

Management of urban organic waste in an energy and climate perspective

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International Conference on Waste Management
Vienna November 16-18, 2009

Abstract

Urban organic wastes are for example wastewater sludge; food waste; yard (garden and park) wastes; and other organic wastes such as cardboard, paper and plastics not separated for material recycling. These wastes represent a resource in terms of energy recovery and/or soil improvement, the latter only after appropriate source separation and treatment to avoid soil contamination. Based on historical data, the city of Aalborg in Denmark has been studied in terms of actual organic waste management systems in operation since 1970. Focus has been on energy recovery, which for the Municipality has had high priority for some decades. Additionally, Greenhouse Gas emissions were evaluated based on Life Cycle Assessment for carbon and nutrients in the organic waste flows. It was found that the strong focus on energy savings and substitution of fossil fuel implies high efficiency in terms of extracting the calorific value from the organic waste and also effective greenhouse gas mitigation. As an example, the Municipality has changed from being a net emitter to becoming a significant net saver of greenhouse gas emissions. Given the location in the North of Europe and hence the possibility to sell both electricity and heat, the energy recovery solution is superior to the soil improvement solution in terms of both total energy recovery and greenhouse gas mitigation. Given other climate conditions, e.g. Southern Europe, and substitution of other than fossil fuel for energy production, the choice between energy recovery and soil application of treated organic waste may be different, but it should still be possible to make waste management a net GHG emission saver.

Introduction

Climate change is on the political agenda and hence the discussion about ways and means to mitigate greenhouse gas (GHG) emissions. The major GHG in question are Carbon Dioxide (CO₂), Methane (CH₄) and Di-nitrogen Oxide (N₂O); when converted into units of global warming, they all are calculated in CO₂-equivalents, CO₂-eq. In this context it is important to assess how the waste industry impacts climate change in terms of GHG mitigation. And it is interesting to assess to which extent the waste sector is able to significantly reduce or even avoid GHG emissions.

The objective of this study was therefore to evaluate how the implementation of new waste treatment technologies over time has affected energy production, nutrient recycling and GHG emissions from waste and wastewater treatment at a selected location. Using a

fixed location and having access to local data recordings, a number of uncertainties can be eliminated in the calculations. On this background

- ∇ Assessment was made of the GHG mitigation potential of the waste sector at a Municipality level,
- ∇ Assessment was made of the relative importance of different real-life waste treatment technologies and management schemes in terms of energy recovery and GHG mitigation

A more detailed description of this study can be found in Poulsen & Hansen (2009).

Approach

Aalborg Municipality in Northern Denmark was used as case location as it has changed its waste treatment systems and technologies several times during recent decades, beginning with landfilling in an unlined landfill and ending at present with a combination of controlled landfilling, anaerobic digestion, composting and incineration with energy production. The evaluation focused on the effects of treating organic wastes and included four key waste categories: (1) Food waste, (2) yard and park waste, (3) other organic waste (plastic, paper, cardboard etc.), and (4) wastewater sludge. Development in balances for: (a) Energy, (b) nutrients (N, P), and (c) GHG emissions were evaluated as function of time. Balances for both biogenic and fossil carbon as a function of time were also developed as they are necessary for calculating the GHG balances.

The balances for energy, nutrients, and GHG were evaluated at five specific years: 1970, 1980, 1990, 2005 and 2020. The first four years were selected so they fall between events where significant changes to the waste and wastewater treatment systems have been made. The last year was selected as it coincides with the current long-term plan for waste and wastewater treatment development in Aalborg. Systems for treatment of the above mentioned wastes 1 – 3 (encompassing collection, treatment and final disposition) and waste 4 (encompassing sewer transport, wastewater treatment, sludge treatment, and sludge final disposition) were considered. For each of the five years the layout of the corresponding waste and wastewater treatment systems in terms of unit processes as well as in and outputs of energy, nutrients and GHG for each of these unit processes were identified based on existing data from the waste and wastewater treatment facilities in Aalborg. These data were then used to calculate the energy, nutrient and GHG balances for waste and wastewater treatment for each of the five years. The calculations do not include energy, nutrient, and GHG associated with constructing, maintaining and end-of-life management of the systems (buildings, pipelines, treatment plants, etc) used for waste and wastewater treatment.

In 1970 wastewater was collected by sewer and discharged untreated to the ocean, and thus no sludge was generated. The three remaining waste categories were all collected and deposited at an unlined landfill with daily soil cover over the deposited waste. No methane collection was carried out at the landfill.

By 1980 biological removal of organic matter from the wastewater was implemented via construction of aeration tanks at the wastewater treatment plants and the sludge produced

was dewatered using a filter press and deposited at a sludge deposit. The three remaining waste fractions were incinerated in a rotary oven incinerator without energy extraction and the ash was deposited at a landfill.

By 1990 the wastewater treatment process had been expanded with a set of mesophilic (37°C) anaerobic digesters for extracting biogas from the sludge. Biogas was subsequently converted into electricity and heat using a gas engine and generator. The digested sludge was subsequently dewatered in a filter press and transported for use on agricultural land as fertilizer. Yard and park waste was collected separately and composted in open windrows. The compost was subsequently used as soil amendment and fertilizer on both agricultural and urban soils. The remaining waste (food waste and other organic waste) was being incinerated in a rotary oven incinerator with extraction of the energy in the form of heat for district heating. Ash from the incineration process was being utilized for various purposes such as road construction.

During the period 1990 – 2005 the wastewater treatment process was modified for nitrogen and phosphorous removal by addition of extra process tanks at the wastewater treatment plants, the anaerobic digesters were modified to operate under thermophilic conditions (53°C), the digested sludge was dewatered in a centrifuge and dried using a fluid bed drying facility operated on biogas from the digesters and on natural gas. The drying facility was located at one of Aalborg's two wastewater treatment plants and thus had access to 30% of the biogas produced from wastewater sludge. This also meant that 70% of the digested sludge was to be transported to the drying facility from the other wastewater treatment plant. The dried sludge was subsequently incinerated for heat and power production at a commercial combined heat and power generation plant. The remaining solid waste incineration process was also modified to allow for production of both heat and electricity by installation of a steam turbine-generator system at the incinerator.

In 2020 it is expected that the incinerator will be operating with condensation of the water vapour present in the flue gases to allow for increased heat recovery. This process technology was installed in 2007 and put into operation in 2008. Aalborg municipality has also been experimenting with source separation of household food waste and although no separation takes place at present, it is assumed in this paper that a separation scheme where source separated household food waste is treated by anaerobic digestion together with sewage sludge will be in place by 2020. In addition it is assumed that the sludge is thermally pre-treated (high temperature and pressure treatment) prior to digestion to allow for increased biogas production. Thermal pre-treatment of biomass has been tested at full scale Danish biogas plants and it is likely that this process will gain increased interest. It is further assumed that the digested and dewatered sludge and food waste is incinerated separately to avoid contamination and that phosphorous is extracted from the ash and used as fertilizer.

The GHG balances for each of the above five waste and wastewater treatment systems are determined considering both upstream impacts (emissions associated with provision of energy and fuel for process operation) direct impacts (emissions from treatment

processes and fuel combustion) and downstream impacts (saved emissions associated with substitution of fossil fuel by energy, nutrients produced from waste (including energy savings due to substitution of commercial fertilizer) and due to storage of biogenic carbon in soil and landfill). Biogenic carbon storage and emissions from landfill and soil as well as atmospheric effects of the emissions from the waste treatment activities are considered over a 100 year period. Table 1 gives an overview of the upstream, direct and downstream impacts on the GHG balances for each of the unit processes in the five waste treatment systems considered in this paper.

Table 1 Upstream, direct, and downstream effects on greenhouse gas (GHG) emissions considered in the evaluation of GHG emissions from the waste treatment systems in Aalborg Municipality.

Process	Indirect (Upstream) impacts	Direct impacts	Indirect (Downstream) impacts
Composting	CO ₂ emissions associated with heat & electricity provision	CH ₄ & N ₂ O production from composting process, CO ₂ from fuel combustion	
Dewatering	CO ₂ associated with electricity provision		
Digestion	CO ₂ emissions associated with heat & electricity provision	CH ₄ emissions from digestion plant and gas engine	Fossil CO ₂ substitution by produced heat and electricity
Drying	CO ₂ emissions associated with heat & electricity provision		
Incineration	CO ₂ emissions associated with heat & electricity provision	CO ₂ production from combustion of wastes containing fossil carbon	Fossil CO ₂ substitution by produced heat and electricity
Land application	CO ₂ emissions associated with fuel provision	CO ₂ production from fuel combustion, N ₂ O emissions due to degradation	Fossil CO ₂ substitution by nutrient provision, biogenic carbon storage
Land filling		CH ₄ emissions due to degradation	Biogenic carbon storage
P extraction from ash	CO ₂ emissions associated with energy provision		Fossil CO ₂ substitution by nutrient provision
Sewer transport	CO ₂ emissions associated with electricity provision		
Sludge pre-treatment	CO ₂ emissions associated with heat provision		
Truck transport	CO ₂ emissions associated with fuel provision	CO ₂ production from fuel combustion	
Wastewater treatment	CO ₂ emissions associated with electricity provision		

Data used

Data for the current organic waste composition as well as the quantities of specific organic wastes and wastewater treated in Aalborg Municipality in 2005 were collected from the municipality and from the specific treatment plants. Part of both waste and wastewater treated in Aalborg Municipality originates from municipalities outside Aalborg. The number of people served by the Aalborg waste and wastewater treatment systems was in 2005 approximately 230.000 of which about 170.000 lived inside Aalborg Municipality itself. An overview of waste and wastewater composition and quantities collected and treated is given in Table 2. Characteristics of the wastes in terms of energy, nutrient and moisture contents, etc. were collected in part from the waste and wastewater treatment facilities in Aalborg Municipality and in part based on literature data. Table 3 shows the characteristics of the types of organic waste considered. Data for characterizing the energy and material balances for each of the unit processes in the five waste and wastewater treatment systems were also collected from the waste and wastewater treatment facilities in and around Aalborg. In connection with landfilling no reliable data for degradation of wastes containing fossil carbon (mainly plastics) could be found. In general most plastics are broken down by initial photodegradation followed by microbial degradation. As photodegradation is limited in covered landfills, it was assumed here that no degradation of plastics took place in the landfill. If degradation does take place the above assumption will mean that GHG emissions from the landfill will be slightly underestimated. An overview of the data used is given in Table 4. It is assumed that electricity and heat generated from waste and wastewater processing substitute heat and electricity produced from coal in a modern combined heat and power plant as this has been the main energy source in the Aalborg area. It is also assumed that nutrients supplied to plant growth as a result of waste and wastewater treatment substitutes nutrients produced by commercial means. In case the ratio of heat and electricity production resulting from waste and wastewater treatment does not match the corresponding ratio of the coal based CHP plant, excess heat or electricity is assumed to be produced in plants dedicated to either heat or power production based on coal. Data for energy conversion, fuel consumption and global warming potentials etc. are given in Table 5. As the focus of this paper is on the impact of waste and wastewater treatment technology changes on energy, nutrient and GHG balances, it was chosen to use the waste and wastewater quantities and compositions corresponding to the situation in 2005 in the calculation of energy, nutrient, carbon and GHG balances for all five systems (all five years). If the true waste quantities and compositions for each of the five years were used instead it would not be possible to specifically identify the effect of technology changes between the years as these would be masked by changes in waste quantity and composition.

Table 2. Annual quantities of solid organic wastes, wastewater sludge and wastewater treated in Aalborg Municipality (waste and wastewater produced by 230,000 persons) in 2005. Data were collected in part via interviews with plant managers and municipality employees and in part from Reno Nord (2005).

<i>Fraction</i>	<i>Quantity</i>	<i>Unit</i>
Food waste	50,000	Tons
Yard waste	27,300	Tons
Other solid organic waste	132,000	Tons
Wastewater sludge	141,000	Tons
Wastewater	30,000,000	m ³

Table 3. Characteristics of the Aalborg Municipality organic waste fractions. Numbers are calculated based on data from Nissen et al. (1994) and US EPA (1997).

<i>Parameter</i>	<i>Food waste</i>	<i>Yard waste</i>	<i>Other organic waste</i>	<i>Wastewater sludge</i>	<i>Unit</i>
Dry matter content	30	70	30	3.2	%
Upper fuel value	18	7	22	15	GJ/ton dm
VS content	85	30	95	80	% of dm
Biogenic C-content	45	42	35	45	% of dm
Fossil C-content	0	0	14	0	% of dm
N-content	0.8	2	3	3	% of dm
P-content	1.3	1	1	1	% of dm
CH₄ potential	460	0	0	440	Nm ³ /ton VS

Table 4 Data for characterization of waste and wastewater treatment unit processes in waste and wastewater treatment systems in Aalborg Municipality, collected in part via interviews with plant managers and municipality employees and in part from Reno Nord (2005).

<i>Process/parameter</i>	<i>Value</i>	<i>Unit</i>	<i>Process/parameter</i>	<i>Value</i>	<i>Unit</i>
Anaerobic digestion			Digestate C availability	97	% of input
CH ₄ loss	2	% of production	Compost C availability	95	% of input
Heat & power use	2	% of production	N ₂ O emission	2	% of N input
Dry matter content	10	% dry matter	Land filling		
Composting			CH ₄ production	60	% of potential
CH ₄ emission	1	% of initial C content	CH ₄ loss	80	% of production
N ₂ O emission	0.2	% of initial N content	Biogenic C availability	95	% of initial C content
Electricity use	3 10 ⁻⁵	GJ/ton input	Fossil C availability	0	% of initial C content
Fuel use	10 ⁻⁴	ton/ton input	P extraction from ash		
N loss	33	% of input N	Fuel consumption	15	GJ diesel/ton P extracted
P loss	6	% of input P	P extraction efficiency	80	% of initial ash content
C loss	50	% of input C	Sewer transport		
Mass loss	31	% of input mass	Power consumption	3.8 10 ⁻⁴	GJ/m ³ water transported
Gas engine, biogas to energy			VS/Dm degradation	10	% of input to sewer
Gas loss	3	% of input gas	CH ₄ from sewer	9 10 ⁻⁸	ton CH ₄ /m ³ water

Power prod. present	38	% of gas energy	Sludge drying		
Power prod. 2020	43	% of gas energy	Power use	0.47	GJ/ton input
Heat production	45	% of gas energy	Heat use	4.8	GJ/ton H ₂ O evaporated
Incineration (CHP), with condensation			Heat recovery	72.5	% of use
Combustion efficiency	99	%	Output dry matter content	92.9	%
Power production	28	% of LHV	Max biogas use	28	% of prod.
Heat production	83	% of LHV	Gas to heat efficiency	100	%
Power use	13	% of production	Sludge dewatering		
incineration CHP) no condensation			Electricity use	4.2 10 ⁻³	GJ/ton input
Combustion efficiency	99	%	N in solid fraction	30	% of input N
Power production	23.5	% of LHV	P in solid fraction	70	% of input P
Heat production	69.5	% of LHV	Dry matter in solid fraction	28.5	% dry matter
Power use	13	% of production	Sludge transported	70	% sludge mass
Incineration heat production only			Sludge pre-treatment		
Combustion efficiency	99	%	Power use	0.005	GJ/ton input
Heat production	85	% of LHV	Heat use	0.77	GJ/ton input
Heat use	5	% of production	Increase in CH ₄ production	25	%
Power use	5	% heat production	Transport		
Incineration no energy utilization			Fuel consumption	9 10 ⁻⁴	GJ/ton km
Combustion efficiency	99	% of LHV	Transport distance	20	Km
Equivalent electricity use	3	% of LHV	Provision of fuel	0.6	Ton CO ₂ /ton fuel
Land application			Wastewater treatment		
N availability	50	% of input	Power use COD removal	0.001	GJ/m ³
P availability	100	% of input	Power use COD, N, P removal	0.0011	GJ/m ³
Sludge C availability	97	% of input			

LHV: Lower heating value

Table 5 Energy and GHG conversion factors used in the evaluation of the waste and wastewater treatment systems in Aalborg Municipality.

Factor	Value	Unit	
CHP power production efficiency	24*	% of input	
CHP heat production efficiency	68*	% of input	
Non-CHP power production efficiency	45*	% of input	
Non-CHP heat production efficiency	95*	% of input	
Coal energy content (anthracite)	31	GJ/ton	IEA (2005)
Diesel oil energy content	48	GJ/ton	US EPA (2005)
N production power use	70	GJ electricity/ton	Poulsen and Hansen (2003)
P production oil use	15	GJ diesel/ton	Poulsen and Hansen (2003)
CO ₂ from coal combustion	2.5	ton CO ₂ / ton	IEA (2005)
CO ₂ from diesel oil combustion	2.8	ton CO ₂ /ton oil	US EPA (2005)
CH ₄ GWP factor	25	ton CO ₂ eq./ton	IPCC (2007)
CH ₄ energy content	55.5	GJ/ton	
N ₂ O GWP factor	310	ton CO ₂ eq./ton	IPCC (2007)
CH ₄ density	0.00071	tons/Nm ³	

* Averages for Danish energy producing plants based on authors personal communication with plant managers.

Results and discussion

The total energy potential in the four organic waste fractions from Aalborg in terms of upper fuel value plus the energy represented by nutrients contained in waste materials is 1.6 10¹⁵ J per year. This is equivalent to 0.2% of the total annual Danish energy consumption including transport. The population responsible for waste and wastewater production in Aalborg is about 4% of the Danish population. Figure 1 shows the energy balances for the five waste and wastewater treatment systems (five years) for Aalborg Municipality. Energy balances are presented as relative values normalized using the total annual energy potential (as defined above) in the waste. In 1970 and 1980 energy balances show relatively small energy consumptions (equivalent to less than 5% of the energy contained in the organic wastes). The reason is that none of the energy in the waste is utilized while waste treatment (transport, incineration, and wastewater treatment) requires energy. By 1990 the energy balance is positive and net energy production is equivalent to about 40% of the total energy content in the organic wastes. The main contributor to the positive energy balance is the production of heat by waste incineration. The energy consumption by wastewater treatment is offset by the energy produced via biogas production from the sludge, thus the net contribution to the energy balance by wastewater treatment is almost nil. By 2005 the overall energy balance is slightly improved and a net energy production equivalent to 42% of the total energy in the waste is now produced via waste and wastewater treatment. The main reason for the improvement compared to 1990 is the implementation of sludge drying and incineration. Again incineration contributes the largest amount of energy.

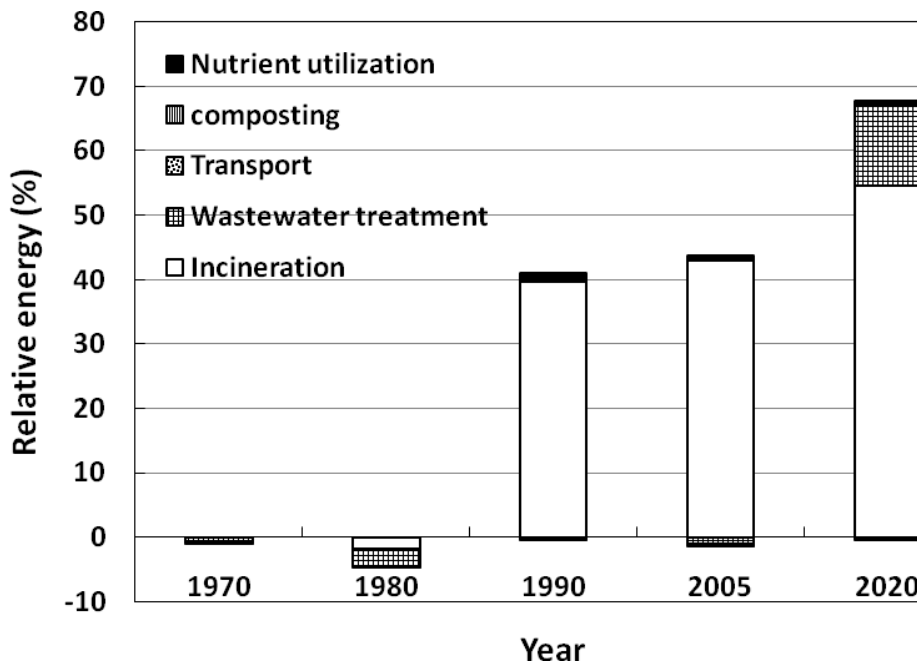


Figure 1 Relative net loss and gain of energy (normalized to the energy content in the organic waste on a dry matter basis including energy represented by nutrients) for the different waste and wastewater treatment processes used in the Aalborg Municipality waste and wastewater treatment system as a function of time. Negative numbers indicate energy losses and positive energy gains.

By 2020 it is expected that total net energy production will be equivalent to about 68% of the total energy content in the wastes. The improvement compared to 2005 is mainly due to the implementation of condensation of water vapour in the flue gas from incineration and biogas production from the food waste. Again the incineration contributes to most of the net energy production but wastewater treatment also has a significant contribution due to the digestion of the food waste in the wastewater treatment plant digester. In general it is the incineration process that has the largest impact on the energy balances while the remaining processes have negligible or small contributions only. As the energy turnover in the wastewater treatment process also is quite large (even though the net energy production is small) improvements to the wastewater treatment process for instance by implementation of a more energy efficient aeration system or a more efficient biogas production, will likely be relatively effective in improving the overall waste and wastewater treatment energy balance.

Figure 2 shows the net heat and electricity production by each of the five waste and wastewater treatment systems. In 1970 and 1980 there is a modest electricity consumption which is mainly associated with sewer transport and wastewater treatment. In 1990 there is a net energy output in the form of heat produced by waste incineration. There is also a relatively small electricity consumption associated with wastewater transport and treatment as well as with operation of the incineration plant. In 2005 both net electricity and net heat productions are positive. About 9% and 33% of the total energy contained in the waste is converted to electricity and heat, respectively. The main reason for the improvement in the electricity balance is the implementation of a combined heat and power production unit at the waste incineration plant instead of the previous unit that produced only heat. In 2020 the electricity and heat production are estimated at 19% and 49%, of the total energy content in the waste, respectively. The main reason for the improvement in the electricity balance is the production of biogas from the food waste with subsequent electricity production in a gas engine at the wastewater plant while the main reason for the improvement in the heat balance is the implementation of flue gas water vapour condensation at the incineration plant. In general the incineration and the biogas production processes have the largest impacts on the heat and electricity production while the other processes have less influence.

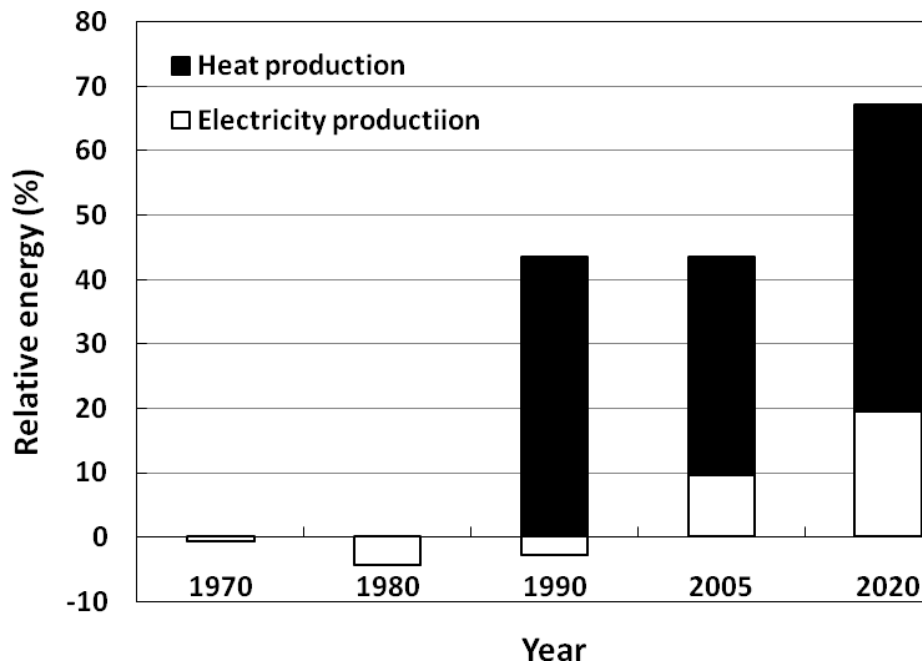


Figure 2. Net gains and losses of electricity and heat (normalized to the energy content in the organic waste on a dry matter basis including energy represented by nutrients) for the different waste and wastewater treatment processes used in the Aalborg Municipality waste and wastewater treatment system as a function of time. Negative numbers indicate energy losses and positive, energy gains.

The contribution by each of the main waste and wastewater treatment processes to the overall GHG balance for each system is shown in Fig. 3. In 1970 landfilling is the most important GHG emitter with CH₄ emissions accounting for 94% of total GHG emissions. In 1980 waste incineration is the most important emitter accounting for 52% of GHG emissions (due to combustion of wastes containing fossil carbon) while wastewater treatment (aeration) and sludge disposal (sludge beds) accounts for 21% and 25% of the GHG emissions, respectively. In 1990 and 2005 incineration (with energy utilization) is the main saver of GHG emissions accounting for 100% of emissions saved and approximately 85% of the total GHG turnover, respectively due mainly to the substitution of fossil carbon as fuel. Here saving is defined as the reduction of GHG emissions from processes such as energy and nutrient production based on fossil fuels due to substitution

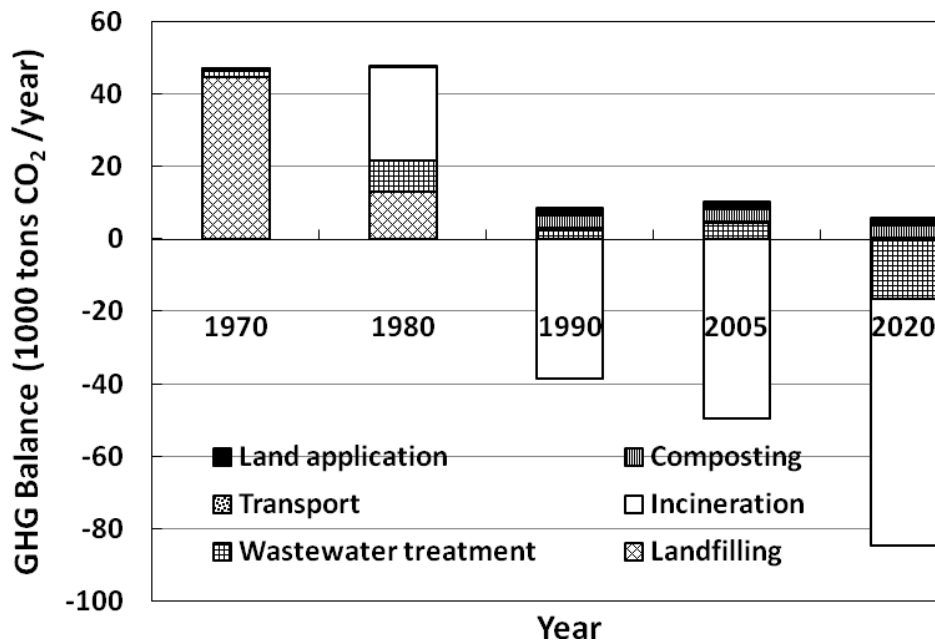


Figure 3 Contributions to overall annual GHG balances by the different waste and wastewater treatment processes used in the Aalborg Municipality waste and wastewater treatment system. Positive numbers indicate emissions while negative numbers indicate saved emissions (due to substitution of fossil fuel based energy).

by energy and nutrients produced via waste and wastewater treatment. The main GHG emitters for these two years is the wastewater treatment process (primarily aeration) accounting for approximately 7%, composting (primarily CH₄ and N₂O emissions), accounting for approximately 5% and application of compost and sludge to land (emissions of N₂O), accounting for approximately 3 % of the total GHG turnover, respectively. In 2020 incineration is still the most important saver of GHG emissions accounting for approximately 80% of the emissions saved while wastewater treatment (including digestion of the food waste) accounts for approximately 20% of emissions saved. Composting and land application of compost are net emitters accounting for approximately 3% and 2% of total GHG turnover, respectively. Generally incineration with or without energy production and biogas production (in connection with sludge and food waste digestion) with energy extraction are the two most important processes for the overall energy balance mainly due to the substitution of fossil fuel based energy. Methane emissions from landfilling of organic waste, substitution of fossil fuel based energy via incineration with energy production and biogas production with energy extraction are the three most important processes for the overall GHG balance. The remaining processes are all of minor importance with respect to both energy and GHG balances.

Figure 4 shows the net GHG balances per capita for the five waste and wastewater treatment systems in terms of CO₂ equivalents emitted or saved annually. In the period 1970 – 2005 the waste and wastewater treatment system in Aalborg changes from being a

net emitter of CO₂ (about 200 kg CO₂/(capita year)) to a net saver of CO₂ emissions (170 kg CO₂/(capita year)). With the improvements in waste and wastewater treatment assumed for 2020, emissions of as much as 340 kg CO₂/(capita year) could be saved. In comparison the total net average carbon footprint of citizens in the European Union is an emission of 8700 kg CO₂ per year (IPCC 2007).

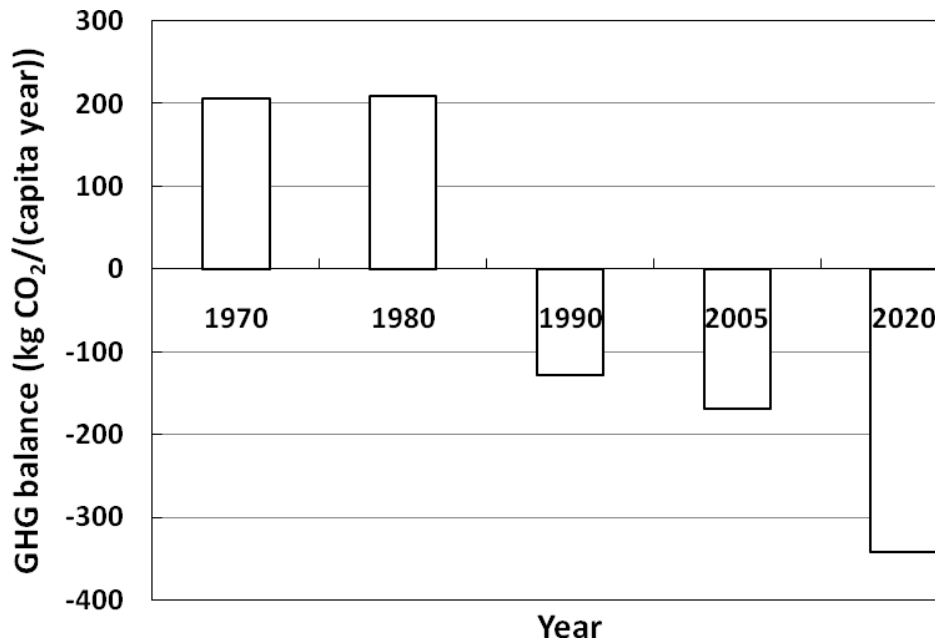


Figure 4 Net annual emissions of GHG per capita, produced (positive) or saved (negative) by the Aalborg Municipality waste and wastewater treatment system as a function of time.

An alternative: More biological treatment and land application

During the last two decades Aalborg city has wanted to improve the energy budget for the wastewater and waste management system at the same time as it has been a target to be master in own house and in control of costs. This applies to for example sludge management, where it has become essential to not depend on the mercy of farmers to accept sludge on their land; and to food waste where household collection became costly and pre-treatment before anaerobic digestion seemed both costly and with poor recovery rates of organics and high amounts of rejects.

However, what would have been the result in terms of energy recovery and GHG mitigation aspects, if focus had been on organic recovery and land application of biologically treated organic wastes? To evaluate that it has been calculated what would happen if all wastewater sludge and food waste were treated together in an anaerobic digester at the wastewater treatment plant followed by composting (to allow storage and easy handling during periods where the compost can be applied to land). Obviously the Municipality would not any more need to dry and burn the digestate from the anaerobic

digester but would instead compost it and take it to land whenever the season allows that. To illustrate the result of such alternative, figures 5 and 6 are useful.

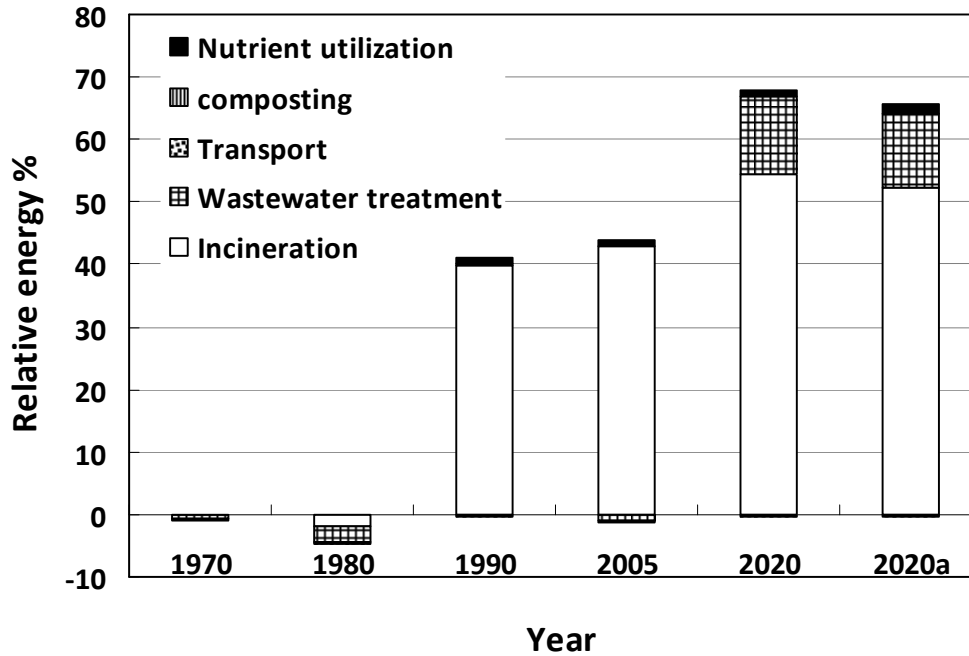


Figure 5 Equal to figure 1 but with the last column (2020a) added to illustrate the difference between an energy recovery focus versus an organic recovery focus in terms of utilising the energy (by calorific value) potentially available in the organic waste.

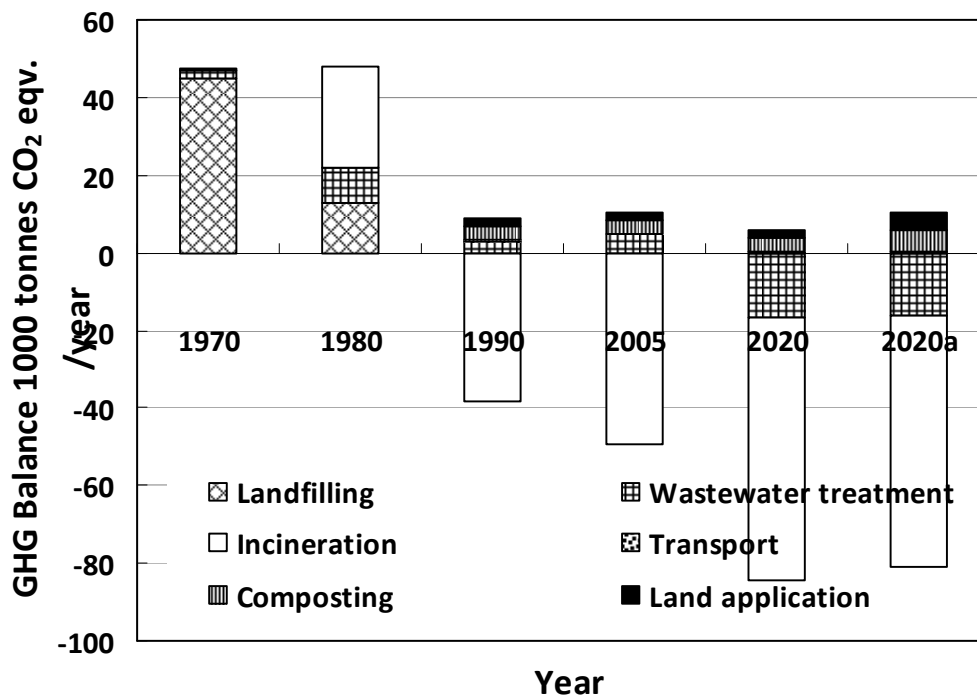


Figure 6 Equal to figure 3 but with the last column (2020a) added to illustrate the difference between an energy recovery focus versus an organic recovery focus in terms of annual GHG emissions and their origin

Obviously the recovery of potential energy stored in the organic material is very similar in the two options, giving a slightly higher recovery where focus is on energy recovery through thermal processing.

Similarly the GHG savings in the energy recovery scenario exceed those in the organic recovery scenario. But the difference is not big.

Conclusions

Based on historic organic waste and wastewater treatment data, energy and GHG balances for management of waste and wastewater in Aalborg Municipality (treating waste and wastewater from about 230.000 inhabitants) in northern Denmark for the period 1970 – 2005 were evaluated. Based on current plans for development of the waste and wastewater treatment system in Aalborg, predictions of energy and GHG balances for 2020 were also made. The evaluation included sewage sludge and municipal waste (including food waste, yard waste and other organic waste such as paper and plastic). The results show that the Aalborg waste and wastewater treatment system has progressed from being a net energy consumer and GHG emitter (corresponding to 200 kg CO₂ eqv. per capita) in 1970 to becoming a net energy producer and GHG emission saver (corresponding to 170 kg CO₂ eqv. per capita) in 2005. This has been achieved via diversion of the organic waste away from landfilling toward wastewater sludge treatment by anaerobic digestion with energy production from biogas and incineration of the

remaining waste with energy production. Predictions for 2020 indicate that both energy and GHG balances can still be significantly improved by reducing the energy consumption for wastewater treatment (primarily for aeration) increasing the efficiency of the anaerobic digestion and incineration processes and source separating food waste for anaerobic co-digestion with wastewater sludge.

In 1970 the main contributor to the energy turnover was wastewater transport in the sewer system (electricity for pumping) contributing 70%, while the main contributor to the GHG balance was landfilling (methane emissions) contributing almost 100%. Waste incineration with combined heat and power production is the largest contributor to the net energy and GHG turnover while wastewater treatment (including anaerobic digestion of sewage sludge) is the second largest accounting for approximately 80 and 10%, respectively in 2005. Remaining waste treatment processes including composting, transport, and land application of treated waste all had minor impact on energy and GHG balances.

In stead of the chosen energy recovery scenario, the Municipality of Aalborg might have chosen a organic recovery scenario, i.e. digestates from anaerobic digestion (for biogas production and energy recovery) of sludge and food wastes would be composted and applied to land. An assessment of this alternative scenario showed that the energy recovery scenario was superior both in terms of efficiency in recovering energy and in terms of GHG mitigation. However, given the wide range of variation for GHG emissions after application to land of compost (carbon sequestration and release of N₂O in particular), it would normally demand a local investigation to decide which approach is better in terms of energy recovery and climate change impact.

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