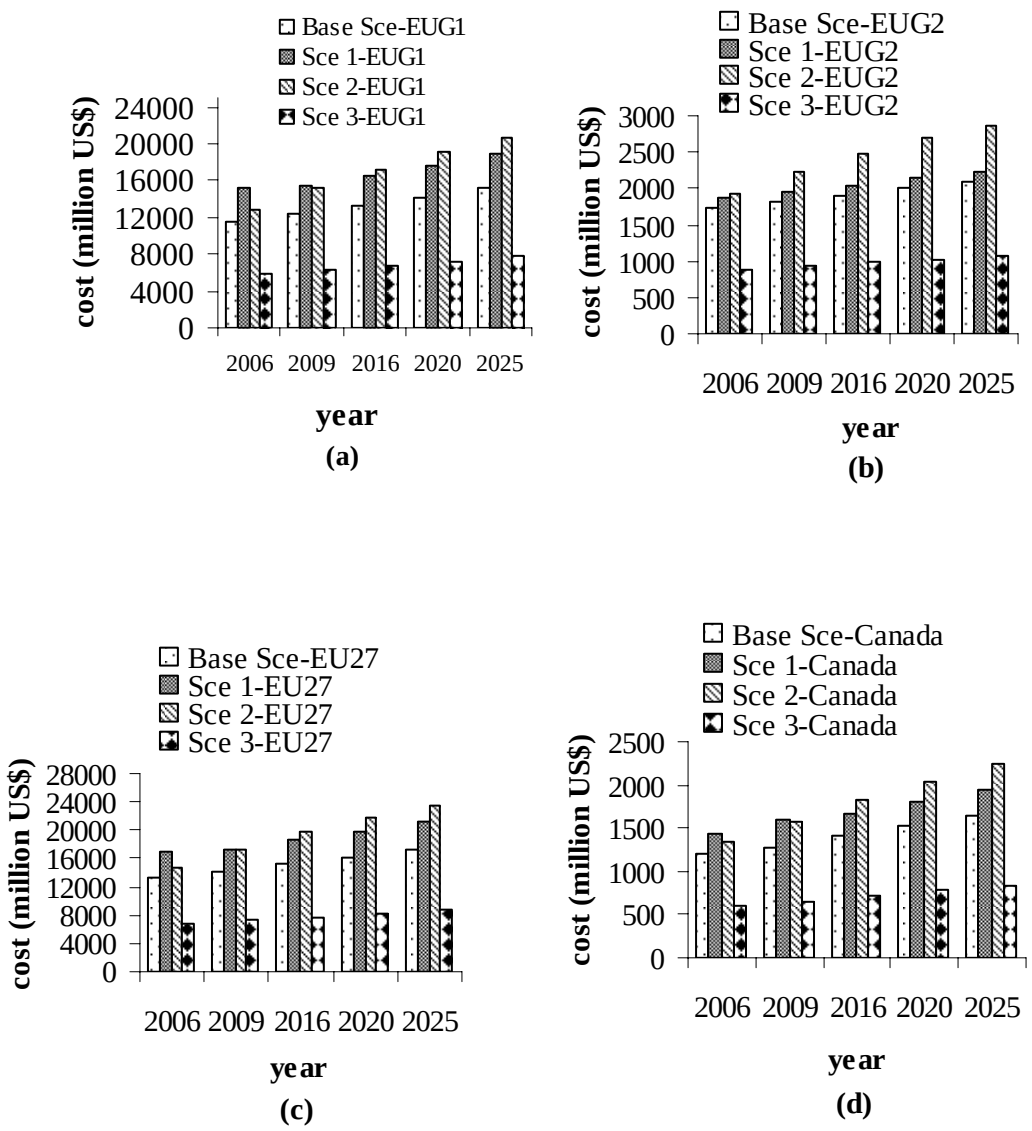
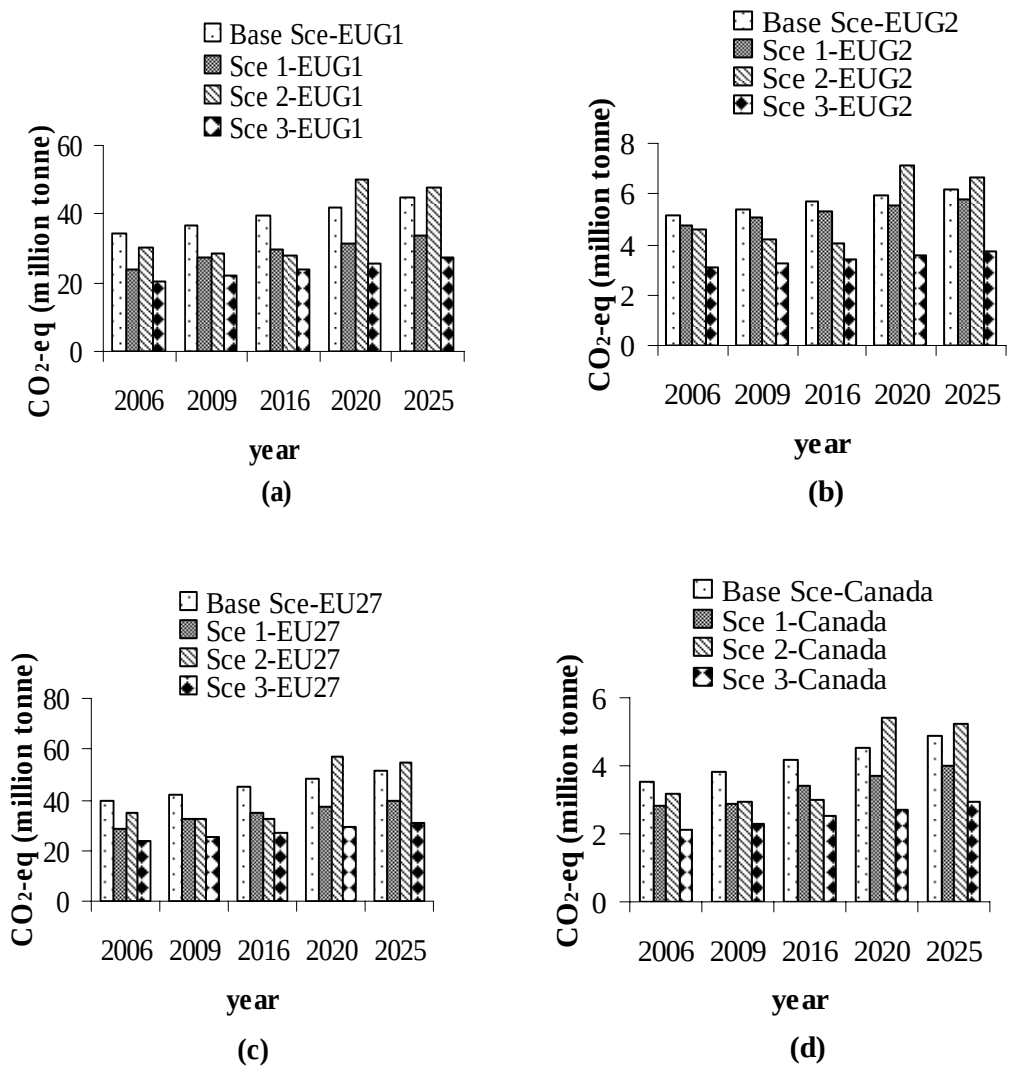



Fig. 3: Cost of urban organic waste (UOW) handling and treatment in consideration of various scenarios for (a) The European Union Group one (EUG1 with annual GDP over $25000 US); (b) The European Union Group two (EUG2 with annual GDP under $25000 US); (c) 27 countries of The European Union (EU27 or EUG1 + EUG2); and (d) Canada.

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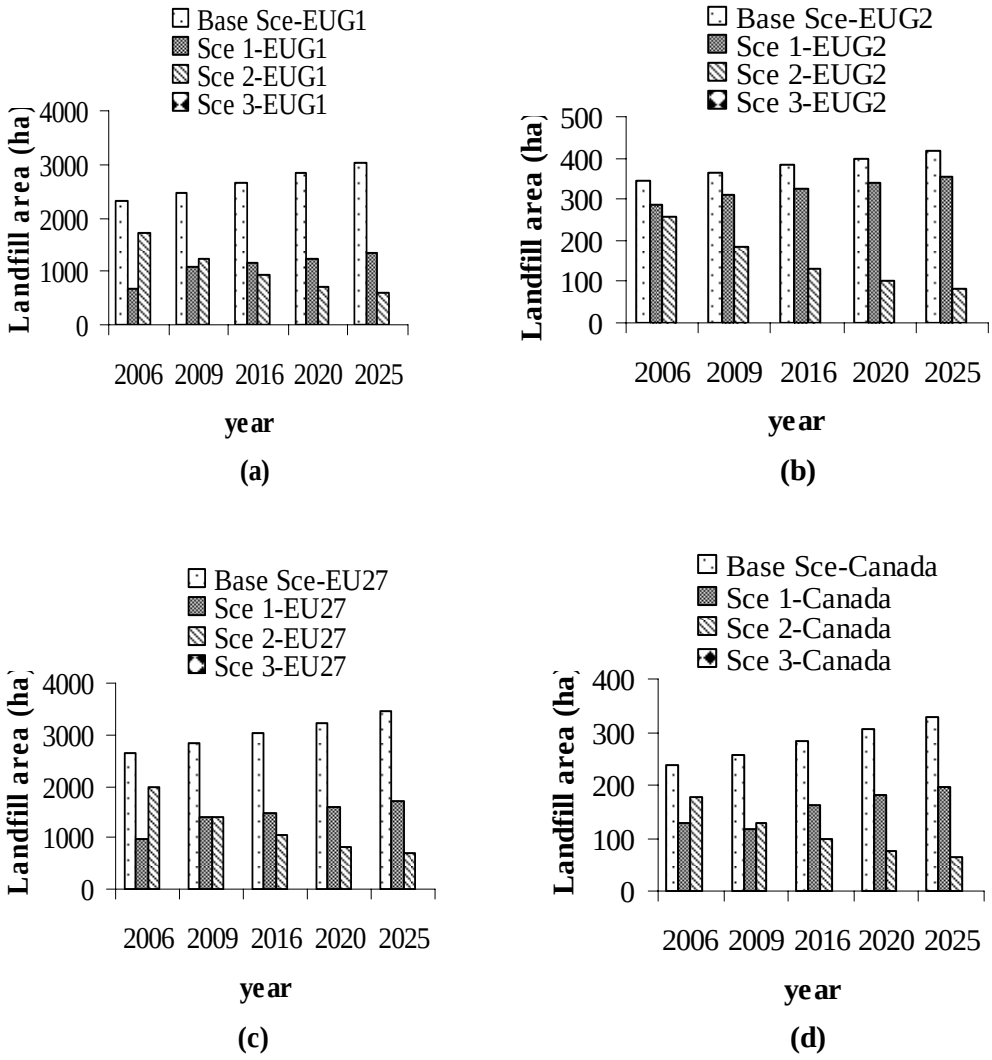


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Table 1: Legislation to divert MSW from landfill in some EU countries and provinces of Canada in 2006.

| Country | Diversion | Legislation for diversion |
|---|---|---|
| Germany | 99 % | - Waste Disposal Act (1972): closure of uncontrolled landfills and introduction of strict and costly regulations for new and larger landfills.<br>- Waste Avoidance and Management Act (1986) and German Packaging Ordinance (1991): obligatory packaging recovery by producers and users.<br>- Technical Guidelines for Hazardous Wastes (1991) and Solid Household Wastes and Wastes Similar to Household Wastes (1993): more stringent and costly regulations on landfills and incinerators; realisation that organic wastes create most leachate and gas issues.<br>- Ordinance on Biowaste (1998): control for the sanitary treatment of organic wastes.<br>- Renewable Energy Law (2000): subsidizing of biogas production from organic wastes and municipal support for home composting. |
| The Netherlands | 98 % | - National Environmental Policy (1988): brought awareness for recycling with slow progress in terms of mass recycled.<br>- Regulation Air Emissions on Incineration (1989): strict and costly regulations imposed on incinerators.<br>- Regulation on the anaerobic digestion of UOW: subsidization of OW to produce electricity. |
| France | 56 % | - Directive aimed at MSW (2005): has producers share the cost of waste management.<br>- Action Plan for 2009-2012: aims at increasing recycling, by applying a higher tax on waste management and requiring manufacturers to help finance packaging management.<br>- Incineration: air quality policies improved from 1995 to 2006; early softer policies allowing the incineration of 47% of all MSW to generally produce energy. |
| United Kingdom | 22 % | - Hazardous Waste Directive (1991), Packaging Waste Directive (1994), White paper *Making Waste Work* (1995), Landfill Directive (1999): UK fails to draw 1999 waste management plan.<br>- Waste Strategy for England and Whales (2000): making local authorities responsible for waste management has limited impact on landfilled MSW.<br>- Renewable Obligation Order (2002): sets a 2010 target for the UK to generate 10 % of its electricity from renewable sources with power to be purchased by the Non-Fossil Purchasing Agency (NFPA). |
| **Canada** British Columbia | 32% | - Emission Criteria for Municipal Solid Waste Incinerators (1991): imposed emission standards and gives all incinerators 5 years to comply.<br>- Landfill Criteria for Municipal Solid Wastes (1993) and Guidelines for Environmental Monitoring (1996): controls and sets standards for the management of landfills; landfill operators have to show that they meet performance criteria.<br>- Regional District Solid Waste Management plan Guidelines (1994): each district sets its plan and several have banned the disposal by landfill of recyclable, hazardous and organic materials.<br>- Recycling Regulation - Product Stewardship (revised 2009): industry and the consumer are responsible for the disposal of packaging and containers. |
| Nova Scotia | 41 % | - Nova Scotia Environment Act (1994): proposed to develop a Solid Waste Resource Development Strategy with the 55 municipalities, introduced strict regulations on new landfills and required existing landfills to conform by 2006.<br>- Environment Goals and Sustainable Prosperity Act (1996): committed to recycling 50% of all municipal solid wastes; ban on disposal of all containers and packaging, refillable or recyclable beverage containers, and all organics which can be composted. |
| Ontario | 19 % | - Waste Diversion Act (2002) giving Board the responsibility to develop and implement waste diversion programs: reviewed by public consultation to recommend path towards zero waste. |
| Quebec | 27 % | - Bylaw on landfill tax (2006): a landfill tax of \$10 $ton^{-1}$.<br>- Bylaw on the disposal by landfill and incineration of municipal solid wastes (2006): revision with strict environmental requirements whereas before, in many instances a landfill liner was not even required.<br>- Law and several bylaws on recovery and recycling (1990): creation of Recy-Quebec to manage the recycling of glass, paper and metal. |

Note: regulations on compost quality are excluded. References : Eurostat (2009); Statistics Canada (2008); CCC (2010); MEEDDM (2009); LAP (2003); Zhang et al. (2009); Schnurer (2000); Bergs (2005); van der Sloot (1996); Gervais (2002).

Table 2: Population and waste generation for countries categorized by GDP per capita (US$) in 2005.

| Category | Countries | GDP[a] per capita US$ | TP[b] ('1000) | UP[b] ('1000) | UP % | MSW[c] generated million tonne | UOW[d] generated million tonne | MSW[c] landfilled million tonne |
|---|---|---|---|---|---|---|---|---|
| EU Group 1 | Luxembourg | 64102 | 457 | 378 | 82.8 | 0.32 | 0.14 | 0.06 |
| (EUG1) | Ireland | 39040 | 4143 | 2507 | 60.5 | 3.07 | 0.77 | 1.84 |
| GDP> | Denmark | 34298 | 5417 | 4653 | 85.9 | 3.99 | 1.16 | 0.21 |
| 25000 | Netherlands | 34289 | 16328 | 13095 | 80.2 | 10.19 | 3.57 | 0.18 |
| | Austria | 33299 | 8292 | 5514 | 66.5 | 5.13 | 1.80 | 0.66 |
| | UK | 33125 | 60245 | 54040 | 89.7 | 35.18 | 13.13* | 22.65 |
| | Belgium | 32955 | 10398 | 10117 | 97.3 | 4.95 | 1.93 | 0.38 |
| | Sweden | 32750 | 9038 | 7619 | 84.3 | 4.36 | 2.12* | 0.21 |
| | Finland | 32467 | 5246 | 3274 | 62.4 | 2.49 | 1.13* | 1.48 |
| | France | 31846 | 60991 | 46780 | 76.7 | 33.06 | 10.58 | 11.89 |
| | Germany | 29913 | 82652 | 60667 | 73.4 | 46.62 | 6.53 | 3.97 |
| | Italy | 29189 | 58646 | 39645 | 67.6 | 31.79 | 9.22 | 17.30 |
| | Spain | 26792 | 43397 | 33285 | 76.7 | 25.91 | 12.69 | 12.67 |
| **Total/Average** | | **34928** | **365250** | **281574** | **77** | **207** | **65** | **74** |
| EU Group 2 | Greece | 23386 | 11100 | 6704 | 60.4 | 4.86 | 1.40* | 4.30 |
| (EUG2) | Slovenia | 22294 | 1999 | 990 | 49.5 | 0.85 | 0.24* | 0.66 |
| GDP | Portugal | 21168 | 10528 | 6064 | 57.6 | 4.70 | 1.60 | 2.93 |
| <25000 | Czech Republic | 20931 | 10192 | 7491 | 73.5 | 2.95 | 0.90* | 2.13 |
| | Cyprus | 19724 | 836 | 579 | 69.3 | 0.62 | 0.11* | 0.55 |
| | Malta | 19239 | 403 | 377 | 93.6 | 0.25 | 0.05* | 0.22 |
| | Hungary | 18257 | 10086 | 6687 | 66.3 | 4.64 | 1.35 | 3.85 |
| | Slovakia | 15991 | 5387 | 3027 | 56.2 | 1.56 | 0.44* | 1.23 |
| | Estonia | 15990 | 1344 | 933 | 69.4 | 0.59 | 0.10* | 0.37 |
| | Lithuania | 14538 | 3425 | 2281 | 66.6 | 1.29 | 0.21* | 1.17 |
| | Poland | 14156 | 38196 | 23491 | 61.5 | 9.36 | 3.08* | 8.63 |
| | Latvia | 13692 | 2302 | 1565 | 68 | 0.71 | 0.15* | 0.56 |
| | Bulgaria | 9220 | 7745 | 5437 | 70.2 | 3.68 | 0.42* | 3.14 |
| | Romania | 9067 | 21628 | 11614 | 53.7 | 8.15 | 1.17* | 6.40 |
| **Total/Average** | | **16975** | **125171** | **77241** | **65** | **44** | **11** | **36** |
| North Americas | US | 41410 | 299846 | 242276 | 80.8 | 222.90 | 55.73 | 121.03 |
| | Canada | 33400 | 32271 | 25849 | 80.1 | 13.40 | 3.22 | 8.05[e] |
| | Mexico | 10689 | 104266 | 79555 | 76.3 | 36.00 | 18.36 | 34.81[f] |

GDP - Gross domestic product; UP - Urban population; TP - Total population; MSW - Municipal solid waste; OW - Organic waste; [a]UN (2007); [b]World Population Prospects (2007); [c]Eurostat (2008); [d]OECD (2006/2007); *Estimated from Adhikari et al. (2006) with 2005 UOW and GDP data; [e]2004; [f]2006; MSW generated and landfilled data for North America from OECD (2006/2007).

Table 3: Municipal solid waste (MSW) composition for the EU and North America in 2005.

| Country | TMSWG million tonne | OW % | P&PB % | T&O % | GMP % | OW million tonne | P&PB million tonne | T&O million tonne | GMP million tonne |
|---|---|---|---|---|---|---|---|---|---|
| Luxembourg | 0.32 | 45 | 22 | 16 | 16.8 | 0.14 | 0.07 | 0.05 | 0.05 |
| Ireland | 3.07 | 25 | 31 | 23 | 20 | 0.77 | 0.95 | 0.71 | 0.61 |
| Denmark | 3.99 | 29 | 27 | 32 | 11.8 | 1.16 | 1.08 | 1.28 | 0.47 |
| Netherlands | 10.19 | 35 | 26 | 12 | 27 | 3.57 | 2.65 | 1.22 | 2.75 |
| Austria | 5.13 | 35 | 22 | 19 | 24 | 1.80 | 1.13 | 0.98 | 1.23 |
| Belgium | 4.95 | 39 | 17 | 29 | 15 | 1.93 | 0.84 | 1.44 | 0.74 |
| France | 33.06 | 32 | 20 | 26 | 22 | 10.58 | 6.61 | 8.59 | 7.27 |
| Germany | 46.62 | 14 | 34 | 12 | 39 | 6.53 | 15.85 | 5.59 | 18.18 |
| Italy | 31.79 | 29 | 28 | 22 | 20 | 9.22 | 8.90 | 6.99 | 6.36 |
| Spain | 25.91 | 49 | 21 | 7 | 24 | 12.69 | 5.44 | 1.81 | 6.22 |
| Hungary | 4.64 | 29 | 15 | 35 | 21 | 1.35 | 0.70 | 1.62 | 0.97 |
| Portugal | 4.70 | 34 | 21 | 23 | 22 | 1.60 | 0.99 | 1.08 | 1.03 |
| Slovakia | 1.56 | 38 | 13 | 31 | 18 | 0.59 | 0.20 | 0.48 | 0.28 |
| USA | 222.90 | 25 | 34 | 16 | 25 | 55.73 | 75.79 | 35.66 | 55.73 |
| Canada | 13.40 | 24 | 47 | 8 | 22 | 3.22 | 6.30 | 1.07 | 2.95 |
| Mexico | 36.00 | 51 | 15 | 16 | 15 | 18.36 | 5.40 | 5.76 | 5.40 |

Source: OECD (2006/2007); Eurostat (2008)

TMSWG - Total municipal solid waste generated; OW - Organic waste;

P&PB - Paper and cardboard; T&O - Textile and others; GMP - Glass, metal and plastics.

Table 4: Composting of urban organic waste (UOW) in some of the EU countries and Canada.

| Country | Composting million tonne | Composting % | Composting million tonne | Composting % |
|---|---|---|---|---|
| | 1995 | | 2005 | |
| Luxembourg | 0.02 | 7.04 | 0.06[b] | 19.28[b] |
| Ireland | - | - | 0.03[a] | 1.25[a] |
| Denmark | 0.32 | 10.69 | 0.55[b] | 15.28[b] |
| Netherlands | 2.01 | 23.72 | 2.38[c] | 23.49[c] |
| Austria | 0.94 | 26.56 | 2.06[c] | 44.7[c] |
| Belgium | 0.27 | 5.95 | 1.05[b] | 22.76[b] |
| France | 2.53 | 9.14 | 4.87 | 14.33 |
| Germany | 5.59 | 10.96 | 8.30[c] | 17.14[c] |
| Italy | 0.12 | 0.45 | 10.55 | 33.30 |
| Spain | 2.09 | 10.38 | 7.43[c] | 32.69[c] |
| Slovenia | 0.00 | 0.00 | 0.01[a] | 1.15[a] |
| Portugal | 0.50 | 12.90 | 0.31 | 6.26 |
| Hungary | - | - | 0.05[b] | 1.07[b] |
| Canada | - | - | 1.66[c] | 12.50[c] |

Source: OECD (2006/2007); Eurostat (2008)
UOW - Urban organic waste
[a]2002; [b]2003; [c]2004.

Table 5: Municipal Solid Waste (MSW) composting facilities in some EU countries and Canada.

| Country | No of composting facilities | Description | References |
|---|---|---|---|
| France | 119 | 65 mixed MSW and 54 source-separated urban organic waste (UOW) composting facilities. | ECN (2009) |
| Germany | 700-900 | Source separated UOW composting is the main focus in Germany for quality assurance. | ECN (2009) |
| Finland | 20 | In-vessel composting facilities with a capacity ranging from 5 to 35 million kg. | ECN (2009) |
| Canada | 54 | Composting of food waste from institutions, commercials & industries (IC&I) and residential sectors | Antler (2009) |

Table 6: Various scenarios for Urban Organic Waste (UOW) treatment strategies.

| Scenarios | LF % | CCF % | CCC % | HC % |
|---|---|---|---|---|
| **Base Scenario (Base Sce)** | 100 | 0 | 0 | 0 |
| **Scenario one (Sce 1)** | | | | |
| EUG1 | 42 | 57 | 0 | 1 |
| EUG2 | 84 | 15 | 0 | 1 |
| Canada | 56 | 43 | 0 | 1 |
| **Scenario two (Sce 2)** | | | | |
| **Year** | | | | |
| 2006 | 75 | 25 | 0 | 0 |
| 2009 | 50 | 50 | 0 | 0 |
| 2016 | 35 | 65 | 0 | 0 |
| 2020 | 25 | 75 | 0 | 0 |
| 2025 | 20 | 80 | 0 | 0 |
| **Scenario three (Sce 3)** | 0 | 10 | 30 | 60 |

LF - Landfilling; CCF - Centralized composting facility; CCC - Community composting Centre; HC - Home composters.

Table 7: Cost of landfilling and composting systems for urban organic waste (UOW).

| Costs ($ US tonne$^{-1}$ wet UOW) | LF[a] | CCF[b] | CCC | HC |
|---|---|---|---|---|
| **Collection** | **115** | **153** | 0 | 0 |
| **Capital costs** | | | | |
| Land acquisition | 2 | 4 | 0 | 0 |
| [h]Civil works | 19 | 17 | 20[c] | 0 |
| Equipments | 0 | 18 | 64[d] | 0 |
| Site assessment/restoration | 2 | 0 | 0 | 0 |
| After care | 7 | 0 | 0 | 0 |
| Compost bin | 0 | 0 | 0 | 31[f] |
| **Sub-total** | **30** | **39** | **84** | **31** |
| **Variable costs** | | | | |
| Annual maintenance | 0 | 7 | 0 | 0 |
| [i]Manpower/operation | 18 | 23 | 28[e] | 0 |
| Fuel and disposal of rejects | 0 | 19 | 0 | 0 |
| Training/Promotion | 0 | 0 | 6 | 11[g] |
| [j]Gas capturing | 2 | 0 | | |
| **Sub-total** | **20** | **49** | **34** | **11** |
| **Total** | **165** | **241** | **118** | **42** |

LF - Landfilling; CCF - Centralized Composting Facility; CCC - Community Composting Center; HC - Home Composter; UOW - Urban Organic Waste;

[a&b] values adjusted using an annual inflation rate of 2.5% from 2002 to 2009 and an exchange of $1.00 US = 0.72 € mid-month average for 2009 (Eunomia 2002; Bank of Canada 1995-2010); for EU, collection cost averaged from a range of $50 to $210 US tonne$^{-1}$ ; CCF increased by 33 % because of double collection at a lower frequency for MSW other than UOW; other costs for LF and CCF were based on UK and Italian values;

[c] Site preparation and installation costs for CCC of $40000 US (Eco- Quartier 2009);

[d] CCC costing $30000 US for 11.5 m$^3$ total capacity (Eco-Quartier 2009) serving 360 persons generating 0.63 kg UOW person$^{-1}$day$^{-1}$ (OECD 2006/2007);

[e] Annual management cost of $5700 US;

[f] Wooden 400L composting bin at $200 US (Recycle works Ltd 2010) serving 4 persons per household generating 0.63 kg UOW person$^{-1}$day$^{-1}$ (OECD 2006/2007);

[g] Promotion of bins and education of producer (Nash 1992);

[h] Civil works for LF including capital investment and interest;

[i] Manpower/operation for labour, power and equipment maintenance;

[j] Gas capturing cost consisting of vertical extraction wells at $246 US m$^{-1}$ drilling and installation cost with a 25 m influence radius, and at $525 US per wellhead assembly with piping and valves (CIWMB 2008), based on a landfill 15 m deep with an average waste density of 380 kg m$^{-3}$ (Peavy et al. 1985; Bhide 1994).

Table 8: Proposed community and home composting in Paris, France and Toronto, Canada.

| Description | Paris | | Toronto | |
|---|---|---|---|---|
| | [a]TP million(2005): | 10.4 | [a]TP million(2006): | 5.671 |
| | [a]Total area ($km^2$): | 3043 | [a]Total area ($km^2$): | 2279 |
| | % NUP: | 22 | % NUP: | 22 |
| | Population $km^{-2}$: | 3400 | Population $km^{-2}$: | 2500 |
| | [b]UOW$person^{-1}day^{-1}$: | 0.63 | UOW$person^{-1}day^{-1}$: | 0.63 |
| | CCC | HC | CCC | HC |
| [c] composting centre $km^{-2}$ | 2 | - | 1 | - |
| In-vessel composters $centre^{-1}$ | 3 | - | 2 | - |
| In-vessel composter size | 6 m long x 1.8 m diameter | - | 6 m long x 1.8 m diameter | - |
| [d] Compost bins $km^{-2}$ | - | 255 | - | 438 |
| Capacity of home composter $bin^{-1}$ | - | 400L | - | 400L |
| Composting costs | \$118 US $tonne^{-1}$ | \$42 US $tonne^{-1}$ | \$118 US $tonne^{-1}$ | \$42 US $tonne^{-1}$ |
| Total UOW composted $yr^{-1}$ $km^{-2}$ | 548 tonne | 235 tonne | 173 tonne | 403 tonne |
| Cost saving compared to landfilling | \$47 US $tonne^{-1}$ | \$123 US $tonne^{-1}$ | \$47 US $tonne^{-1}$ | \$123 US $tonne^{-1}$ |
| Cost saving compared to CCF | \$123 US $tonne^{-1}$ | \$199 US $tonne^{-1}$ | \$123 US $tonne^{-1}$ | \$199 US $tonne^{-1}$ |

TP - Total population; NUP - National urban population; UOW - Urban Organic Waste;
CCC - Community composting centre; HC - Home composter;
The density and capacity of CCC and HC corresponds to the waste generated by the population.
[a] Demographia (2009);
[b] OECD (2006/2007) and assuming same for Toronto;
[c] Assuming 70 % and 30 % population live in multi-storey buildings in Paris and Toronto, respectively; [d] Assuming 30 % and 70 % people live in single unit house in Paris and Toronto, respectively with 4 persons $household^{-1}$.