A technical assessment of different food waste treatment technologies in campus dining hall from the perspective of global warming and resource recovery: An implementation in the Aristotle University Thessaloniki

G. Perkoulidis, C. Karkanias, A. Malamakis, S. Kontogianni and N. Moussiopoulos

Laboratory of Heat Transfer and Environmental Engineering, Department of Mechanical Engineering, Aristotle University of Thessaloniki, Box 483, GR-54124 Thessaloniki, Greece

Keywords: Food waste, treatment, campus, dining hall

Presenting author e-mail: gperk@aix.meng.auth.gr

Abstract

Food waste is a huge net contributor to the waste stream and its generation has significant and immediate economic as well as environmental consequences. Nowadays, there is a trend in universities towards reducing the amount of food waste from dining halls but only a few of them implement a successful recycling program.

In this manuscript, solutions are presented for the management of food waste from the campus dining hall of Aristotle University Thessaloniki. First, the advantages and disadvantages of anaerobic and aerobic processes for food waste are presented. Next, the current situation of food waste management in the campus dining hall is analysed. Technical and economic aspects of their implementation are assessed and greenhouse gas reduction is estimated. The results can be used by decision-makers in maximising the energy recovery and high value-added material recovery from food waste of dining hall in universities.

1 Introduction

Universities are the place where knowledge is taught, ideas are inspired and technologies are developed. These activities lead to the consumption of resources, including energy, water and food, which in turn result in the generation of waste (Alshuwaikhat and Abubakar, 2008; Smyth et al., 2010, Tu et al., 2015). A mission of many universities was to promote the idea of sustainability among students, faculty and the society (Cortese, 2003). Improving resource management and minimizing waste generation were two key challenges for universities to address in achieving those campus sustainability goals. One solution was to recycle wastes and reuse them on-site for energy production. Converting campus waste into renewable energy, organic waste fraction disposal by landfill is minimised while at the same time the greenhouse gas emissions are reduced. The on-site implementation of the energy recovery and high value-added material recovery options have also an additional advantage of eliminating the transportation required for disposal, which further reduces fuel consumption and associated greenhouse gas emissions (Tu et al., 2015).

This paper evaluated the energy and material recovery pathways from food waste at the Aristotle University Thessaloniki, Greece, which is located in the city center and comprises 334,000 m^2. Around 70,000 students attend the courses and 12,000 of them eat in campus dining facility. This study developed an inventory of the food waste stream and assessed the implementation of the corresponding food waste to biogas and food waste to compost technologies. An evaluation of its technical feasibility, economic feasibility and greenhouse gas reduction was also performed.

The European Union waste hierarchy requires that waste prevention should be prioritised and promoted and that disposal (mainly landfilling) has the lowest priority and should be minimised (Figure 1). In the Communication from the Commission on future steps in bio-waste management in the European Union, the European Commission states that compost and digestate from bio-waste are under-used materials [COM(2010) 235]. Composting and recycling increased by 28 Mt in the European Union - 27, while landfilling decreased by 41 Mt and incineration increased by nearly 15 Mt (EEA, 2013).

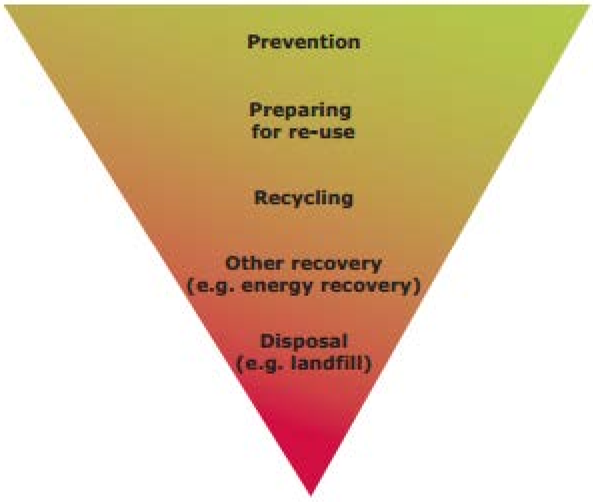

Figure 1: The European Union waste hierarchy (ETC/SCP, 2011).

The anaerobic digestion process degrades organic matter in the absence of oxygen and generates biogas, which typically has a volumetric composition of 65% methane (CH_4) and 35% of CO_2 (Møller et al., 2009). Food waste is a suitable feedstock for anaerobic digestion due to its high organic content and moisture level.

The Cranfield anaerobic digestion large scale pilot plant opened in 2014. The plant is available as a plug-and-play facility for research into anaerobic digestion. The demonstrator is of a modular construction and mounted on skid-type frame assemblies. The produced biogas is then collected in a 40 m^3 membrane biogas holder, which is also linked to two gas engines (Figure 2).

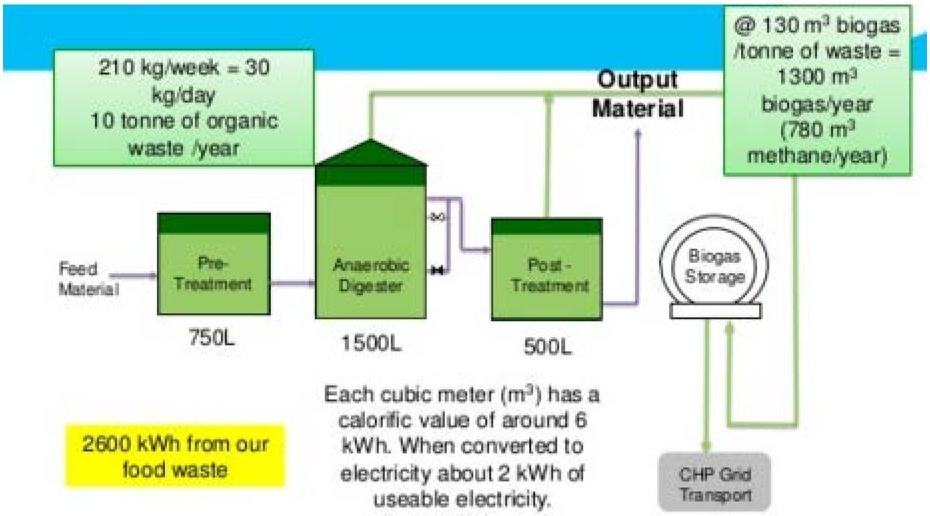

Figure 2: Anaerobic digestion pilot plant in Cranfield University (Villa, 2015). http://www.slideshare.net/adbiogas/raffaella-villa-47283577, 2016)

From the other hand, composting is an effective way to reduce organic solid waste through decomposition of organic debris achieved by microorganisms (bacteria, actinomycetes and fungi) under controlled environmental conditions. In-vessel composting refers to a group of methods that confine the composting materials within a building, container or vessel (Bourgault et al., 2005). They are automated compost units usually constructed on a concrete pad with a building covering all or part of the unit. Some are very technologically advanced with computerized continuous feed systems and mechanisms to maintain an optimal composting environment (Figure 3). Use of composting to manage residential and commercial food has grown considerably in recent years, as people learn how composting converts food waste into a valuable soil amendment and waste management professionals search for ways to divert organics from rapidly filling landfills.

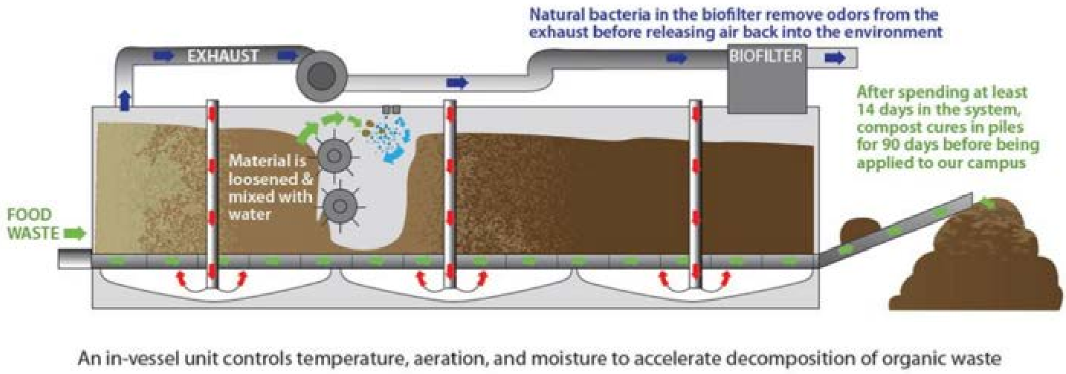

Figure 3: Ohio University's in-vessel composter (Ohio University, 2015).

In-vessel composting equipment basically includes a drum (vessel), loading conveyors, air systems (blowers), temperature monitors, electric panels and downloading conveyors. The drum usually rotates only four revolutions per hour by electrical power only 2 hours on and 10 hours off using very little electrical energy. Heat is generated inside the drum by the combination of carbon and nitrogen in the organic waste combined with oxygen (the aerobic process) as the mixture is turned very slowly (Levy, 2013). Proper composting results in thermophilic temperatures due to generation of microbial metabolic heat which can effectively destroy pathogens and weed seeds, and converts biodegradable solid organic matter into a stable humus-like substance which can be handled, stored, and/or applied to land without adversely affecting environment (Zhou et al., 2015).

Several universities have adopted AD as a way to reduce food waste disposal and fossil fuel consumption. The Ohio State University (2012), for instance, initiated the construction of a dry AD process in 2012 with a processing capacity of 30,000 t of agricultural and food waste per year. The system was expected to produce 7800 MWh of electricity every year. Single and two-phase operations were compared at mesophilic operating conditions using a digester system consisting of three 5-m3 reactors treating food waste generated daily within the Clarkson university campus kitchens (Grimberg et al., 2015). The operation rate of the anaerobic digester was 2461 L per day. Using this operation rate, the following benefits occurred: i) 211 t of waste diverted per semester, ii) 32,367 € saved per semester, iii) 19.7 trips saved to the landfill, iv) 5,704 fewer kilometers were driven per semester. In Imperial College in London, 18,000 persons (students and personnel) were fed every day. 1.1 t of food waste was arise weekly by this feeding and it was aerobically digested in the campus. The composter, which had been created using research from the College's Department of Civil & Environmental Engineering, would turn the waste from the South Kensington Campus's food outlets into compost used to enhance campus green spaces. This move contributed towards the College's target of recycling 40% of all College waste during 2010 (Imperial College London, 2015).

2 SWOT analysis

The strengths for the management of food waste in campus are based partly in the link and they are the following: a) divert of food waste from landfill, b) easy to use, c) students and personnel feel like they are making a difference, d) students have more recycling options, e) adapting a system that works well, does not require a big change in the habits in the campus, f) successful in another universities. The weaknesses are the following: a) vermin could get into bins, b) odours from bins in hot weather, c) contamination of food waste with plastic, d) only certain technologies can be used to compost, e) large startup costs and f) some composting methods are energy intensive.

As far as the opportunities are concerned, the compost can be sold to primary producers. Furthermore, the collected biogas, could supplement power on site, while there is the opportunity to apply for multiple grants in research and development. The life of landfill will be extended by saving space. The collection frequency of green waste bins will be reduced.

Finally, the first threat is the competition with other universities for national and international sustainability grants. Furthermore, smells generated from plant could cause complaints from locals. The pretreatment regulations can extend processing time slowing turn over from food waste to compost, while the legislation may prevent sale of compost to farms due to hygiene restrictions.

3 Methodology

3.1 Technical analysis

The technical feasibility of the anaerobic and aerobic digestion technologies was evaluated by: (1) reviewing the process type (reactor type for anaerobic digestion, capacity), (2) reviewing the process requirements (e.g., feedstock, material and energy inputs), (3) reviewing existing examples at other universities, and (4) performing a material and energy on each process. One main parameter of the technologies was the residence time, which was referring to the length of time for complete degradation of food waste in a digester (NREL, 2013).

3.2 Economic analysis

The economic feasibility assessment was conducted by determining: (1) the capital investment and operational costs, (2) the savings on utility bills, and (3) the repayment period

The repayment period was calculated by the following equation:

$$P = \frac{B}{C} \quad (1)$$

where P = repayment period (y); B = investment cost (€); C= net annual revenues (€).

3.3 Greenhouse gas emission analysis

The following steps were considered in the analysis for the anaerobic digestion facility (European Communities, 2001):

- Treatment. Emissions of short-term carbon dioxide and leakage of methane during the AD process. Energy use to operate the plant was provided by the anaerobic digestion gas.
- Use / Disposal. Carbon sequestered in soil as a result of composted digestate application.
- Displaced emissions. Avoided emissions from energy generation displaced by the heat and power exported by the AD plant. Also avoided emissions from displacement of peat or fertilisers by the composted digestate.

The mobilisation was not taken into account because there wasn’t any kind of transportation of food waste from campus dining facility to the anaerobic digestion plant and transport of products (composted digestate and liquor) to market or landfill. The emission factor for food waste processed through anaerobic digestion was taken -246 kg CO_2 eq/t food waste (European Communities, 2001).

As far as the composting process is concerned, the IPCC has identified carbon sequestration in soils as one of three carbon mitigation measures for agriculture, the other two options being a reduction in agriculturally related emissions and the replacement of fossil fuels with biofuels [68]. Energy use during composting varies depending on the type of process. The higher energy use of closed plants reflects the use of gas cleaning systems to remove odour emissions as well as the electricity used for aerating the piles and maintaining correct temperature and humidity.

In terms of greenhouse gas impact the different centralised treatment options (open, closed, semi-closed) differ only in energy use, although there are cost differences and differences in local environmental impacts (odours and bio-aerosols). The emission factor for food waste processed through composting was taken -32 kg-CO_2 eq/t food waste treated in closed treatment option.

4 Results and discussion

There were three main steps for selecting the AD facility (Tu et al., 2015): (1) pretreatment of waste such as grinding, shredding, screening and mixing, (2) digestion of the waste including feeding and mixing in the reactor and (3) biogas collection, treatment, storage and utilization. The food waste generation at AUTH dining hall was estimated to be 60 kt per day and the predicted annual energy generated was 26 MWh.

The fixed cost of the AD facility was depended on: i) the fermentation time, ii) the capacity (L) and iii) number of reactors. The installation cost of reactor and cogeneration unit cost were estimated to 31,280 € and 12,420 € correspondingly, as a function of the fermentation time (20 days), and the capacity (400 L) of the reactor.

The annual cost of aerobic fermentation facility was calculated to 1,104 €/y. The required fermentation days were 40 and the capacity was 750 L. The cost of the reactor was 4,600 €, while the running cost was estimated to 4 €/d. The annual revenues from the marketing of produced compost were estimated to 1,800 €, while the annual expenses of facility were 1,104 € (Table 1 and Figure 4).

Table 1: Parameters and values that were used for the management of food waste produced by the dining hall in Aristotle University Thessaloniki (Vavoura et al., 2016).

	Anaerobic digestion	Aerobic digestion
Residence time (days)	20	40
Capacity (L)	400	750
Reactor cost (€)	31280	0
CHP* cost (€)	12420	

	Anaerobic digestion	Aerobic digestion
Produced energy (MWh/y)	25,55	0
Revenues from compost sales (€/y)	300	1800
Annual revenue (€)	5921	1104
Repayment (years)	7.0	6.6

* CHP: Combined Heat and Power

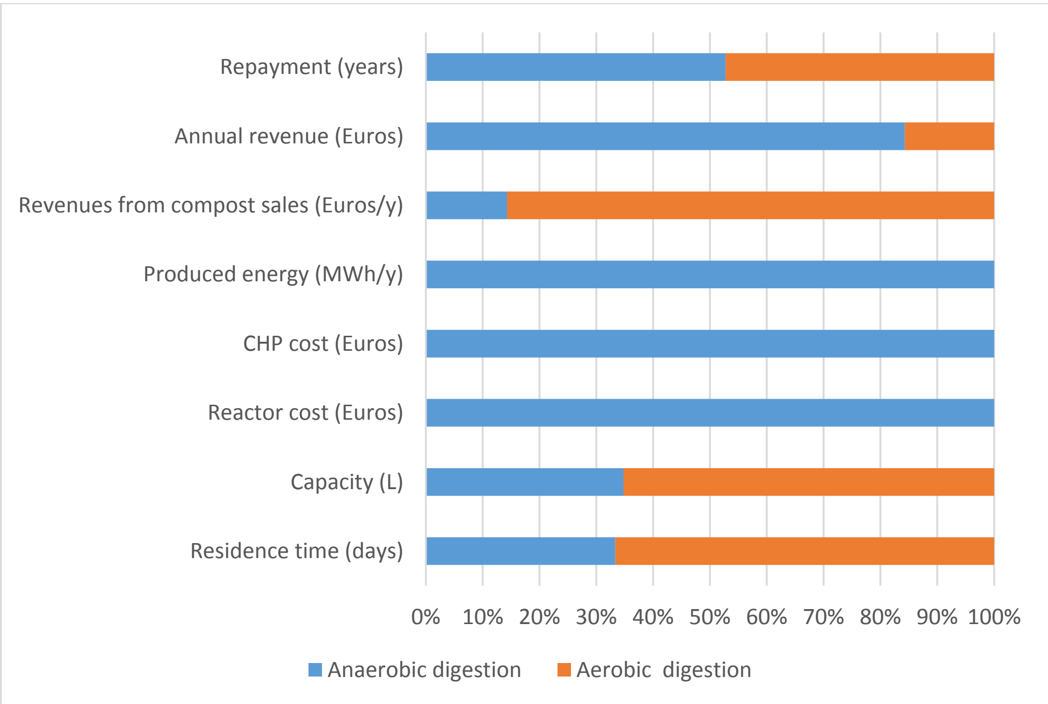

Figure 4: The percentage of contribution (of each parameter) for the management of food waste produced by the dining hall in Aristotle University Thessaloniki.

5 Conclusions

This study illustrated the utilization of food waste generated at the dining hall of Aristotle University Thessaloniki for on-site energy production and use. 10,000 students had meals on a daily basis for 300 days per year. The inventory study and technical feasibility assessment showed that the payback periods for the two options were estimated to be 79 months and 89 months for the aerobic and anaerobic digestion, respectively. The estimated reduction of greenhouse gas emission from the implementation of the two material and energy recovery projects were estimated to 1.92 t CO_2-eq/y for aerobic and 14.76 t CO_2-eq/y for anaerobic digestion. Future research should take place for evaluating energy recovery perspectives, as biodiesel production from waste cooking oil, refuse derived fuel from plastic and paper and burning of wood residue in boilers.

References

Alshuwaikhat, H.M., Abubakar, I.: An integrated approach to achieving campus sustainability: assessment of the current campus environmental management practices, J. Clean. Prod. 16 (16), 1777–1785 (2008)

Bourgault, A., Guinn, W., Herchenroder, K., Stechmann, D.: Composting for sustainable waste management, Project report. https://www.wpi.edu/Pubs/E-project/Available/E-project-052005-004450/unrestricted/CompostingPR-D05.pdf (2005). Accessed 30 April 2016

COM(2010) 235: Communication from the Commission to the Council and the European Parliament on future steps in bio-waste management in the European Union. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52010DC0235&from=EN. Accessed 30 April 2016

Cortese, A.D.: The critical role of higher education in creating a sustainable future. Plan. High. Educ. 31 (3), 15–22 (2003)

EEA: Managing municipal solid waste – a review of achievements in 32 European countries, European Environment Agency, Report No 2. http://www.eea.europa.eu/publications/managing-municipal-solid-waste (2013). Accessed 29 April 2016

ETC/SCP: Projections of municipal waste management and greenhouse gases, ETC/SCP working paper, 4/2011. http://scp.eionet.europa.eu/publications/2011WP4 (2011). Accessed 28 April 2016

European Communities: Waste Management Options and Climate Change, Final report to the European Commission, DG Environment (2001)

Grimberg, S.J., Hilderbrandt, D., Kinnunen, M., Rogers, S.: Anaerobic digestion of food waste through the operation of a mesophilic two-phase pilot scale digester – Assessment of variable loadings on system performance, Biores. Technol. 178, 226–229 (2015)

Imperial College London: From café to compost: Imperial College London to reduce food waste to landfill by one tonne a week. http://www3.imperial.ac.uk/newsandeventspggrp /imperialcollege/newssummary/news_14-5-2010-9-10-12 (2015). Accessed 24 April 2015

Levy, M.: In-vessel aerobic composting of organic waste on site and re-use on site for environmental and economic advantage. http://www.southdadeswcd.org/wp-content/uploads/2010/10/White-Paper-on-In-Vessel-Composting-05-10-10.pdf (2013). Accessed 29 April 2016

Møller, J., Boldrin, A., Christensen, T.H.: Anaerobic digestion and digestate use: accounting of greenhouse gases and global warming contribution. Waste Manage. Res. 27, 813–824 (2009)

NREL: Feasibility Study of Anaerobic Digestion of Food Waste in St. Bernard, Louisiana, Technical Report, NREL/TP-7A30-57082, January (2013).

Ohio State University: http://extension.osu.edu/news-releases/archives/2012/february/ohio-state-anaerobic-digestion-technology-now-beingcommercialized (2012). Accessed February 2014

Ohio University: Compost facility. https://www.ohio.edu/sustainability/programs/compost-facility.cfm (2016). Accessed April 2016.

Smyth, D.P., Fredeen, A.L., Booth, A.L.: Reducing solid waste in higher education: the first step towards ‘greening’ a university campus. Resour. Conserv. Recy. 54 (11), 1007–1016 2010

The Black Mamba’s: Exercise 4.3: SWOT analysis of kerbside food scarp collection. https://theblackmambas.files.wordpress.com/2014/08/swot.jpg (2014) Accessed on 15 April 2016)

Tu, Q., Zhu, C., McAvoy, D. C.: Converting campus waste into renewable energy – A case study for the University of Cincinnati, Waste Manag. 39, 258–265 (2015)

Vavoura, E., Golema, S., Capetanios, N. – R.: Food waste management of Aristotle University Thessaloniki dining hall, Students work at the course “Treatment and Management of Solid Waste”, Department of Mechanical Engineering, Polytechnic School, Aristotle University Thessaloniki (in Greek) (2016)

Villa, R.: RED: Supporting SMEs in anaerobic digestion.). http://www.slideshare.net/adbiogas/raffaella-villa-47283577 (2015). Accessed 12 April 2016

Zhou, C., Liu, Z., Huang, Z.-L., Dong, M., Yu, X.-L., Ning, P.: A new strategy for co-composting dairy manure with rice straw: Addition of different inocula at three stages of composting, Waste Manag. 40, 38–43 (2015)