abowe
Implementing Advanced Concepts for Biological Utilization of Waste

Biomethane production from fine MSW fraction in Västerås

Assessment in material-, energy- and greenhouse gas balance point of view

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1. Introduction

Aim of Abowe project is to enhance adoption of biological utilization of waste. Project is divided into work packages where dry digestion and biorefinery systems are piloted and assessed in regional impact point of view. Assessment of material, energy and greenhouse gas (GHG) emissions belongs to work package 2. The aim of the assessments is to support business modeling of the dry digestion and biorefinery systems. Aim of this study is to assess material-, energy- and GHG balance in a biomethane production system in Västerås.

Västerås aims to increase biogas production from municipal based biodegradable waste. In current status there is collected about 16 000 t/year of separately collected biowaste to Växtkraft biogas plant, but additional biodegradable waste feedstocks are needed (1). Now, the aim is to find out that could fine fraction of municipal residual waste be used in biogas production. It was estimated that 30 000 ton of fine MSW fraction could be used in dry digestion (2). Fine MSW is sieved from crushed residual MSW with sieve size of 40 mm. In this study it is also estimated that materials that are difficult to handle in biogas process such as metals, glass and large plastic objects are removed (2). It was estimated that these difficult materials represent 20 % of total fine MSW, resulting prepared mass of 24 000 ton for dry digestion (2). This prepared fine MSW contains considerable amounts of biodegradable waste that can be digested.

There was need to assess climate impacts in dry digestion system using fine MSW fraction. In Abowe project pilot scale dry digestion system was piloted at VafabMiljö AB by key experts Tim Freidank and Johan Lindmark (2). Piloting was carried out with above mentioned fine MSW fraction for estimating its operation in full scale. Previously, utilization of fine MSW fraction was studied in technical point of view by Niklas Bergh (3) and Henny Andersson (1) as well as in economical point of view by Emma Moberg (4). These studies and piloting showed interest towards utilizing fine MSW fraction in full scale biomethane production system. However, there was still need to find out climate impacts of this system. Thus, this study introduces biomethane production system and its mass-, energy and GHG balance based on these previous studies and experiences from piloting.

2. Feedstock potential

In Sweden MSW production is millions of ton and it is mostly produced in the most inhabited areas around Stockholm and southern Sweden (Figure 1). In 2012 MSW production in Sweden was 460.3 kg/inh when total MSW production was 4 398 680 ton (5). Energy utilization was 2 270 650 ton which is 52 % of total MSW production. In 2012 biological utilization of waste was 70.4 kg/inh when total amount was 673 180 ton. Biological utilization included both composting and anaerobic digestion. Thus, 15 % of total MSW production was processed biologically. In 2013, total MSW production at VafabMiljö waste collection area was 485 kg/inh which is 154504 ton (6). In 2013 received amounts of residual MSW (*restavfall*) and source separated house hold biowaste were 49 677 t and 16 498 t, respectively (6). If 58 % of residual MSW can be separated from residual MSW as fine MSW it would correspond annually mass of 28 812 ton (3). To guarantee safe availability fine MSW of 30 000 ton per year, there might be need to increase residual MSW collection.

Biologically treated residual MSW waste could be used in landfill covering (5). Even landfilling of biodegradable waste is denied after 2016, there would be need to landfill covering material. Total landfill covering area is estimated at 25 square kilometer in Sweden. Estimated costs for landfill cover are at 6 000 M kr. It is estimated that covering material need is annually about 6 to 8 M ton until 2030 most of the landfills will be closed.

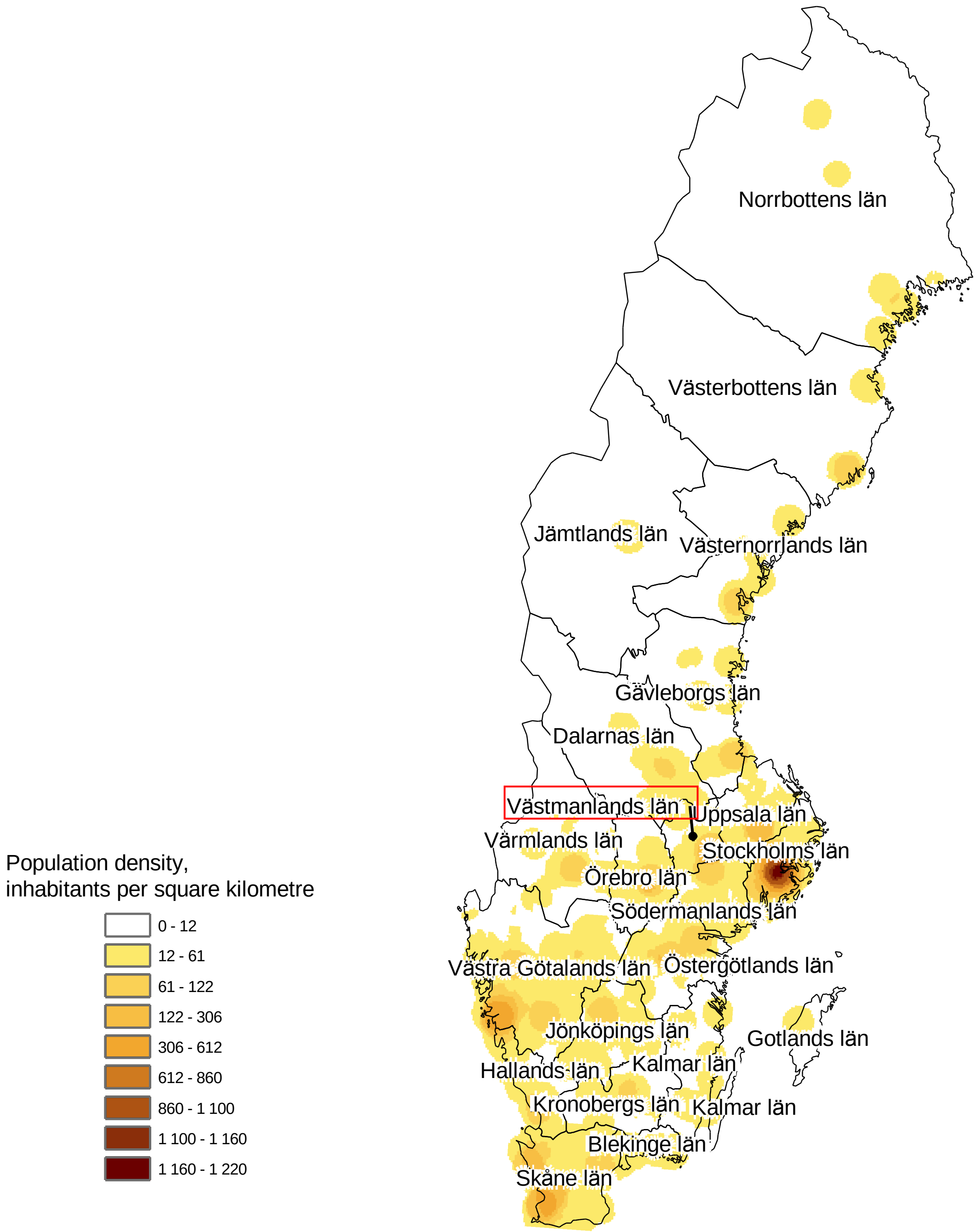


Figure 1. Population density was calculated from Eurostat grid data (7).

3. Sustainability perspective

For determining sustainability of biomethane production from MSW fine fraction, GHG emissions were assessed. GHG emission estimation is carried out according to Renewable Energy Directive (RED) GHG calculation rules (2009/28/EC). Directive determines that GHG emissions are to be calculated through the biofuel production system and those emissions are to be compared to the fossil fuel reference value. According to directive GHG emissions should be at least 60 % after 2018. This section considers GHG emission savings that can occur if MSW fine fraction is used in biomethane production instead of incineration. GHG emissions in biomethane production system are represented in section 6.

In current status most of MSW is incinerated, so it is estimated how much GHG emissions would be reduced according to RED if MSW fine fraction would be used in biomethane production instead of incineration. According to Swedish waste statistics 52 % of total MSW is incinerated (5). Thus, it is assumed that incineration of fine MSW fraction could contribute GHG emissions of 52 % of total. From life cycle inventory data base it is known than incineration of typical European MSW with typical incineration system would cause GHG emissions of 902 g CO_2 equivalents per kilo gram of waste (8). In this case it was assumed that incineration of fine MSW would cause these same GHG emissions. To determine emissions from a typical MSW fine fraction it was assumed that 52 % of MSW goes to incineration and thus cause GHG emissions of 52 % of total emissions. It result GHG emission of 469 g CO_2 equivalents per kilo gram of MSW fine fraction which is also used as initial value in GHG calculations in Section 6.

4. Biomethane production system

Biomethane production from fine MSW fraction is considered in this system (Figure 2). Fine MSW is first pre handled to adjust suitable organic loading for dry digestion at thermophilic temperature of 55 °C. Residue from dry digestion, called digestate is dewatered and liquid part is recirculated to digester. Part of produced biomethane is used in reactor heating and rest is used in biogas upgrading up to 98 % volumetric methane concentration. Biomethane is pumped to gas grid for distribution.

Dry digestion

Biogas productivity and its limitations estimation was based on piloting and literature values. Biogas reactor volume was derived from volatile solid mass flow, organic loading rate of 4 kg VS/(m^3·d) (2) and assuming that reactor volume needs 25 % for gases and 75 % for biodegradable material (1). It was also estimated that wanted feedstock TS concentration is 25 % of FM (2) and density is 650 kg/m^3 (1). Methane productivity of 217 Nm^3/(t VS) was assumed according to piloting with TS of 58 % of fresh mass and VS of 60 % of TS (2). It was estimated that 50 % of VS mass is converted into biogas and dissolved organic material when biogas volumetric methane concentration was estimated as 65 % (1).

Biogas potential test were also done for whole MSW fraction (Appendix 1.). Anna Kaivola and fellows concluded that methane potential for MSW was 167 $m^3/(t\ VS)$. They also measured average TS of 60 % of fresh mass and VS of 71 % of TS. Their result gives good perspective for understanding biogas from whole MSW fraction. By comparing methane productivities from whole MSW fraction and fine MSW fraction it can be lightly deduced that successful separation of organic fraction from MSW is highly important.

Heating

Heat consumption was calculated according to well used approximation based on enthalpy change of feedstock from its initial temperature up to target temperature (9). Thus, in this case heat consumption depends on also feedstock's water and dry matter contents. It was assumed that temperature difference between feedstock initial and final state is 50 °C. It was also assumed that gas boiler with thermal efficiency of 90 % is used to heat up biogas reactor by produced biogas. Total heat exchanger effectiveness was estimated at 50 %.

Mixing

Electricity consumption in mixing strongly depends on mixed material properties and mixer itself, but in this case electricity consumption is estimated at calculated reactor volume (10). In this case it is assumed that traditional mechanical blade mixer is used to guarantee homogenous conditions for microbes. Mixer's power need depends on speed of revolution, mixer's dimensionless constant and mostly diameter of mixer's blade, to the power of five.

Belt filter press

For further treatment of digestate there is a need to apply dewatering for it to increase its dry matter concentration and to decrease transportation costs. In this case belt filter press is considered which is known to be secure in operation for anaerobically digested sludge. Even there is need to found out case specific parameters for each material, electricity consumption and achieved dry matter concentration is estimated.

It is assumed that electricity consumption is 3 kWh/m^3 as reported by van der Roest (11). Usually, dewatering of anaerobically digested material with belt filter presses can achieve dry matter concentrations from 20 to 25 % of FM (12). Thus, in this study it was assumed that dry matter concentration of 25 % can be achieved.

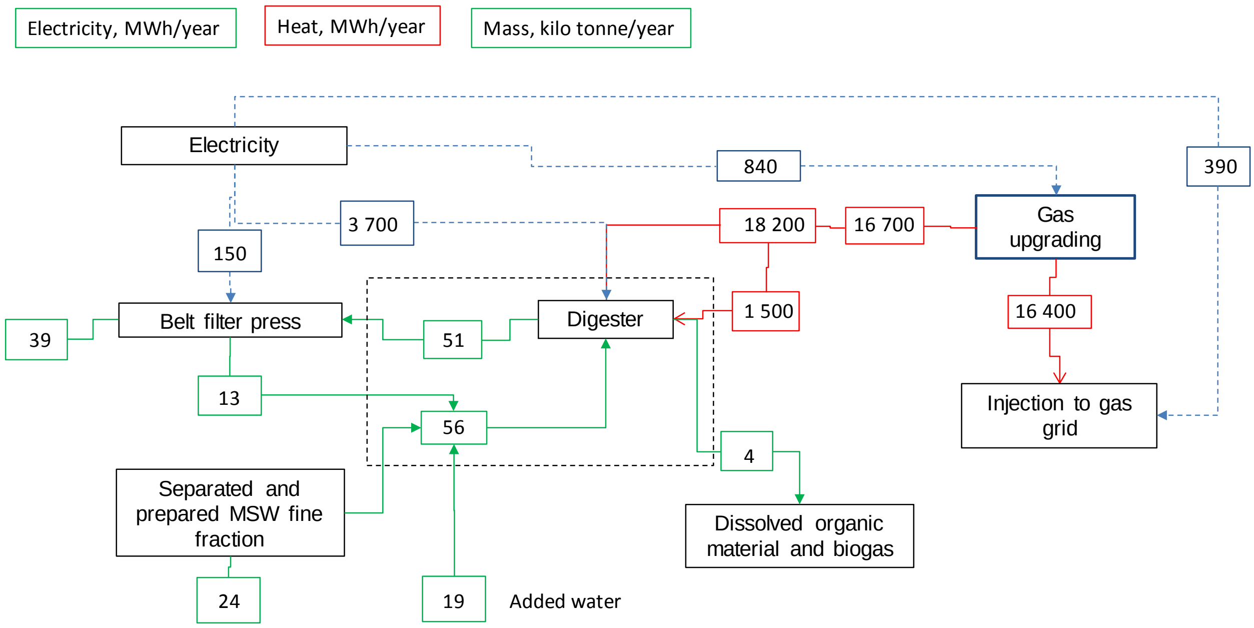
Gas upgrading

Even there are many biogas cleaning technologies it is assumed that water wash process is used to remove carbon dioxide and impurities from biogas. It is reported that with water wash it is possible to achieve methane volumetric concentrations of 98 % which is also a limit in European standardization (13). It is assumed that 2 % of methane is released to atmosphere and cause GHG emission load. Carbon dioxide is also released to atmosphere when carbon dioxide is removed from biogas with volumetric carbon dioxide concentration of 35 % to obtain biomethane volumetric carbon dioxide concentration of 2 %. It is assumed that electricity consumption is 0.3 kWh per Nm^3 of biogas fed to the system (13).

Injection to gas grid

After gas cleaning there is need to inject biomethane to highly pressurized gas grid. It is assumed that pumping work is needed to inject biomethane from 1 bar pressure to 54 bar pressure. Electrical work to the system was calculated when pump efficiency of 50 % and isothermal conditions were assumed.

5. Mass- and energy balance



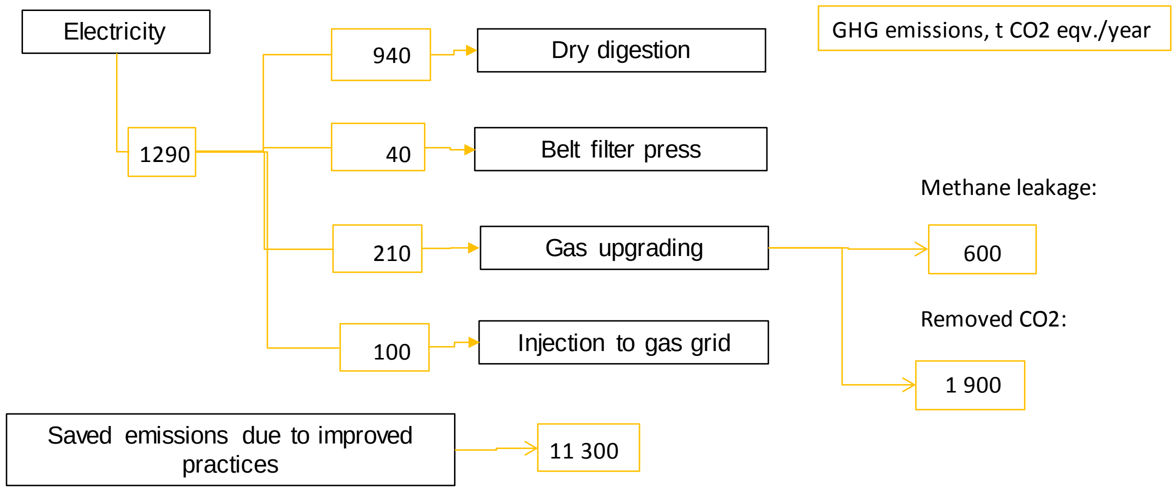
Heat in:	1 500 MWh/year	Reactor volume, m3:
Electricity in:	5 080 MWh/year	7 200
Biomethane out:	16 400 MWh/year	
Energy out/Energy in ratio:	2,5	

Figure 2. Mass and energy balance in a dry digestion system is based on input values of this report.

Digestate dewatering plays important role in dry digestion material balance. If 24 000 ton of fine MSW fraction have total solid concentration of 58 % of fresh mass as assumed, there would be need to add 19 000 ton of water and recirculated water of 13 000 ton to adjust feedstock total solid concentration to 25 % of fresh mass. In total, 56 000 ton of feedstock would be processed in the dry digestion system while 4 000 ton of volatile solids would be converted into dissolved organic compounds and biogas. When maximum TS concentration of 25 % of fresh mass in a typical belt filter press is assumed, there would be 39 000 ton of digestate for further end treatment.

One energy unit to the biomethane production system would give 2.5 unit of energy as upgraded biomethane. After adding water and reject water from dewatering step to incoming feedstock its methane productivity per fresh mass decreases. When feedstock with methane productivity of 217 m^3 /(t VS) have adjusted total solid concentration of 25 % of fresh mass and VS concentrations of 60 % of TS its methane productivity is 33 m^3/(t fresh mass). Still, compared to dairy cows methane productivity of 10 m^3/(t fresh mass), methane productivity of fine MSW fraction fresh mass would be at its moisture content three time more (14). From produced methane of 16.4 GWh/year there is extracted 1.5 GWh/year of methane for dry digestion heating considering temperature increase of feedstock from 5 °C to 55 °C and total heat exchanger effectiveness of 50 %. In gas upgrading it was assumed that 2 % of the produced biogas is lost which contribute to overall GHG emissions. Electricity consumption in the system is based on description in section 4.

6. Greenhouse gas emissions



Reference value for GHG emissions from fossil vehicle fuel production:	302	g CO2 eqv/kWh
GHG emissions in modeled system:	-7 500	t CO2 eqv.
	-460	g CO2 eqv/kWh
GHG savings	250	%
Required GHG savings after 2018	60	%

Figure 3. Greenhouse gas calculations are based on mass- and energy balance of dry digestion system.

GHG emission balance follows the results from mass and energy balance. Most of the savings are shown when biogas production from fine MSW fraction produces less GHG emissions than in its incineration. It was assumed that fine MSW fraction would contribute 52 % of the total emissions in a typical European MSW incineration resulting GHG emissions of 469 g CO_2 equivalents per fresh mass kilogram of fine MSW. If incineration of fine MSW fraction is replaced by dry digestion, GHG emissions would be degreased by 11 300 ton of CO_2 equivalent. Because Renewable energy directive does not count GHG emissions from biomethane use as vehicle fuel, GHG emissions occur only in biomethane production system (2009/28/EC). Net GHG emissions in the system are 7 500 ton of CO_2 equivalent. When compared to fossil fuel reference value of 302 g CO_2 per kWh actual reductions of 250 % could be achieved.

Even result from GHG balance is very promising there should be paid attention into digestate end use. Probably most of the organic material is degraded in biogas process, but there can be still some amounts of organic and volatile compounds that can cause GHG emissions. In this study these emissions were neglected, but in the future it would be important to know how much GHG emissions occur when fine MSW fraction is used in covering landfills. Still, GHG reductions seem to be quite promising, even if GHG emissions would be counted from biomethane use. It would result GHG emissions of 3 200 t of CO_2 equivalent which could still result GHG reductions more than 60 %.

7. Conclusions

Material-, energy and GHG balances in biomethane production system look promising. The most important variables in these balances are methane productivity, total solid and volatile solid concentration of fine MSW fraction and dewatering properties of digestate. So far assessments about digestate dewatering properties are estimated and thus needs to be defined in further studies. In *Abowe* project it is shown that piloting of dry digester would work and sufficient methane productivities can be achieved. Further information is needed about possible GHG emissions from digestate use as landfill covering material. Possible changes of fine MSW fraction properties due to waste producer’s behavior are also important. So far assessments from material, energy and GHG point of view looks promising to continue applying dry digestion system for fine MSW fraction.

8. List of appendix

1. **Anna Kaivola, Niina Kosunen & Katja Ylönen.** *Sekajätteen lämpöarvon ja metaanintuottopotentiaalin määrittäminen.*

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14. Tuomas Huopana, et al. ***A Regional Model for Biogas production; Case Study: North Savo, Finland*****. Kuopio : Remowe project, 2012. ISBN:978-952-203-170-9.**