Comparing environmental impacts of end-of-life treatments of food waste

Mischa Zschokke[1,*], Thomas Kägi[1], Fredy Dinkel[1]

[1] Carbotech AG, environmental consulting, 4002 Basel, Switzerland
[*] Corresponding author. E-mail: *m.zschokke@carbotech.ch*

The goal of this study was to compare the environmental burden of landfilling food waste with three alternative biowaste treatments "composting", "anaerobic digestion" and "municipal solid waste incineration". The life cycle inventories for anaerobic digestion and composting includes a new approach to account for benefits in using biowaste as a fertiliser substitute. Depending on the impact assessment method used, the ranking of the different treatment methods tend to vary. But taking into account the range of uncertainty the three examined treatment methods show comparable environmental impacts. Landfilling of food waste in contrast results in a much higher environmental impact compared to the other three treatment methods. As all investigated treatment methods show similar results, the decision on which technique to use can be based on other factors such as economics, available infrastructure or even on the composition and nature of the food waste because different methods are favourable for treatment.

Keywords: biowaste, benefits of biowaste, incineration, composting, anaerobic digestion

1. Introduction

Every year huge quantities of edible food end up in landfills worldwide (e.g. 7 million tonnes in the United Kingdom and 34 million tonnes in the United States (Eunomia 2006, WRAP 2007a and 2007b, EPA 2011). Roughly one third originates from producers/supply chain, one third from retail and the final third from regular households (Sibrián et al., 2006, Parfitt et al., 2010,).

In addition to the costs for disposal, these landfills generate large amounts of greenhouse gases. Landfill gas emissions are one of the largest anthropogenic sources of methane especially because of food waste (Adhikari 2006). In the United States food waste now represents the single largest component of municipal solid waste reaching landfills and incinerators, and generates more than 16 percent of all methane emissions in that country (EPA 2012). Not only could the direct emissions from landfills be decreased by reducing the amount of landfilled food waste but the use of alternate methods for treatment of food waste could further reduce the environmental impact.

2. Methods

2.1 Goal and Scope

The goal of this study was to compare the environmental burden of landfilling food waste with three alternative biowaste treatments "composting", "anaerobic digestion" and "municipal solid waste incineration" (MSWI) as described in Dinkel et al. (2011).

The functional unit used in the presented study is 1 kg of treated food waste. The applied inventory methodology is derived from the ecoinvent version 2.2 guidelines (Frischknecht R. and Jungbluth N., 2007). Data for the investigated methods of treatment are based on existing ecoinvent version 2.2 processes and were extended and updated with new values in the following fields:

- emissions from anaerobic digestion: updated values for N_2O, CO_2, CH_4 and NH_3 in the digestion process and from spreading digestate
- emissions from composting: updated values for N_2O, CO_2, CH_4 and NH_3
- TCDD-2,3,7,8-emissions in municipal solid waste incineration were adjusted to account for the current regulatory values
- the heating value of biowaste was adapted according to own calculations to be suitable to model incineration in municipal solid waste incineration plants

2.2 Inventory data

In particular, the emissions for composting and anaerobic digestion were updated by field measurements and generally show lower values than previously reported. The methane emissions in the current version of ecoinvent are overestimated by about 5 times.

The used values for the biological treatment methods are summarised in the following tables:

Table 1: Composting – converted to CO_2-equivalents per kg food waste

Emissions [g] / kg	Transport / Pre-treatment	Average	Biological Process	Average	Total
	[g]	in [g] CO_2eq	[g]	in [g] CO_2eq	in [g] CO_2eq
CH_4, biogenic	0.01-0.1	1.25	0.5-1.5	25.00	26.25
CO_2, biogenic			260.00		
CO_2, fossil	4 - 13	10.00	2 - 10	7.80	17.80
N_2O		0.00	max 0.05	14.90	14.90
Total		11		48	**59**

Table 2: Anaerobic digestion – converted to CO_2-equivalents per kg food waste

Emissions [g] / kg	Pre-storage	Aver-age	AD[a] Process	Aver-age	Storage/ Post-comp.	Aver-age	CHP[b]	Aver-age	Gas condi-tioning	Aver-age	Total
	[g]	in [g] CO_2eq	[g]	in [g] CO_2eq	[g]	in [g] CO_2eq	[g]	in [g] CO_2eq	[g]	in [g] CO_2eq	in [g] CO_2eq
CH_4, biogenic	<= 0.1	1.25	0.5-0.8	15.00	1-2.5	37.50	0.5-1.5	25.00	0.1-1.5	12.50	78.75
CO_2, biogenic			260.00								
CO_2, fossil	4 - 13	10.00	2.60	2.60		2.60					15.20
N_2O	0-0.010	2.98	0-0.010	14.90		14.90					32.78
Total		14		32		55		25		12	**126**

[a] anaerobic digestion; [b] combined heat and power generation

The life cycle inventories for anaerobic digestion and composting includes a new approach to account for benefits in using biowaste as a fertiliser substitute. Studies comparing different technologies to utilise bio-waste normally only take into account the benefits for energy and nutrients. These studies usually show that digestion or incineration is ecologically favourable to composting. In this study we used an approach pro-posed by Fuchs and Schleiss (2008) making a substitution with peat and straw in order to include the value of soil structure on applying compost or digestate. The effect of the new approach proposed on specific re-sults can be considerable as shown in the following two figures:

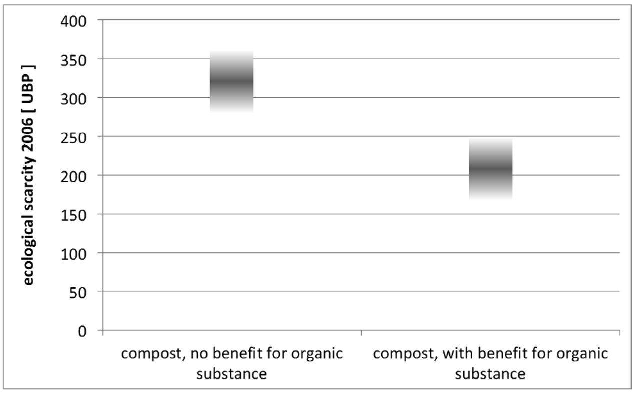

Figure 1: effect of accounting organic substance in composting, using ecological scarcity method 2006

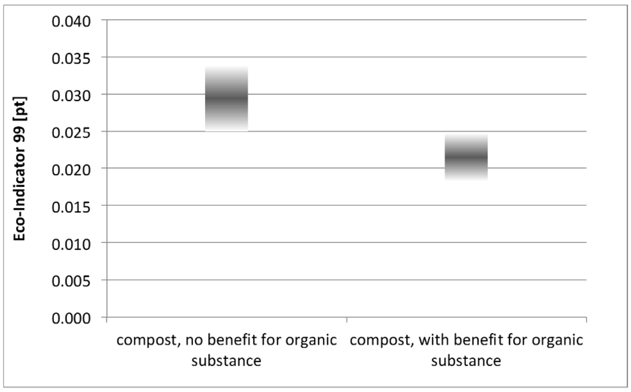

Figure 2: effect of accounting organic substance in composting, using Eco-indicator 99 (H/A) Total

To assess the impacts of landfilling, several sources from the United States of America, from the United Kingdom, from the FAO (Food And Agriculture Organization Of The United Nations) and from Switzerland were used. The life cycle inventory calculations are based on ecoinvent 2.2 (ecoinvent 2010) and were updated with current values from literature (EPA 2009 and 2011, Gustavsson et al. 2011, WRAP 2007). It is assumed that the emitted landfill gas (LFG) consists of about 50 percent methane and about 50 percent carbon dioxide as well as a small amount of non–methane organic compounds. For the presented comparison no capturing of landfill gas is assumed, all emissions go to the atmosphere. Leaching of certain compounds from landfill such as heavy metals is considered. Due to lack of data and the large margin of error with ecotoxicity data, the resulting uncertainties are fairly large.

2.3 Impact assessment

The LCA was performed using the software EMIS 5.7 (Environmental Management and Information System) developed by Carbotech AG and SimaPro 7.3.3 by PRé Consultants.

To compare the different treatment processes, the systems were expanded using an avoided burden and basket of benefits approach (Dinkel et al. 2009). Different environmental impacts were calculated and to evaluate the impacts the methods Eco-indicator 99 (Goedkoop and Spriensma, 2001) and ecological scarcity 2006 (Frischknecht, 2009) were used. Several sensitivity analyses were made to determine the robustness of the impact methods. Specific midpoint indicators such as global warming potential (IPCC 2007) are shown separately.

Inclusion of ReCiPe as a substitute method for Eco-indicator 99 was evaluated but had to be dismissed because of irregularities in the assessment of phosphorus emissions and the valuation of heavy metals in soil.

3. Results

The results presented are shown for Eco-indicator 99 and IPCC 2007, the ecological scarcity method 2006 is not displayed, as the outcomes are comparable to Eco-indicator 99.

Depending on the impact assessment method used, the ranking of the different treatment methods tend to vary. But taking into account the range of uncertainty the three examined treatment methods show comparable environmental impacts. As shown in the following figures, the landfilling of food waste in contrast results in a much higher environmental impact compared to the other three treatment methods.

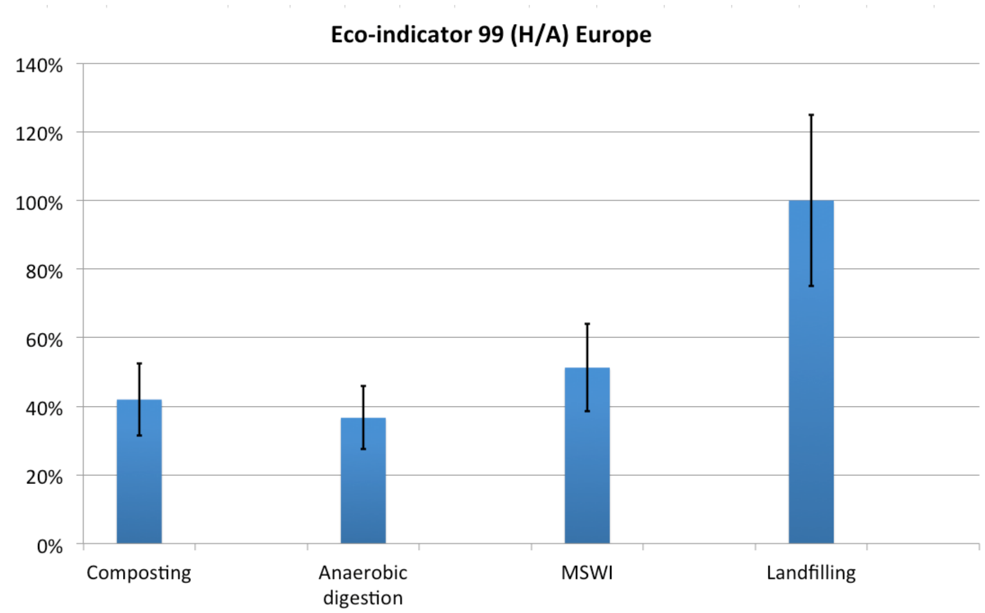

Figure 3: Eco-indicator 99 (H/A) Total (system modelled according to basket of benefits approach)

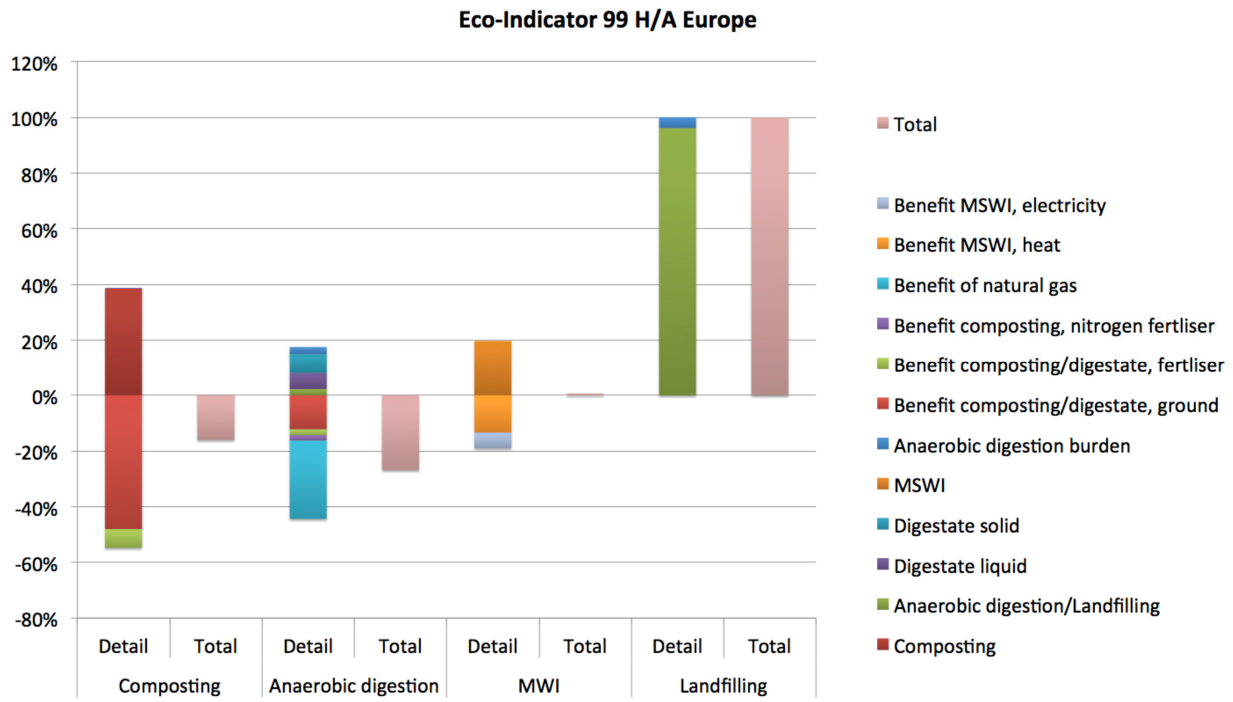

Figure 4: Eco-indicator 99 (H/A) Total, detail (system modelled according to avoided burden approach)

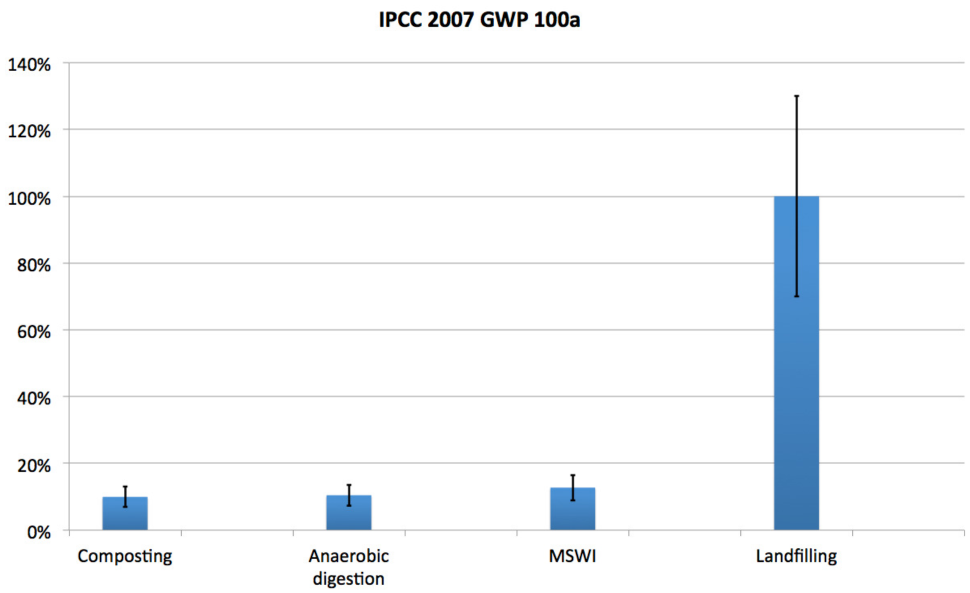

Figure 5: IPCC 2007 100a (system modelled according to basket of benefits approach)

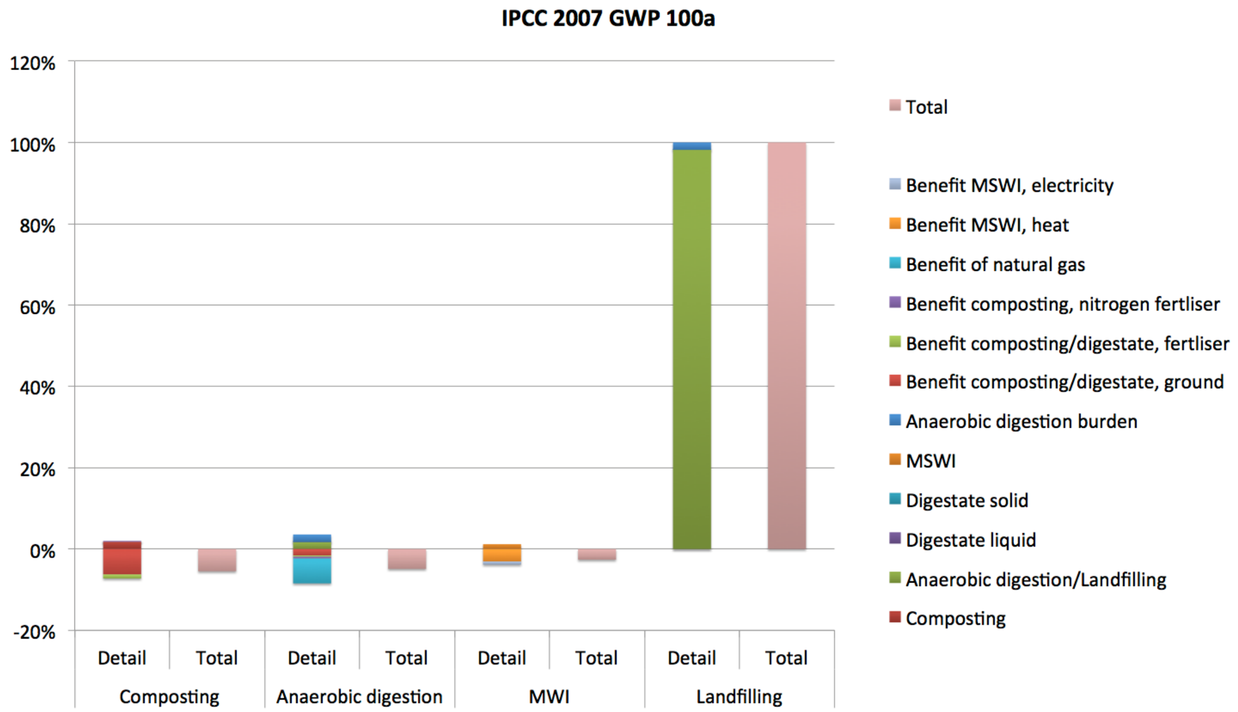

Figure 6: IPCC 2007 100a, detail (system modelled according to avoided burden approach)

Compared to Figure 4 (Eco-indicator 99), Figure 5 and Figure 6 clearly show that the main burden with landfilling originates from greenhouse gas emissions, essentially from methane.

4. Discussion

Our calculations have confirmed that all three treatment methods display comparable environmental impacts. Landfilling always has significantly higher environmental burdens regardless of which impact assessment method is used. In this study we did not include efforts to capture and use emissions from landfills. Such programmes (e.g. the U.S. EPA's Landfill Methane Outreach Program (LMOP)) could considerably reduce the environmental impacts from landfills and help to use landfill gas as energy resource. We estimate that the possible reductions will nonetheless not be able to place landfilling ahead of the other three methods investigated.

The sheer amount of food waste still going to landfills basically makes any treatment method favourable to simple landfilling: in the United States 35 Million tonnes of food were sent to landfill in 2010, responsible for the emission of approximately 20 to 40 Tg of CO_2eq into the atmosphere.

As all investigated treatment methods show similar results, the decision on which technique to use can be based on other factors such as economics, available infrastructure or even on the composition and nature of the food waste because different methods are favourable for treatment.

5. Conclusions

This study shows the enormous emission reduction potential if food waste is not landfilled but otherwise treated. Naturally it would be even better to reduce the amount of food going to waste as all presented methods are only end of pipe solutions and the environmental impact of food production itself is normally much higher (usually by a factor of 2 to 20) than the impact of the landfill or any other treatment method. As long as we still lose about one third of the produced food along the chain (Gustavsson et al. 2011), we still have lots of room for improvement.

6. References

Adhikari B. K., October 2006, Waste Managment Research, vol. 24 no. 5 421-433

Dinkel et al., 2009, Ökobilanz zur Grüngutverwertung in Basel, Amt für Umwelt und Energie, Basel-Stadt

Dinkel et al., 2011, Ökobilanzen zur Biomasseverwertung, Forschungs- und Entwicklungsprogramm Biomasse und Holzenergie, Schwerpunkt Biomasse ohne Holzenergie, Bundesamt für Energie BFE

ecoinvent, 2010, ecoinvent 2010, version 2.2, Swiss Center for Life Cycle Inventories, May 2010

EPA 2009, December 2010, Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2009, United States Environmental Protection Agency, Solid Waste and Emergency Response (5306P) Washington, DC 20460

EPA 2011, November 2011, Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2010, United States Environmental Protection Agency, Solid Waste and Emergency Response (5306P) Washington, DC 20460

EPA 2012, Inventory of U.S. greenhouse gas emissions and sinks: 1990 – 2010, April 15, 2012, U.S. Environmental Protection Agency, 1200 Pennsylvania Ave., N.W. Washington, DC 20460 U.S.A.

Eunomia (2006), "A Changing Climate for Energy from Waste?", Friends of the Earth, 26-28 Underwood Street, London

Frischknecht et al. (2009) Methode der ökologischen Knappheit - Ökofaktoren 2006. Bundesamt für Umwelt (BAFU)/ÖBU.

Frischknecht R. and Jungbluth N., ecoinvent report No.1, Overview and Methodology, 2007

Fuchs J., Schleiss K., 2008, Ökologische Bewertung der organischen Substanz, Zusatzmodul zu Forschungsprojekt Auswirkungen von Komposten und von Gärgut auf die Umwelt, Bodenfruchtbarkeit, sowie die Pflanzengesundheit, im Auftrag des BAFU, Bern

Goedkoop and Spriensma, The Eco-indicator 99 – a damage oriented method for LCIA, Methodology Report, Third edition, 22 June 2001, PRé Consultants B.V., Amersfoot http://www.pre-sustainability.com/content/reports

Gustavsson et al., 2011, Global food losses and food waste, Swedish Institute for Food and Biotechnology (SIK) Gothenburg, Sweden

IPCC, 2007. Climate Change 2007: The Scientific Basis. In: Solomon, S. et al. (eds.), Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). IPCC, Intergovernmental Panel on Climate Change, Cambridge University Press, The Edinburgh, Building Shaftesbury Road, Cambridge, UK.

Parfitt et al., 2010, Food waste within food supply chains: quantification and potential for change to 2050, Phil. Trans. R. Soc. B 2010 365, 3065-3081

Schleiss K. und Jungbluth N., 2006, Verwertung der biogenen Abfälle in der Stadt Zürich, Bericht mit besonderer Berücksichtigung der biogenen Abfälle aus Haushalten, ERZ Entsorgung + Recycling Zürich, Hagenholzstrasse 110, Postfach, 8050 Zürich, LCA not published

Sibrián et al., 2006, Estimating household and institutional food wastage and losses in the context of measuring food deprivation and food excess in the total population. Statistics Division, Working Paper Series no: ESS/ESSA/001e, Rome, Italy: FAO.

WRAP, 2007a, "Understanding Food Waste", WRAP The Old Academy, 21 Horse Fair, Banbury OX16 0AH, England

WRAP, 2007b, "New WRAP Research Reveals Extent of Food Waste in the UK", WRAP The Old Academy, 21 Horse Fair, Banbury OX16 0AH, England