

**Emission of greenhouse gases from home aerobic composting,
anaerobic digestion and vermicomposting of household wastes in
Brisbane (Australia)**

Author

Chan, YC, Sinha, RK, Wang, W

Published

2011

Journal Title

Waste Management and Research

DOI

[10.1177/0734242X10375587](https://doi.org/10.1177/0734242X10375587)

Rights statement

© 2010 The Authors. This is the author-manuscript version of the paper. Reproduced in accordance with the copyright policy of the publisher. Please refer to the journal's website for access to the definitive, published version.

Downloaded from

<http://hdl.handle.net/10072/37594>

Griffith Research Online

<https://research-repository.griffith.edu.au>

1

2 Emission of greenhouse gases from home aerobic composting, anaerobic
3 digestion and vermicomposting of household wastes in Brisbane (Australia)

4

5 **Y.C. Chan^{1*}, R.K. Sinha¹, W. J. Wang²**

6

7 ¹Griffith University, Nathan, QLD 4111, Australia

8 ² Department of Environment and Resource Management, 80 Meiers Rd, Indooroopilly QLD 4068,
9 Australia

10

11 * Corresponding author. Fax: 617 37357459. Email address: a.chan@griffith.edu.au.

12

13

14 **Abstract**

15 This study investigated greenhouse gas (GHG) emissions from three different home waste treatment
16 methods in Brisbane, Australia. Gas samples were taken monthly from 34 backyard composting bins
17 from January to April 2009. Averaged over the study period, the aerobic composting bins released
18 lower amounts of CH₄ (2.2 mg m⁻² hr⁻¹) than the anaerobic digestion bins (9.5 mg m⁻² hr⁻¹) and the
19 vermicomposting bins (4.8 mg m⁻² hr⁻¹). The vermicomposting bins had lower N₂O emission rates (1.2
20 mg m⁻² hr⁻¹) than the others (1.5-1.6 mg m⁻² hr⁻¹). Total GHG emissions including both N₂O and CH₄
21 were 463, 504 and 694 mg CO₂-e m⁻² hr⁻¹ for vermicomposting, aerobic composting and anaerobic
22 digestion, respectively, with N₂O contributing >80% in the total budget. The GHG emissions varied
23 substantially with time and were regulated by temperature, moisture content and the waste properties,
24 indicating the potential to mitigate GHG emission through proper management of the composting
25 systems. Comparing to other mainstream municipal waste management options including centralised
26 composting and anaerobic digestion facilities, landfilling and incineration, home composting has the
27 potential to reduce GHG emissions through both lower on-site emissions and the minimal need for
28 transportation and processing. On account of the lower cost, our results suggested that home
29 composting provides an effective and feasible supplementary waste management method to
30 centralised facility in particular for cities with lower population density such as the Australian cities.

31

32 **Keywords:** greenhouse gases, home composting, vermicomposting, anaerobic digestion, organic
33 waste.

34

35 **Introduction**

36 Disposal of municipal solid waste (MSW) has been mainly through landfilling, incineration and
37 centralised composting and anaerobic digestion facilities in urban areas around the world. These
38 processes involve direct and indirect emissions of greenhouse gases (GHGs) including carbon dioxide
39 (CO₂), methane (CH₄), nitrous oxide (N₂O) and non-methane hydrocarbons (NMHCs) and contribute

40 to around 3-4% of the anthropogenic GHG emissions in terms of CO₂-equivalent (CO₂-e) (Pipatti and
41 Savolainen 1996, Papageorgiou et al. 2009, Australian Greenhouse Office 2007). More than 70% of
42 MSW is disposed of in landfills in Australian and overseas cities (Queensland Environmental
43 Protection Agency 2002; Aumonier 1996, Ernst 1990, Mohareb et al. 2008). Anaerobic decomposition
44 of these wastes in the landfills results in the emission of CH₄ and as such contributes significantly to
45 the global greenhouse budget (Hobson et al. 2005). Disposal of MSW contributed 17 million tonnes
46 CO₂-e of GHG emissions in Australia in 2005, equivalent to the emissions from 4 million cars or 2.6%
47 of the national emissions (Australian Greenhouse Office 2007).

48

49 Due to the challenge of climate change and other environmental concerns on landfills (Lisk 1991),
50 government authorities around the world have introduced regulations to phase out or reduce waste
51 going to landfills (Lee et al. 2007, Murphy and Power 2006, Department of Climate Change 2007) and
52 encouraged alternative waste management options (Nolan ITU Pty Ltd 2004). The reduction of
53 emissions from waste disposal has mainly been achieved by capturing the landfill gases and diversion
54 of MSW (mainly by paper and material recycling) (Australian Greenhouse Office 2007). Domestic
55 food and garden wastes contribute 15-70% of the MSW in urban areas. Composting of domestic
56 wastes in centralised facilities and/or at source by residents has been perceived to have great potential
57 in reducing GHG emissions (Tchobanoglous et al. 1993, Wei et al. 2000). For example, the Victorian,
58 New South Wales and South Australia Governments in Australia have set targets of increasing the
59 recycling rate to up to 75% by 2010 by promoting the composting of organic waste (Victorian
60 Government Department of Sustainability and Environment 2009, Department of Climate Change
61 2007, Zero Waste South Australia 2005).

62

63 Three types of methods are common for the recycling of organic wastes, namely aerobic composting,
64 anaerobic digestion and vermicomposting. In aerobic composting the waste is aerated by air flowing
65 constantly through the open system and by intermittent turning of the waste by the operator. Anaerobic
66 digestion is carried out in the oxygen deprived environment inside the closed chamber.
67 Vermicomposting is similar to aerobic composting except that the composting and aeration processes

68 are aided by the use of detritivorous worms. The type and emission rate of GHGs emitted from these
69 processes, in particular household practices, have not been well studied (He et al. 2000). There have
70 only been a small number of studies on the emission of GHGs from centralised composting and
71 anaerobic digestion facilities. The findings from these studies indicate that GHG emissions are
72 dependent on the method used and other factors such as the windrowing rate, age, depth, temperature
73 and pore space of the compost mix (He et al. 2000; Majumdar et al. 2006; Hobson et al. 2005; Amon
74 et al. 2006, Wihersaari 2005, Lundie & Peters 2005). Under aerobic composting conditions, the gas
75 emitted is mainly CO₂ rather than CH₄ (Majumdar et al. 2006). Since this CO₂ is biogenic in origin it
76 is usually not counted in the GHG emission budget (Intergovernmental Panel on Climate Change
77 2007, Department of Climate Change 2007). Emission of NMHCs has been found to be relatively
78 small compared to emissions of CH₄ and N₂O. Anaerobic digestion has been found to emit more CH₄
79 than aerated composting (Mata-Álvarez et al. 2000). These findings show that the use of different
80 methods under different conditions could result in very different type and amount of GHGs (Beck-
81 Friis et al. 2000). More information is required on the actual effectiveness of different methods and
82 conditions on GHG reduction.

83

84 The aim of this study was to investigate GHG emissions from different types of household organic
85 waste treatment methods (aerobic composting, anaerobic digestion and vermicomposting) in relation
86 to environmental conditions and the properties of the waste materials. The result will assist in the
87 identification of better MSW management systems and practices with maximum GHG mitigation
88 potential.

89

90 **Materials and methods**

91 **Experimental design**

92 This study was undertaken in 15 suburbs within 20 km from the Brisbane Central Business District
93 (27.5°S 153°E) in southeast Queensland of Australia (Figure 1). Brisbane has a population of 1.95
94 million and a population density of 380 people per km² in 2008 (Australian Bureau of Statistics 2009).

95 22 volunteer households with 11 aerobic composting bins, 12 anaerobic digestion bins and 11
96 vermicomposting bins in total were involved in this study. The bins were located either in the
97 backyard or front yard of the households.

98

99 (Figure 1 here)

100

101 Results of a survey conducted at the beginning of the study showed that the households in this study
102 composted on average 4-5 kg of food and green waste in each bin each week. Similar to those reported
103 in literature (Tchobanoglous et al. 1993), the waste the households composted in this study was about
104 50-70% food waste (mainly fruits and vegetables remnants and food left-over) and 30-50% green
105 waste (mainly grass clipping). The actual mass and composition of waste and the maintenance of the
106 bins varied among the volunteers. Most of the volunteers added the waste daily and retrieved the
107 compost products monthly.

108

109 The bins used were commercially available from hardware stores with a volume of approximately 220
110 L (Figure 2). The aerobic bins have ventilation slots to facilitate airflow through them. The anaerobic
111 bins were only opened during the addition of waste and retrieval of compost, and represent an
112 anaerobic digester when the lid is closed. The vermicomposting bins are similar in structure to the
113 aerobic bins but with a reservoir at the bottom to collect the leachates. The vermicomposting bins
114 normally contained approximately 1500-2000 worms. Tiger Worm (*Eisenia fetida*), Indian Blue
115 Worm (*Perionyx excavatus*), African Night Crawler (*Eudrilus euginae*) and Red Worm (*Lumbricus*
116 *rebellus*) were the main worm species found in the vermicomposting bins in this study (Sinha et al.
117 2002). General instructions and guidance were also provided to the volunteers on the proper operation
118 of the three types of systems. The vermicomposting bins were placed in shaded area. Meat products
119 were not used, while dried grass clippings (high in carbon) were added to the food wastes (high in
120 nitrogen) to maintain a carbon to nitrogen (C/N) ratio close to 25 to 1. Bulking agents such as mulches
121 were also added in aerobic composting and vermicomposting bins to increase air pockets. Waste in the
122 aerobic composting bins was turned weekly. Water was sprinkled in the bins to maintain a moisture

123 content of 50-60% for the aerobic composting and anaerobic digestion bins and 60-70% for the
124 vermicomposting bins. A two-bin rotating system was also recommended to allow 2-3 months for the
125 compost to mature, although most of households in this study operated only one bin.

126

127 (Figure 2 here)

128

129 **Sampling of CO₂, CH₄ and N₂O**

130 Gas samples were collected during the last weekend of each month during January-April 2009. This
131 period covers the humid summer and autumn seasons in Brisbane. In total 132 samplings were
132 conducted (43 from aerobic bins, 45 from anaerobic bins and 44 from vermicomposting bins). Gas
133 samples were taken by using the static chamber method (Zhang et al. 2008). A 0.7 L glass funnel with
134 the stem cut off and replaced with a removable septum was used as the collection chamber (Figure 2).
135 Duplicate sampling from different areas on the waste surface indicates good precision in results
136 (relative standard deviation < 25% in general).

137

138 In each sampling, the inverted funnel with the septum removed was first pushed approximately 1 cm
139 deep into the waste surface inside the bin. The rim of the funnel was wrapped around with waste and
140 water applied if needed to provide a good air seal. The open funnel was left inside the bin with the lid
141 of the bin closed for approximately 5 minutes before the septum was put back onto the funnel. Then
142 the first air sample was taken from inside the funnel by inserting a 30 mL syringe through the septum.
143 The air sample was then transferred from the syringe into an evacuated container. The bin was closed
144 again for approximately 30 minutes then the second air sample was taken. Results from preliminary
145 samplings show that the 30-minute duration was sufficient to produce precise results comparable to
146 the results of longer duration.

147

148 Environmental and waste parameters including ambient temperature, temperature near the waste
149 surface (at 2 cm below the surface) and inside the waste (at 8 cm below the surface), and the pH and
150 moisture content in the waste were also determined. pH and moisture content were determined with a

151 soil pH and moisture tester (Takemura Electric Works Model DM-15) by inserting the tester at 3
152 random positions to approximately 7 cm deep into the surface. DM-15 scales moisture content from 1
153 to 8. Most of the composting bins in this study returned a high moisture scale of 8 or beyond. Moisture
154 scale readings beyond 8 were treated as 9 in the statistical analysis. The measured values from the
155 replicate samplings were within ± 2.8 °C, ± 1.0 pH and ± 1.2 moisture scale. Measurements of a set of
156 compost-water mixtures with varying mass percentage of moisture showed that moisture scale 1 was
157 equivalent to a moisture content of approximately 20%, while moisture scale 8 was equivalent to
158 approximately 33%.

159

160 **Analysis of CO₂, CH₄ and N₂O and estimation of GHG emission rates**

161 The gas samples in the containers were analysed by a gas chromatograph (Varian 3800) within one
162 week after the sampling. The Gas Chromatograph was equipped with a Thermal Conductivity Detector
163 (GC-TCD), a Flame Ionisation Detector (GC-FID) and an Electron Capture Detector (GC-ECD) for
164 the analysis of CO₂, CH₄ and N₂O, respectively. Dual Porapak columns using helium as the carrier gas
165 for CO₂ and CH₄, and nitrogen as the carrier gas for N₂O were used in the analysis. CO₂ standards of
166 513, 1000, 2009 and 4020 ppm were used for the calibration of results, while 1.8 and 5.1 ppm
167 standards were used for CH₄ and 0.50, 5.02, 12.1 and 18.7 ppm standards were used for N₂O.

168

169 The concentrations of CO₂, CH₄ and N₂O in the two samples collected from each sampling were used
170 to estimate the emission rate of the GHGs from the bin. The emission rate in mg m⁻² hr⁻¹ was
171 calculated by Eq. 1, based on the Ideal Gas Equation:

172

$$173 \quad \text{Rate (mg m}^{-2} \text{ hr}^{-1}) = (C_2 - C_1) \times MW \times V / (0.08206 \times T \times A_1 \times D) \quad (1)$$

174

175 where C₁ and C₂ are the concentrations of the GHG in ppm in the two samples. MW is the molecular
176 weight of the GHG. V is the volume of air above the waste surface inside the funnel = 5.44×10^{-4} m³.
177 A₁ is the area of the waste surface inside the funnel = 1.42×10^{-2} m² (Figure 2). T is the temperature in

178 Kelvin. D is the duration between the two samples in hour. The emission rate in terms of kg GHG kg⁻¹
179 waste was estimated by Eq. 2:

$$181 \quad \text{Rate (kg GHG kg}^{-1} \text{ waste)} = \text{Rate (mg m}^{-2} \text{ hr}^{-1}) \times A_2 \times 24 \times 7 \times 10^{-6} / W \quad (2)$$

182
183 Where A_2 is the area of the waste surface inside the composting bin and W is the amount of food and
184 green waste treated each week. The area of the waste surface was approximately 0.24 m² for the
185 anaerobic bins and 0.25 m² for the aerobic and vermicomposting bins. The volunteers in this study
186 added waste and retrieved compost products on a regular basis and W was assumed to be 4.5 kg. The
187 CO₂-equivalents (CO₂-e) of CH₄ and N₂O were estimated using the global warming potential of 21
188 and 310, respectively (Intergovernmental Panel on Climate Change 2007).

189 190 **Statistical analysis**

191 Five of the 132 samplings conducted were found to have extreme CH₄ and/or N₂O emission rate
192 values (beyond average + 4 s.d.) and were thus excluded from the statistical analysis. All the measured
193 parameters were tested for normality by using the Kolmogorov-Smirnov test (Beck-Friis et al. 2000).
194 At the significance level of 0.05, the emission rates of CO₂, CH₄ and N₂O were found to be
195 lognormally distributed, and consequently the natural logarithmic values of these parameters were
196 used in statistical comparison.

197
198 Pearson correlation analysis was used to investigate the correlation between the emission rates of the
199 GHGs and the other measured parameters (Beck-Friis et al. 2000). ANOVA F-test was used to
200 identify the influencing factors (waste treatment method, month of sampling and time of the day of
201 sampling) of the GHG emission rates. Then t-test (Least Significant Difference, LSD) was used to
202 investigate the influence of the identified factors on the emission rates. The significance level of 0.05
203 was used in these statistical tests. In this study, the samplings were conducted between 8 am and 7 pm,
204 therefore the time of the day of sampling was categorised as 'am' (8- 10 am), 'noon' (11 am – 1 pm),
205 'pm' (2 – 4 pm) or 'late pm' (5 – 7 pm).

206

207 **Results and Discussion**

208 **Emission rates of GHGs**

209 A summary of the GHG emission rates and the environmental and waste parameters measured in this
210 study is listed in Table 1. Anaerobic bins and vermicomposting bins emitted significantly higher
211 amounts of CO₂ and CH₄ than the aerobic bins. This indicates that anaerobic bins and
212 vermicomposting bins were more efficient in decomposing the carbon in waste into CO₂ and more
213 favourable for CH₄ production than the aerobic bins.

214

215 (Table 1 here)

216

217 On the other hand, aerobic bins and anaerobic bins emitted significantly higher amounts of N₂O than
218 the vermicomposting bins. Presumably, the N₂O emitted from the composting bins were mainly from
219 the denitrifying process in anaerobic zones in the compost, but might also be created in the nitrifying
220 process in aerobic zones (Beck-Friis et al. 2000) and the activities of the denitrifying bacteria within
221 the earthworm gut (Hobson et al. 2005). The lower emission of N₂O from vermicomposting bins
222 indicated that the emission of N₂O from worm gut was probably offset by the reduction of anaerobic
223 denitrification, due to the burrowing action of the earthworms.

224

225 On the contrary, Hobson et al. (2005) found that for larger scale systems windrow composting emits
226 more CH₄ but less N₂O than vermicomposting. This indicates that the process and rate of
227 decomposition of organic materials in larger scale systems could be very different to those in home
228 systems, due to the different level of ventilation and different worm density in the two types of
229 systems. Beck-Friis et al. (2000) found that the co-existence of both anaerobic and aerobic conditions
230 is not apparent in small, intensively managed compost heaps, therefore resulting in less CH₄ and N₂O
231 emissions. In their study, a very high level of CH₄ emission was found from large compost heaps.
232 They also found that N₂O emissions tend to be higher in compost heaps after prolonged storage. In this

233 sense home composting systems reduce N₂O emissions because the owners retrieve compost products
234 more frequently.

235

236 In terms of CO₂-e, CO₂ emissions contributed approximately 64% on average of the total GHG
237 emissions in the aerobic bins, and about 80% of the total GHG emissions in the anaerobic bins and
238 vermicomposting bins. When CO₂ emission was excluded from the accounting as is common practice,
239 the three waste treatment methods emitted 463-694 mg CO₂-e m⁻² hr⁻¹ on average, largely attributable
240 to N₂O emissions. LSD t-test showed that in terms of CO₂-e and with CO₂ emission included,
241 anaerobic bins and vermicomposting bins emitted significantly higher amount of GHGs than the
242 aerobic bins. But when CO₂ emission is excluded, there was no significant difference in the total GHG
243 emissions between the 3 waste treatment methods.

244

245 **Variation in GHG emissions in relation to environmental conditions and waste** 246 **properties**

247 The environmental conditions and waste properties for the three waste treatment methods are shown in
248 Table 2. The temperature inside the waste in this study (26-48 °C) was lower than the optimum
249 temperature (45-55 °C) suggested by Jäckel et al. (2005) for the oxidation of CH₄. However, given the
250 much smaller size of the waste heaps for the home systems, attaining the optimum temperature may
251 not be possible under normal circumstances. The temperature at 8 cm below the waste surface was
252 higher than that at 2 cm below the waste surface in the aerobic and anaerobic bins. They were
253 correlated to and higher than the ambient temperature ($r>0.32$), reflecting the biological activities in
254 the waste. However, in the vermicomposting bins the temperature inside the waste was rather uniform
255 and slightly lower than the ambient temperature. This could be due to the movement of the
256 earthworms inside the waste making the temperature in the waste more uniform. Also the owners of
257 the vermicomposting bins tend to moisturise their bins more often, therefore effectively reducing the
258 temperature in the waste in the summer months. The moisture content was also significantly higher in
259 the vermicomposting bins.

260
261
262
263
264
265
266
267
268
269
270
271
272
273
274
275
276
277
278
279
280
281
282
283
284
285
286
287

(Table 2 here)

The pH value of the waste was acidic to neutral (5.8-7.0) in all the waste treatment methods, which was within the range of international control standards on pH of composts (6.0-8.5; Wei et al. 2000, Tsai 2008).

Large variation in emission rates has been reported by other researchers for samples taken at different time of the day (Christensen et al. 1996). The temporal trends of GHG emissions in this study are shown in Table 3. The emission of CO₂ was not significantly different in the different months, and was higher at noon and lower in late afternoon. This is probably due to the higher temperature at noon speeding up the decomposition of organic material in waste. On the other hand the emissions of CH₄ and N₂O did not show any consistent temporal trends.

(Table 3 here)

In the aerobic composting and vermicomposting bins, CO₂ ($r>0.45$) and CH₄ ($r>0.63$) emissions were related to the temperature inside the waste, while N₂O emission was not. These findings are different to those of Beck-Friis et al. (2000) and Amlinger et al. (2008) in which N₂O emission was found to be related to waste temperature, perhaps because of the different size of the compost heaps in their studies and this study. Higher emission of CH₄ from wet waste stock has been reported by Brown and Subler (2007) but this relationship was not significant in this study. In the anaerobic bins, CO₂ emission was correlated to both the temperature ($r>0.33$) and moisture content ($r=0.32$) inside the waste. CH₄ emission correlated to moisture content only ($r=0.32$), while N₂O emission correlated to temperature in the waste only ($r>0.48$). There were smaller variations in temperature, pH and moisture content in the vermicomposting bins. No significant relationship between these factors and CO₂ and N₂O emissions was found, but CH₄ emission increased with increasing temperature in the vermicompost ($r>0.40$).

288

289 **Implications on the environmental benefits of home aerobic composting,**
290 **vermicomposting and anaerobic digestion**

291 The equivalent emission rate of GHGs in kg CO₂-e kg⁻¹ waste for the 3 waste treatment methods,
292 excluding CO₂ emissions, are listed in Table 1. The average GHG emissions from the home systems in
293 this study (0.0043-0.0062 kg CO₂-e kg⁻¹ waste) were generally lower than those estimated in studies of
294 the centralised waste management options (Mata-Álvarez et al. 2000, Fukumoto et al. 2003,
295 Department of Climate Change 2008, Amlinger et al. 2008, Lou and Nair 2009). These studies were
296 generally based on the life cycle analysis approach, using default GHG emission factors for MSW
297 (Intergovernmental Panel on Climate Change 2007, Department of Climate Change 2007). For
298 example, in the case of landfilling, the emission of N₂O is regarded as negligible (Pipatti and
299 Savolainen 1996, Department of Climate Change 2007). There are no GHG emission rate values
300 available for household systems in these protocols. This raises the question of the applicability of these
301 default average GHG emission rates to different waste treatment processes and under different climate
302 conditions (Beck-Friis et al. 2000).

303

304 Although life cycle analysis is beyond the scope of this study, the findings from this study have
305 implications on the environmental benefits of home aerobic composting, vermicomposting and
306 anaerobic digestion of MSW in countries such as Australia. Results from life cycle analysis studies
307 often indicate centralised composting and anaerobic digestion facilities as preferable to landfilling and
308 incineration, due to lower GHG emissions in the processes and the higher potential of recovery of
309 methane gas for fuel use (Murphy and Power 2006). It has been found that for a centralised
310 composting facility, the GHG emissions due to kerbside separation and collection of waste and the use
311 of machinery for processing and turning the waste at the facility could contribute a considerable
312 amount of GHG emissions (Lou and Nair 2009, Lundie and Peters 2005). Apart from greenhouse
313 impacts, the waste separation, transportation and processing activities contribute substantially to the
314 management cost. For example, in Victoria (Australia) the cost of kerbside collection is approximately

315 18% of the management costs (Victorian Government Department of Sustainability and Environment
316 2009). This cost is particularly higher for cities with low population density, such as Australian cities
317 (Lundie and Peters 2005, Victorian Government Department of Sustainability and Environment 2009).
318 Home composting of organic waste in urban areas will reduce the GHG emissions and cost not only
319 from the above mentioned processes, but also from transportation of compost products and chemical
320 fertilisers to the households and crop growers (Lou and Nair 2009).

321

322 As discussed in the previous section, all the 3 types of systems investigated in this study have similar
323 potential in reducing GHG impacts compared to the other waste treatment options. However, the
324 findings from this study show that properly maintained vermicomposting systems have a greater
325 potential of reducing N₂O emissions whilst producing more neutral compost products compared to the
326 other methods. Vermicomposting also results in more efficient digestion of the carbon content in
327 organic waste. As such the compost products from these processes should have lower C/N ratios and
328 better quality. In addition, Mitchell et al. (1980) found that earthworms also decrease emission of
329 volatile sulfur compounds which are readily emitted from the conventional microbial composting
330 process. Lazcano et al. (2008) found that earthworms promote the retention of nitrogen and gradual
331 release of phosphorus as well as reduction in electrical conductivity, therefore producing improved
332 organic fertilizers for agricultural uses as compared to aerobic thermophilic composting.

333

334 According to the Queensland Environmental Protection Agency (2002), about half of the domestic
335 solid wastes in Brisbane are food and green waste. Approximately 130 kg green waste and 190 kg
336 food waste were generated per person per year in Queensland (Australia). This is equivalent to about
337 3.5 kg green and food waste per day for a typical family of 2 adults and 2 children. From the survey
338 and observation made in the study, the households composted approximately 4-5 kg of food and green
339 waste each week on average. This amount is equivalent to about 20% of the food/green waste
340 generated and is also well within the typical treatment capacity of 30-50 kg per month of the home
341 systems. A combination of home composting and other MSW management alternatives including

342 recycling and centralised composting and anaerobic digestion will have a great potential in reducing
343 the GHG impact and management cost in the waste sector.

344

345 **Conclusion**

346 This study investigated the rate of emission of GHGs from different types of home composting bins.
347 On average, aerobic composting, anaerobic digestion and vermicomposting bins released 504, 694 and
348 463 CO₂-e m⁻² hr⁻¹ as N₂O and CH₄, with N₂O accounting for >80% of total emissions. These emission
349 rates are equivalent to 0.0043-0.0062 kg CO₂-e kg⁻¹ waste of GHGs assuming 4.5 kg green wastes
350 were processed in each bin each week. Among the 3 types of bins, vermicomposting bins had the
351 lowest emission of N₂O.

352

353 The GHG emissions generally increased with increasing temperature and/or moisture content. This
354 indicates the importance of proper maintenance of the bins to minimise GHG emissions. Overall,
355 vermicomposting provides more stable and favourable composting conditions than the other two
356 systems.

357

358 The findings from this study indicate that smaller scale home systems tend to emit less GHGs when
359 compared with larger scale systems. Other studies on the environmental impacts of the mainstream
360 MSW management options have found centralised composting and anaerobic digestion facilities
361 preferable to landfilling and incineration. Home composting and anaerobic digestion have the potential
362 to further reduce GHG emissions associated with separation, transport and processing of the wastes as
363 well as transport of the compost products and fertilisers to the users. Among the 3 systems,
364 vermicomposting has greater potential to provide better composting conditions and compost products
365 with lower carbon/nitrogen ratio.

366

367 **Acknowledgements**

368 Special thanks to the Brisbane households who participated in the sampling program. Also thanks to
369 Mr Kurnal Chauhan and Mr Kulvaibhav Singh for conducting the sampling program and to Mr Steven
370 Reeves for analysing the gas samples and proof reading the manuscript. This project was supported by
371 the NRMA Insurance's Community Help Grants Program 2008.

372

373 **References**

374 Amlinger, F. Peyr, S. & Cuhls, C. (2008) Greenhouse gas emissions from composting and mechanical
375 biological treatment. *Waste Management and Research*, 26, 47-60.

376 Amon, B., Kryvoruchko, V., Amon, T. & Sechmeister-Boltenstern, S. (2006) Methane, nitrous oxide
377 and ammonia emissions during storage and after application of dairy cattle slurry and influence of
378 slurry treatment. *Agriculture, Ecosystems and Environment*, 112, 153-162.

379 Australian Greenhouse Office (2007) *National Greenhouse Gas Inventory 2005*. Australian
380 Greenhouse Office.

381 Aumonier, S. (1996) The greenhouse gas consequences of waste management – identifying preferred
382 options. *Energy Conversion Management*, 37, 1117-1122.

383 Australian Bureau of Statistics (2009) <http://www.abs.gov.au/>. (October 1, 2009)

384 Beck-Friis, B., Sonesson, U., Jönsson, H. & Kirchmann, H. (2000) Formation and emission of N₂O
385 and CH₄ from compost heaps of organic household waste. *Environmental Monitoring and Assessment*,
386 62, 317-331.

387 Brown, A. & Subler, S. (2007) Composting and greenhouse gas emissions: a producer's perspective.
388 *Biocycle*, March/2007, 37-41.

389 Christensen, S., Ambus, P., Arah, J., Clayton, H., Galle, B., Griffith, D., Hargreaves, K., Klemedtsson,
390 L., Lind, A., Maag, M., Scott, A., Skiba, U., Smith, K., Welling, M. & Wienhold, F. (1996) Nitrous
391 oxide emission from an agricultural field: comparison between measurements by flux chamber and
392 micrometeorological techniques. *Atmospheric Environment*, 30, 4183-4190.

393 Department of Climate Change (2007) *Australian methodology for the estimation of greenhouse gas*
394 *emissions and sinks 2006*. National Greenhouse Gas Inventory Committee.

395 Department of Climate Change (2008) *National Greenhouse and Energy Reporting (Measurement)*
396 *Determination*. Chapter 5. Waste. Department of Climate Change.

397 Ernst, A.A. (1990) A review of solid waste management by composting in Europe. *Resources,*
398 *Conservation and Recycling*, 4, 135-149.

399 Fukumoto, Y., Osada, T., Hanajima, D. & Haga, K. (2003) Patterns and quantities of NH₃, N₂O and
400 CH₄ emissions during swine manure composting without forced aeration – effect of compost pile
401 scale. *Bioresource Technology*, 89, 109-114.

402 He, Y., Inamori, Y., Mizuochi, M., Kong H., Iwami, N. & Zun, T. (2000) Measurements of N₂O and
403 CH₄ from the aerated composting of food waste. *The Science of the Total Environment*, 254, 65-74.

404 Hobson, A., Frederickson, J. & Dise, N. (2005) CH₄ and N₂O from mechanically turned windrow and
405 vermicomposting systems following in-vessel pre-treatment. *Waste Management*, 25, 345-352.

406 Intergovernmental Panel on Climate Change (2007) *Climate Change 2007: The Physical Science*
407 *Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental*
408 *Panel on Climate Change*. Chapter 2. Changes in Atmospheric Constituents and in Radiative Forcing.
409 Cambridge University Press.

410 Jäckel, U., Thummes, K. & Kämpfer, P. (2005) Thermophilic methane production and oxidation in
411 compost. *FEMS Microbiology Ecology*, 52, 175-184.

412 Lazcano, C., Gómez-Brandón, M. & Domínguez, J. (2008) Comparison of the effectiveness of
413 composting and vermicomposting for the biological stabilization of cattle manure. *Chemosphere*,
414 1013-1019.

415 Lee, S.H., Choi, K.I., Osako, M. & Dong, J.I. (2007) Evaluation of environmental burdens caused by
416 changes of food waste management systems in Seoul, Korea. *Science of the Total Environment*, 387,
417 42-53.

418 Lisk, D.J. (1991) Environmental effects of landfills. *The Science of the Total Environment*, 100, 415-
419 468.

420 Lou, X.F. & Nair, J. (2009) The impact of landfilling and composting on greenhouse gas emissions – a
421 review. *Bioresource Technology*, 100, 3792-3798.

422 Lundie, S. & Peters, G. (2005) Life cycle assessment of food waste management options. *Journal of*
423 *Cleaner Production*, 13, 275-286.

424 Majumdar, D., Patel, J., Bhatt, N. & Desai, P. (2006) Emission of methane and carbon dioxide and
425 earthworm survival during composting of pharmaceutical sludge and spent mycelia. *Bioresource*
426 *Technology*, 97, 648-658.

427 Mata-Álvarez, J., Mace, S. & Llabrés, P. (2000) Anaerobic digestion of organic solid wastes. An
428 overview of research achievements and perspectives. *Bioresource Technology*, 74, 3-16.

429 Mitchell, M.J., Horner, S.G. & Abrams, B.L. (1980): Decomposition of Sewerage Sludge in Drying
430 Beds and the Potential Role of the Earthworm *Elsenia fetida*; *Journal of Environmental Quality*, Vol.
431 9; pp. 373-378.

432 Mohareb, A.K., Warith, M.A. & Diaz, R. (2008) Modelling greenhouse gas emissions for municipal
433 solid waste management strategies in Ottawa, Ontario, Canada. *Resources, Conservation and*
434 *Recycling*, 52, 1241-1251.

435 Murphy, J.D. & Power, N.M. (2006) A technical, economic and environmental comparison of
436 composting and anaerobic digestion of biodegradable municipal waste. *Journal of Environmental*
437 *Science and Health Part A*, 41, 865-879.

438 Nolan ITU Pty Ltd (2004) *Assessment of domestic waste and recycling systems. Final report*. New
439 South Wales Department of Environment and Conservation.

440 Papageorgiou, A., Barton, J.R. & Karagiannidis, A. (2009) Assessment of the greenhouse effect
441 impact of technologies for energy recovery from municipal waste: A case for England. *Journal of*
442 *Environmental Management*, 90, 2999-3012.

443 Pipatti, R. & Savolainen, I. (1996) Role of energy production in the control of greenhouse gas
444 emissions from waste management. *Energy Conversion Management*, 37, 1105-1110.

445 Queensland Environmental Protection Agency (2002) *Green and organic waste processing and*
446 *marketing in Queensland*. Queensland Environmental Protection Agency.

447 Sinha, R.K., Herat, S., Agarwal, S., Asadi, R. & Carretero, E. (2002) Vermiculture technology for
448 environmental management: study of action of earthworms *Elsinia foetida*, *Eudrilus euginae* and
449 *Perionyx excavatus* on biodegradation of some community wastes in India and Australia; *The*

450 *Environmentalist*, 22(2), 261 – 268.

451 Tchobanoglous, G., Theisen, H. & Vigil, S. (1993) *Integrated solid waste management: engineering*
452 *principles and management issues*. McGraw-Hill.

453 Tsai, W.T. (2008) Management considerations and environmental benefit analysis for turning food
454 garbage into agricultural resources. *Bioresource Technology*, 99, 5309-5316.

455 Victorian Government Department of Sustainability and Environment (2009) *Metropolitan Waste and*
456 *Resource Recovery Strategic Plan*. Victorian Government Department of Sustainability and
457 Environment.

458 Wei, Y.S., Fan, Y.B., Wang, M.J. & Wang, J.S. (2000) Composting and compost application in China.
459 *Resources, Conservation and Recycling*, 30, 277-300.

460 Wihersaari, M. (2005) Evaluation of greenhouse gas emission risks from storage of wood residue.
461 *Biomass and Bioenergy*, 28, 444-453.

462 Zero Waste South Australia (2005) *South Australia's Waste Strategy 2005-2010*. Zero Waste South
463 Australia.

464 Zhang, H., He, P., Shao, L., Qu, X. & Lee, D. (2008) Minimizing N₂O fluxes from full-scale
465 municipal solid waste landfill with properly selected cover soil. *Journal of Environmental Sciences*,
466 20, 189-194.

467

468

469 Figure 1. The 15 Brisbane suburbs of the volunteer households in this study (represented by the round
470 dots in the figure)

471 Figure 2. Examples of anaerobic digester, aerobic composting and vermicomposting bins (a), and
472 funnel static chamber used to collect the greenhouse gas samples (b)

473

474 Table 1. Summary of GHG emission rates and regulating factors (min - max values in bracket)

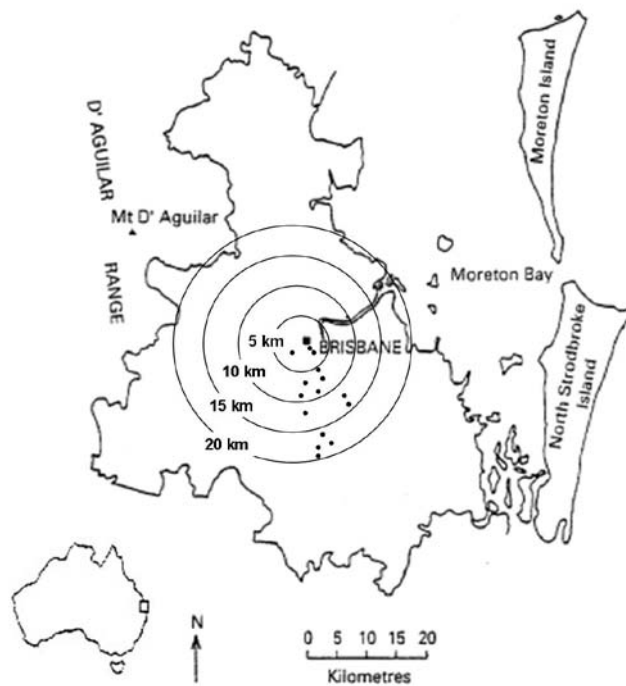
475 Table 2. Comparison of the environmental conditions and waste properties for different composting
476 systems and at different times

477 Table 3. Temporal variations in GHG emissions (averages in $\text{mg CO}_2\text{-e m}^{-2}\text{ hr}^{-1}$)

478

479

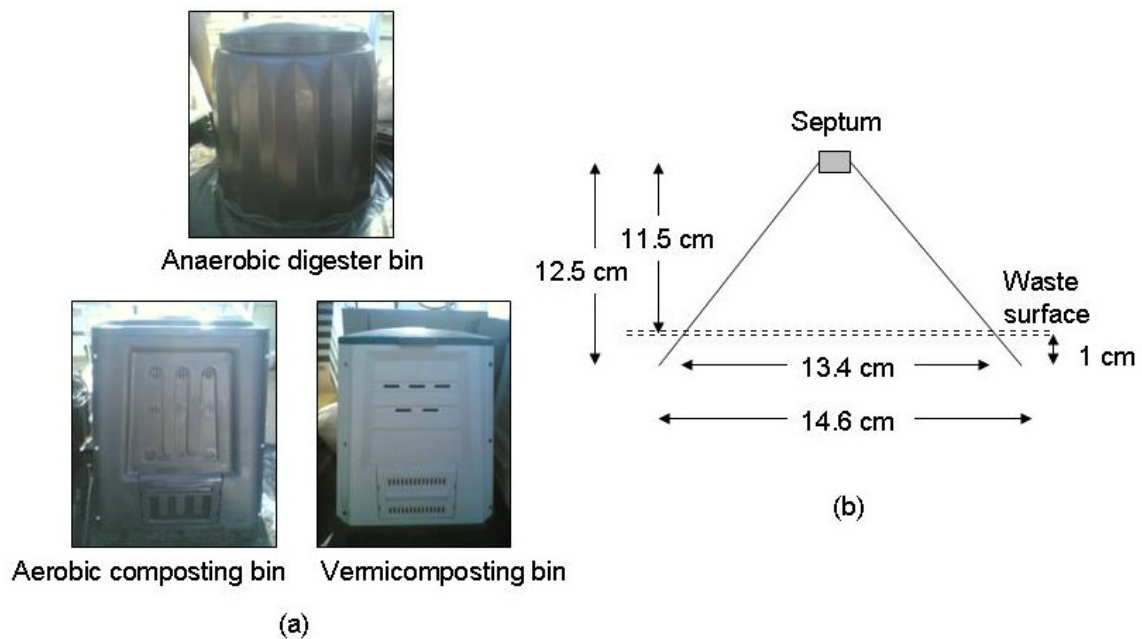
480 Figure 1. The 15 Brisbane suburbs of the volunteer households in this study (represented by the round
481 dots in the figure)



482

483

484 Figure 2. Examples of anaerobic digester, aerobic composting and vermicomposting bins (a), and
485 funnel static chamber used to collect the greenhouse gas samples (b)



486

487

488 Table 1. Summary of GHG emission rates and regulating factors (min - max values in bracket)

Parameters	Aerobic bins	Anaerobic bins	Vermicomposting bins	
Number of samples	40	45	42	
GHG emissions (mg m ⁻² hr ⁻¹)				
CO ₂ ¹	882 ^B (23 – 5764)	2950 ^A (91 – 10069)	1675 ^A (146 – 5669)	
CH ₄ ²	2.17 ^B (0.00 – 38.05)	9.54 ^A (0.00 – 52.90)	4.76 ^A (0.00 – 40.89)	
N ₂ O ³	1.48 ^A (0.01 – 16.25)	1.59 ^A (0.00 – 16.37)	1.17 ^B (0.00 – 24.78)	
Total emissions (mg CO ₂ -e m ⁻² hr ⁻¹)				
Excluding CO ₂	504 (4 – 5038)	694 (0.76 – 5073)	463 (4 – 8475)	
Including CO ₂ ⁴	1386 ^B (28 – 7554)	3644 ^A (259 – 14351)	2138 ^A (189 – 14144)	
Average % of GHG emissions				
Excluding CO ₂	CH ₄	9.1	28.8	21.7
	N ₂ O	90.9	71.2	78.3
Including CO ₂	CO ₂	63.6	80.9	78.3
	CH ₄	3.3	5.5	4.7
	N ₂ O	33.1	13.6	17.0
Average GHG emissions (kg CO ₂ -e kg ⁻¹ waste)				
Excluding CO ₂	0.0047	0.0062	0.0043	
Ambient temperature (°C)	28.7 (20.0 – 35.0)	28.1 (20.0 – 34.5)	28.5 (20.0 – 34.0)	
Temperature below 2 cm (°C)	30.2 (26.0 – 41.5)	31.6 (24.0 – 45.0)	26.9 (22.5 – 32.0)	
Temperature below 8 cm (°C)	31.2 (26.0 – 48.0)	32.4 (25.0 – 46.0)	27.1 (22.0 – 31.0)	
pH	5.7 (3.1 – 6.7)	5.9 (4.1 – 6.7)	6.6 (5.8 – 7.0)	
Moisture scale	6.4 (2.0 – 9.0)	6.8 (2.0 – 9.0)	8.2 (2.9 – 9.0)	
Equivalent moisture content (%)	31 (25 – >33)	31 (25 – >33)	32 (26 – >33)	

489 Remarks: ¹ LSD t-test shown that the waste treatment methods denoted by a superscript ‘A’ on their
490 CO₂ emission values emitted significantly more CO₂ on average than those denoted by a superscript
491 ‘B’ at the significance level of 0.05; ^{2,3,4} and similarly for CH₄, N₂O and total emissions.

492 Table 2. Comparison of the average environmental conditions and waste properties for different
 493 composting systems and at different times

	Ambient temperature (°C) ¹	Temperature at 2 cm below the waste surface (°C) ²	Temperature at 8 cm below the waste surface (°C) ³	pH ⁴	Moisture scale (Equivalent % moisture) ⁵
Aerobic	28.7	30.2 ^A	31.2 ^A	5.7 ^C	6.4 (31) ^B
Anaerobic	28.1	31.6 ^A	32.4 ^A	5.9 ^B	6.8 (31) ^B
Vermicomposting	28.5	26.9 ^B	27.1 ^B	6.6 ^A	8.2 (>33) ^A
January	25.9 ^B	30.1	31.5 ^A	5.8 ^B	8.0 (>33) ^A
February	31.3 ^A	30.6 ^A	30.9	6.1 ^A	7.4 (31) ^D
March	29.8 ^A	29.2	29.8	6.2 ^A	6.2 (31) ^{B,E}
April	26.2 ^B	28.5 ^B	28.7 ^B	6.1 ^A	6.9 (31) ^B
am	29.3 ^A	29.0	29.6	5.9 ^A	5.9 (30) ^{B,E}
noon	29.3 ^A	30.0	30.7	6.3 ^A	7.4 (31) ^D
pm	30.0 ^A	30.1	30.6	6.1 ^A	6.8 (31) ^B
late pm	22.4 ^B	28.3	29.1	5.6 ^B	8.2 (>33) ^A

494 Remarks:

495 ^{1,2,3} The waste treatment methods (and similarly the months and the times of the day) denoted by a
 496 superscript 'A' on the temperature values were significantly higher in the temperature on average than
 497 those denoted by a superscript 'B', and so forth; ^{4,5} and similarly for pH and moisture scale. Also those
 498 denoted by a superscript 'D' were significantly higher in moisture scale on average than those denoted
 499 by a superscript 'E'.

500

501 Table 3. Temporal variations in GHG emissions (averages in mg CO₂-e m⁻² hr⁻¹)

	Total excluding CO ₂	GHG including CO ₂ ¹	Total including CO ₂ ¹	GHG CO ₂ ²	CH ₄	N ₂ O
January	321		2371	2050	5.51	0.66
February	805		2903	2099	6.41	2.16
March	751		2710	1959	6.32	1.99
April	317		1652	1335	4.13	0.74
am	639		2661 ^A	2023	6.05	1.65
noon	848		3143 ^A	2295 ^A	6.95	2.27
pm	313		1822 ^B	1509	4.18	0.73
late pm	338		1910 ^B	1572 ^B	5.33	0.73

502 Remarks:

503 ¹ The months (and similarly the times of the day) denoted by a superscript 'A' on their GHG emission
504 values emitted significantly more GHG on average than those denoted by a superscript 'B'; ² and
505 similarly for CO₂ emission.