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Rural biogas: feasibility and role in Finnish energy system

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Preface

This report is a part of the Sustainable Bioenergy Solutions for Tomorrow (BEST) research program, which is a joint research program by FIBIC Ltd, and CLEEN Ltd. BEST is funded by the Finnish Funding Agency for Technology and Innovation, Tekes. This report was co-funded by Fortum.

The aim of this report is to make a synthesis review (state-of-the-art) of rural biogas production in Finland and to assess its feasibility and role in the Finnish energy system.

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Keywords: biogas, energy, fertiliser

Summary

The Finnish theoretical biogas potential is approximately 24 TWh and techno-economical potential 10 TWh. Agriculture holds 86% of the techno-economical potential, more precisely 1.5 TWh in manure and 7.3 TWh in energy crops and crop residues. The other sources for biogas include biodegradable wastes from municipalities and industry, by-products from food production, municipal sewage sludge, and sludges from pulp and paper industry.

If the entire techno-economical biogas potential was utilised, 2.6 TWh of electricity and 4.0 TWh of heat could be produced in CHP-plants. In relation to the total electricity consumption in Finland, this potential for electricity is rather low (3%). However, if the entire techno-economical biogas potential was realised as a traffic fuel, biogas could provide about 14% of the total Finnish vehicle fuel consumption (7.4 TWh). In 2013, the amount of energy produced from biogas in reactor installations was about 260 GWh, consisting of 64 GWh of electricity, 188 GWh of heat, and 8 GWh of mechanical energy. Additionally 300 GWh of biogas energy was recovered in landfills.

General attitude towards biogas is positive and its environmental benefits are widely acknowledged. Also, support systems exist. However, poor profitability and high investment costs are the main reasons for the few rural biogas plants in Finland. The main income comes usually from energy, though in large plants also from gate fees of receiving external substrates for treatment. The price of electricity sold to grid is low and it is often challenging to find user(s) for the heat. In most profitable cases, all the electricity and heat produced can be utilized on farm and there is no need to sell the surplus. Production of transport fuel is currently limited by the low number of gas-driven cars in Finland. In the future, production of high-quality nutrient products from the digestate could offer additional incomes.

The key recommendations for manure-based biogas given in recent studies are:

- Solutions for solid manure are required
- Profitability can be sought using co-substrates for manure-based biogas
- Proper management of the digestate is vital for environmental benefits
- Biogas energy use should be adjusted according to regional needs
- Stable and clear incentives are needed to boost manure energy use

Contens

1 Introduction

Interest in biogas technology is increasing around the world due to the requirements for renewable energy production, reuse of materials and reduction of harmful emissions. Biogas technology offers versatile and case-specific options for tackling all of the above mentioned targets with simultaneous controlled treatment of various organic materials. It produces methane-rich biogas which can be utilised as renewable energy in various ways. The residual material, digestate, contains all the nutrients of the original raw materials and offers a way to recycle them. Along the process steps, also emissions directly from the raw materials (storage, use, disposal) or from the replaced products (fossil fuels, inorganic fertilisers) can be reduced.

Biogas technology is a sustainable way to utilise the energy content of manure while also recycling the nutrients and minimising the emissions. In this report, special emphasis is given to anaerobic digestion of manure, alone and with co-substrates. It is based on the findings of several projects run by MTT Agrifood Research Finland during recent years. The report provides a synthesis of the current knowledge and visions for the future.

2 Biogas in Finland

In Finland, biogas was produced in 41 reactor installations and recovered in 40 landfill gas recovery plants in the end of 2013 (table 1). The amount of biogas produced by the reactor installations was 59.1 million m^3 of which about 91% was used for the production of thermal, electrical and mechanical energy and the rest combusted without energy recovery (Huttunen and Kuittinen 2014). In landfills about 95 million m^3 of biogas was recovered. Altogether 556 GWh of energy was produced from biogas in 2013. The share of reactor installations corresponded to about 47% of the total energy production, consisting of 64 GWh of electricity, 188 GWh of heat, and 8 GWh of mechanical energy. The increase in the total amount of the produced biogas and utilization of the energy during the recent years is shown in Figure 1.

Table 1. Amount of biogas reactor installations and landfill gas recovery plants in 2013 in Finland (Huttunen and Kuittinen 2014).

Type of installations	Number of installations	Amount of biogas produced/recovered (million m^3)	Share of biogas utilized (%)	Amount of energy produced (GWh)
Farm-scale biogas plants	12			
Co-digestion plants	11			
Anaerobic reactors at municipal wastewater treatment plants	16			
Industrial anaerobic wastewater treatment plants	2			
Reactor installations altogether	**41**	**59**	**91**	**261**
Landfill gas recovery plants	40	95	75	295

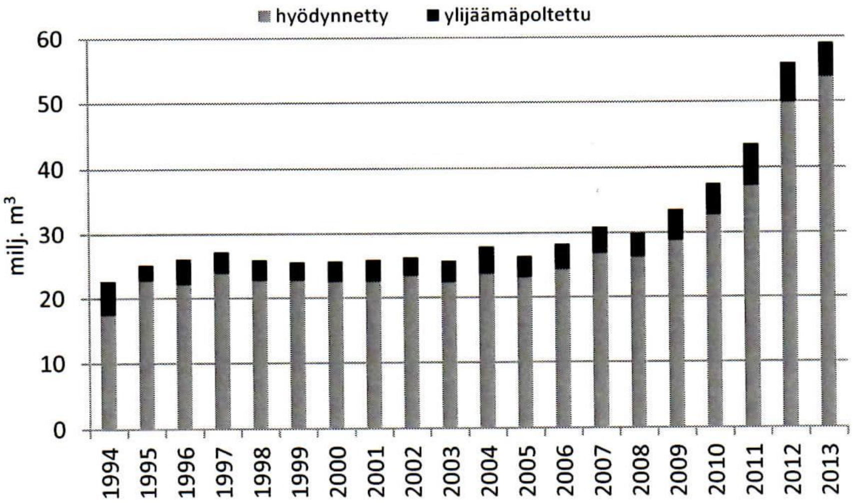


Figure 1. The total amount of the biogas produced in reactor installations and utilization of the energy in 1994-2013 in Finland. utilized, combusted without energy recovery (Huttunen and Kuittinen 2014).

3 Rural biogas production potential in Finland

In this report, rural biogas means the biogas produced from agricultural materials alone or jointly with industrial by-products, municipal biowastes and sludges.

3.1 Calculation methods

3.1.1 Manure

The manure amount (t/a) was calculated using animal numbers and minimum storage volumes for manures as defined in the building regulations and instructions for agriculture in Finland (MMM RMO 2001). The number of cattle, pigs, poultry, sheep and goats were obtained from the official agricultural statistics of 2009 (TIKE 2012) and the number of horses and ponies from 2010 (HIPPOS 2012). The farm size was also from agricultural statistics (TIKE 2012). The manure amounts as different manure types (manure left on pasture, slurry, dung and urine, farmyard manure, deep litter) were calculated using the national model for agricultural nitrogen emissions (Grönroos et al. 2009). The biological methane potentials (BMP) used are reported in Luostarinen 2013, with the additional assumption of the BMP of manure from sheep, goats and fur animal was equal to the BMP of horse manure.

The energy potential of Finnish manure was estimated as biogas, assuming 1 m^3 of methane to contain 10 kWh of energy. The theoretical energy potential included all manure in Finland, while the techno-economical energy potential included only farms with more than 100 animals (cattle, pigs, poultry, sheep and goats). Half of the horse manure available was included into the techno-economical potential, assuming smaller stables not to process their manure in biogas plants. All manure from fur animals was included into the techno-economical potential due to lack of data on farm size. All manure left on pasture was excluded from the techno-economical potential.

3.1.2 Energy crops

Energy crops (table 2) include green biomass from fallow lands, protective zones, grass lands and straw from grain fields. In this context, managed uncultivated arable fields (and some other similar type areas) were considered as “fallow”. The theoretical volume of grass biomass available from fallow lands was obtained by multiplying the cultivation area in 2013 by the average yield (15.1 t/ha) measured by Niemeläinen et al. (2014). The techno-economical volume was estimated to be harvested from areas larger than 1.45 ha (62 % of the total area).

Protective zones are 15 m wide strips of field close to waterways, e.g. rivers or lakes. These areas are covered with perennial plants, often grass, and the biomass should be harvested once a year to prevent nutrient run-off. Since the harvesting is obligatory, the total and the techno-economical biomass volumes are equal in table 3. The same average yield as for fallow (15.1 t/ha) was used for the biomass collected from the protective zones.

The total cultivation area for grass (average of the years 2013 and 2014) and the average yield (17 t/ha) were obtained from the official agricultural statistics (TIKE 2014). The techno-economical potential, however, was taken from Seppälä et al. (2014). In this report, the techno-economical potential was calculated according to the decrease in the number of ruminants in Finland during 1990–2012, which equals to 205 ha. This area could be used for other purposes than feed without lowering the amount for feed production. Seppälä et al. (2014) also estimated an average yield of 18 t/ha for grass production.

The cultivation areas for various grains (average of the years 2013 and 2014) and the corresponding average yields were obtained from the official agricultural statistics (TIKE 2014). Straw is a by-product from grain cultivation. The amount of straw, which can be harvested from the field, can be estimated based on the grain yield. A proportion of straw:grain varies from 0.65:1 to 0.95:1 depending on the variety of the grain (Huusela-Veistola et al., 1991). However, from this theoretical volume, which can be harvested from the fields, only 36% is estimated to be available for energy use (Hakala et al., 2014). Every second year the straw has to be cultivated into the soil to maintain soil organic matter. In addition, unsuitable weather conditions may prevent harvesting, which decreases the straw yield every second year by 10%. Finally, from the straw collected, up to 20% is used as bedding material in animal husbandry.

The energy potential of energy crops was estimated as biogas similarly than the energy potential of manure. Since the biological methane potential (BMP) of energy crops was given per dry matter (DM) of biomass in the references, also the dry matter contents were needed for the energy potential calculations (Table 2). The same values as for fallow were used for the biomass collected from the protective zones.

Table 2. Dry matter content and the biological methane potential (BMP) per dry matter of energy crops

Energy crops	Dry matter (%)	BMP (m^3 / t DM)	Reference
Fallow	33	255	Nieméläinen et al., 2014
Grass	30	314	Seppälä et al., 2014
Straw	90	258	Tähti & Rintala, 2010

3.1.3 Industrial by-products, municipal biowaste and sewage sludge

The theoretical and techno-economical energy potential of vegetable waste was obtained from Tähti & Rintala (2010), where the theoretical potential included the storage losses of grains and vegetables, waste from vegetable farming and the amount of tops of potatoes. To the techno-economical potential only the tops of potatoes and sugar beets were included.

The energy potential of municipal biowaste was obtained from Tähti & Rintala (2010), where the statistics of biowaste production were evaluated.

The theoretical potential of sewage sludge included all sludge types produced in Finland, while the techno-economical potential incorporated only the sludge produced in the largest cities (Tähti & Rintala 2010).

The theoretical energy potential of food industry wastes obtained from Tähti & Rintala (2010) included animal and plant based wastes from both small and larger scale food industries. The same study assumed that half of the food industry waste is used as animal feed or in processing of other materials, which decreased the techno-economical potential by 50%.

Pulp and paper industry sludge potentials included primary and biological sludge produced in Finland and the techno-economical energy potential was estimated to be 96% of the total (theoretical) potential (Tähti & Rintala 2010).

3.2 Biogas potential

The theoretical biogas potential of Finnish biomasses is about 24 TWh, while the techno-economical potential is about 10 TWh (Table 3). Agriculture holds 86% of the techno-economical potential, more precisely 1.5 TWh in manure and 7.3 TWh in energy crops and crop residues.

The Finnish targets for biogas stated in the National Energy and Climate Strategy is 1.2 TWh until 2020, which means 0.7 TWh increase from year 2005. About half of the target was met in 2013 when the biogas-based energy production was 0.556 TWh (0.261 TWh from reactor installations and 0.295 TWh from landfill gas recovery plants).

In relation to total electricity consumption in Finland (85 TWh in 2012; Statistics Finland 2013), the techno-economical biogas potential is rather low (3%). If the entire techno-economical biogas potential was realised as a traffic fuel, biogas could provide about 14% of the total vehicle fuel consumption (54 TWh in 2012; Statistics Finland 2013).

Table 3. Theoretical and techno-economical biogas potentials of different biomasses.

	Volume, theoretical (t/a)	Volume, techno-economical (t/a)	Energy, theoretical (GWh)	Energy, techno-economical (GWh)	$Electricity_{CHP}$ (GWh)[a]	$Heat_{CHP}$ (GWh)[b]	Vehicle fuel (GWh)[c]	Cars (amount)[d]
Manure (cattle)	11 394 827	3 041 258	3 205	770	193	304	556	47462
Manure (pig)	2 039 893	1 760 785	468	395	99	156	285	24332
Manure (poultry)	173 189	158 945	171	157	39	62	114	9698
Manure (sheep and goat)	141 287	53 099	54	20	5	8	15	1260
Manure (horse and pony)	530 706	157 591	204	61	15	24	44	3739
Manure (fur animals)	196 072	147 878	75	57	14	22	41	3509
Fallow	2 567 582	1 587 727	2 161	1 336	335	528	965	82343
Protective zones	111 897	111 897	94	94	24	37	68	5803
Grass	9 647 772	3 758 333	9 088	3 540	888	1 399	2 556	218193
Straw	2 703 063	973 103	6 267	2 256	566	892	1 629	139041
Vegetable waste	1 162 053	288 053	400	94	24	37	68	5793
Biowaste	306 000	260 101	460	283	71	112	204	17441
Waste water sludge	981 486	575 584	390	224	56	89	162	13805
Food industry waste	1 187 060	593 530	560	275	69	109	199	16948
Pulp and paper industry sludge	21 000 000	20 160 000	690	635	159	251	458	39135
Total	**54 142 888**	**33 627 883**	**24 289**	**10 198**	**2 558**	**4 030**	**7 363**	**628503**

[a] Energy consumption of biogas process 24%, electrical efficiency in CHP 33% (www.biokaasulaskuri.fi 2014)

[b] Energy consumption of biogas process 24%, thermal efficiency in CHP 52% (www.biokaasulaskuri.fi 2014)

[c] Energy consumption of biogas process 24%, fuel conversion efficiency 95% (www.biokaasulaskuri.fi 2014)

[d] Fuel consumption 7,1 m^3/km, 16500 km/a (Tähti & Rintala 2010)

According to the National Waste Plan, 10% of manure produced in Finland should be processed in biogas plants in 2016. Currently, there are no official statistics of manure processing in Finland. However, the estimated amount of manure processed in biogas plants is about 220 000 tons, which accounts for 1.5 % of the total volume of manure (about 14 milj. t/a). The Finnish biogas plants, which are suspected to process manure at least as part of the feedstock are shown in Fig. 2. They are mainly located in regions with high animal density.

Figure 2. Locations of Finnish manure processing biogas plants in relation to animal density and manure. Animal data: Evira 2011, Biogas plant data: Huttunen and Kuittinen 2012 and the authors.

3.3 Spatial distribution of biogas potential

3.3.1 Manure

The Finnish pig production is concentrated to South-West Finland and Ostrobothnia (Fig. 3). Poultry production is the densest in South-West Finland, but big production units are located also in South-Ostrobothnia. Cattle production is not as concentrated as pig and poultry production, but dense areas can be found along Ostrobothnia and in North-Savo region. Spatial distribution of techno-economical biogas potential of different manures is shown in Fig. 3 separately for cattle, pig and poultry manure and for all manures in Fig.4.

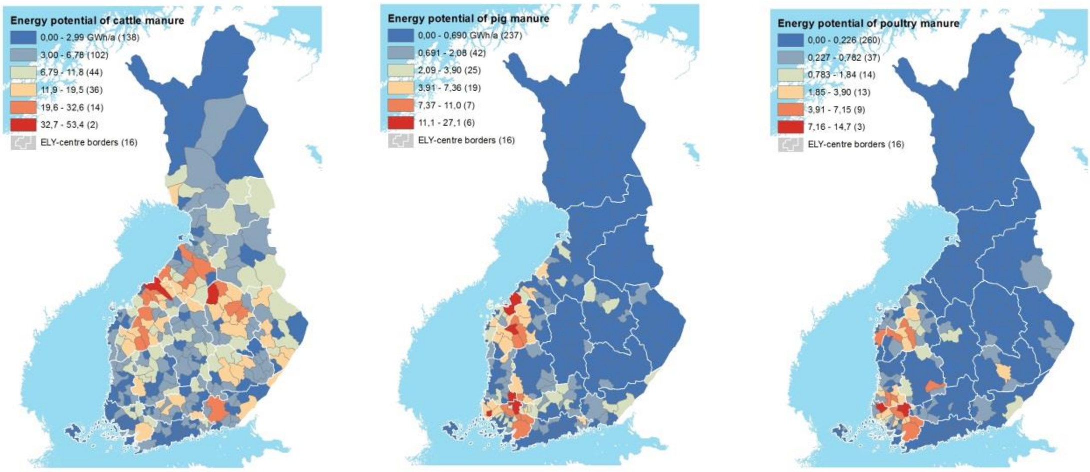


Figure 3. Spatial distribution of techno-economical energy potentials of cattle, pig and poultry manure in Finland (based on information presented in Luostarinen 2013a).

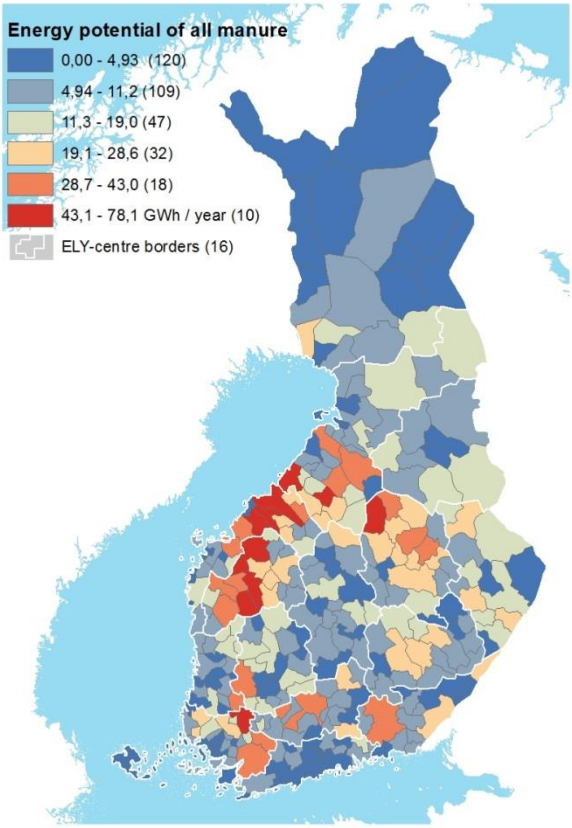


Figure 4. Spatial distribution of techno-economical energy potentials of all manure in Finland (based on information presented in Luostarinen 2013a).

3.3.2 Energy crops

The highest energy crop potential is in the same areas as the manure biogas potential. This is because the energy crop potential was mostly calculated as field area released from animal feed production due to decreasing amount of ruminants, and subsequent use of this area for energy grass production. Spatial distribution of techno-economical biogas potential of energy crops and manure together is shown in Fig. 5.

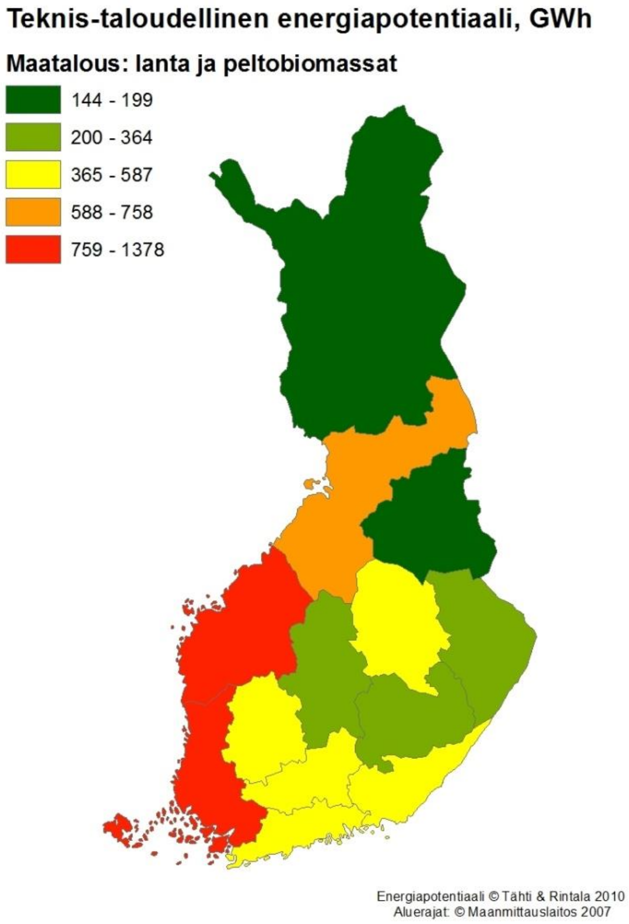
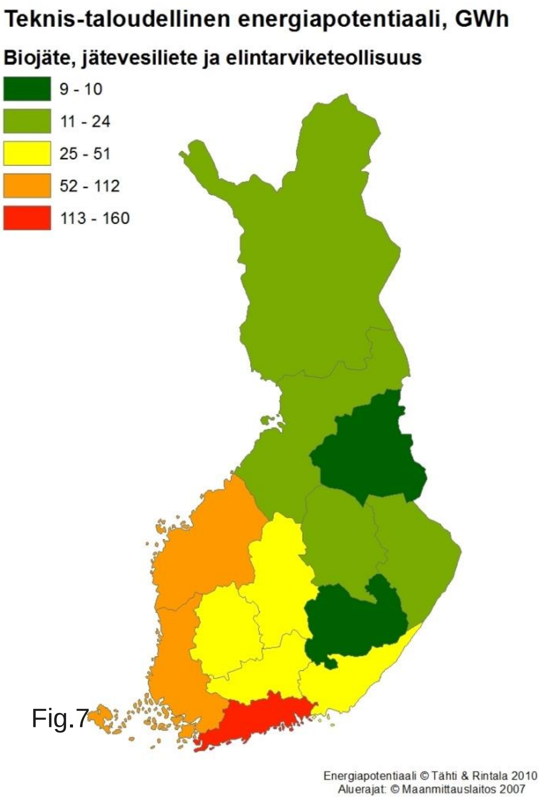


Figure 5. Spatial distribution of techno-economical energy potential of agriculture (manure+energy crops) in Finland. Energy crops account for about 80 % of the total techno-economical energy potential (based on Tähti & Rintala 2010).

3.3.3 Industrial by-products, municipal biowaste and sewage sludge

The biogas potential of municipal biowaste and sewage sludge is related to population density, which is the highest in South Finland. Biowaste account for about 2.8% and sewage sludge 2.2% of the total techno-economical biogas potential in Finland. The biogas potential of food industry by-products (2.7% of the total techno-economical biogas potential in Finland) is more equally distributed around the country than that of municipal biowaste and sewage sludge, the highest potential being in western Finland (Tähti & Rintala 2010). Forest industry is centralized in Eastern Finland resulting the highest biogas potential of pulp and paper industry sludge in that area. It account for about 6.2% of the total techno-economical biogas potential in Finland. Spatial distribution of techno-economical biogas potential of food industry by-products, municipal biowaste and sewage sludge is shown in Fig. 6 and biogas potential of pulp and paper industry sludge in Fig. 7.



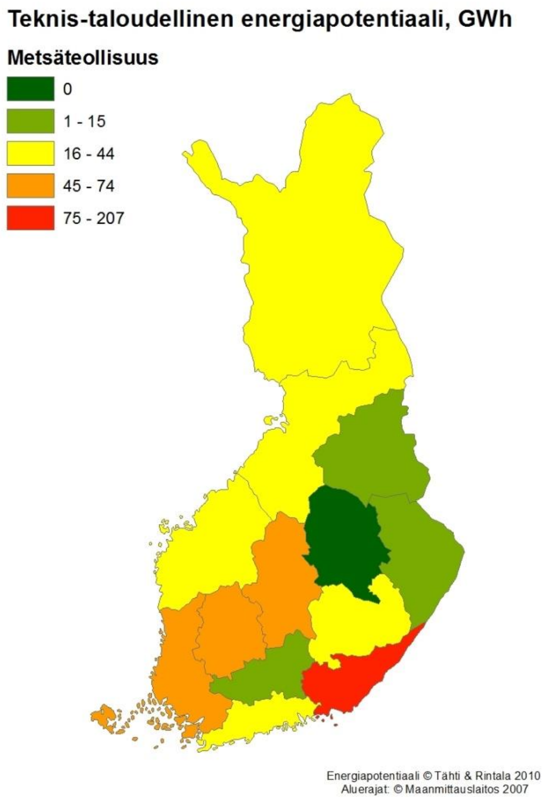


Figure 6. Spatial distribution of techno-economical energy potentials of food industry by-products, municipal biowaste and sewage sludge in Finland. (based on Tähti & Rintala 2010)

Figure 7. Spatial distribution of techno-economical energy potentials of pulp and paper industry sludge in Finland. (based on Tähti & Rintala 2010)

4 Rural biogas production potential in Finland

4.1 Options for establishing biogas plant in rural areas

Agricultural biomasses (manure, energy crops, crop residues) are good substrates for biogas production due to their high biodegradability in anaerobic conditions. Based on the substrate, biogas production processes are divided into wet and dry processes. Particularly slurry-based (cattle, pigs) wet processes are considered to be mature technology. The most common process for digestion of slurry is continuously stirred tank reactor (CSTR) with continuous feeding and simultaneous withdrawal of digestate. Raw materials with high total solids content can be used as co-substrates in wet processes. However, the total solids content in the feed mixture should not be higher than 14% (Luostarinen et al. 2011a).

Dry processes use only substrates with high total solids content, such as poultry and horse manure, grass silage and crop residues. Their technical maturity is not as high as with wet processes, but some reactor types are currently commercially available also for farm scale. So far they are mostly operated as batch processes when agricultural biomasses are used as substrate. The most common batch reactor is a garage type, which is filled with a front loader and then closed for the biogas production period. Also, continuous dry processes have been developed and one example is a plug-flow type.

Although dry processes are somewhat used in Central Europe, e.g. when using maize or solid manure as a substrate, this technology still needs to be adjusted for the Finnish farms, taken in consideration the production scale, available raw materials, digestate quality and northern environmental conditions. In Finland there is at least one farm-scale batch process in Laukaa (Kalmari biogas plant) and one continuous dry process in Sotkamo (MTT biogas plant).

When suitable substrates are available, biogas is a viable option for the farm heat production instead of heating with oil or wood chips. Even the electricity needed on the farm can be produced from biogas with a combined heat and power (CHP) unit. Furthermore, upgrading biogas for vehicle fuel use is possible.

In addition to energy production, a biogas plant on the farm has also other benefits. Biogas process is an easy way to handle possible excess silage, which would otherwise need to be composted and then spread separately on the field. Grass silage used as co-substrate increases the biogas production from the feed and the nutrient content of the digestate. Furthermore, digestate is a better fertilizer than manure as such, since the amount of nitrogen (ammonium) directly available for the plants increases during anaerobic digestion. Experiments with co-digestion of dairy cattle slurry and grass silage showed that the degradation of organic nitrogen resulted in 40–65% increase in ammonium nitrogen in the digestate (Luostarinen et al. 2013c). The odour of the digestate is better tolerated than that of raw manure and its hygienic quality is improved during digestion.

Three operational scales are shortly described here. Technological and operational solutions for biogas plants are more closely referred in Luostarinen et al. (2011a).

4.1.1 Farm-scale biogas plant

A farm-scale biogas plant is one option for producing rural biogas. For example, in MTT Maaninka biogas plant (reactor tank 300 m^3, post-digestion tank 300 m^3) the basic feed is dairy cattle slurry (3 500 m^3/a, approximately 110 cows) and some excess grass silage (max 350 t/a; Luostarinen et al. 2013c). In some farms, like Kalmari farm, Laukaa (reactor tank volume 1 000 m^3), also by-products from food industry and grass silage is co-digested with dairy cattle slurry (Luostarinen et al., 2011b). The farm may build totally new structures for the biogas plant or it may use existing constructions on the farm, e.g. manure storage tanks as part of the biogas plant. The workload for the farmer can be minimized by using simple design and e.g. automated feed and removal. Basic measurements and process control are needed to maintain a stable process.

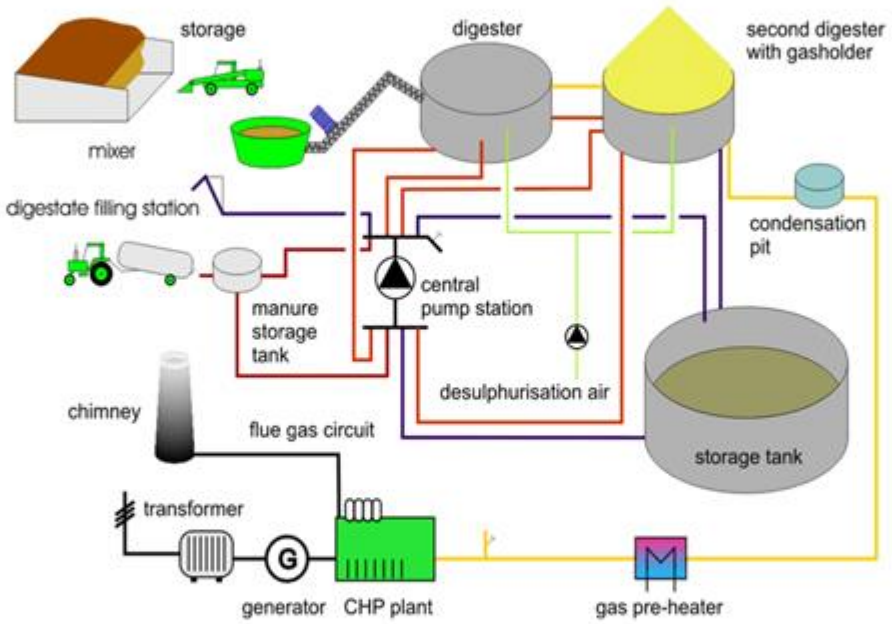


Figure 8. General scheme of a farm-scale biogas plant (http://www.wfuel.info/news.php?s=10)

General scheme of a farm-scale biogas plant is presented in Figure 8. Slurry (or other liquid feed) is collected from animal housing to a covered pre-storage tank, which is equipped with a stirrer. Liquid feed is pumped to a gas-tight reactor tank. If solid substrates are used as a co-substrate, they are transferred directly to the reactor tank with a separate conveyor.

The reactor tank can be made e.g. of concrete or steel and can be located partly under soil surface in order to make use of the insulation capacity of soil. In Finland, the tank needs to be well insulated to minimize heat loss, because typical temperature for mesophilic process is +37°C. The reactor contents are stirred with e.g. a submersible mixer. The digestate is withdrawn (by gravity or pumping) in succession with feeding the reactor. The average hydraulic retention time of the substrates in the reactor can be calculated by dividing the reactor volume by daily feed volume. The retention time needed depends on the substrates. If only cattle slurry is used, 25–30 days is usually sufficient, but with grass silage as a co-substrate the retention time must be increased to ensure proper degradation (Luostarinen et al. 2013c).

A post-digestion tank is recommended for all biogas plants. Due to the continuous mixing mode and daily feed addition, part of the easily degraded organic material leaves the reactor prior to being degraded. It continues to be degraded in the following tank as the microbes are still active. In case of an open storage tank, considerable methane emissions may occur and the energy content is not fully utilized. Thus, a gas-tight post-digestion tank should be used especially when co-digesting manure and energy crops / crop residues. The post-digestion tank (and sometimes also the reactor tank) can be used to store the biogas e.g. by covering it with a two-layered hood. Temperature in the post-digestion tank is usually not controlled but it is insulated to ensure high temperature and thus high microbial activity.

Finally, the digestate is led to storage tank(s) and later used as an organic fertilizer on the fields. The produced biogas is led through a condensation pit (water removal) to heat boiler and/or to CHP unit. In the most profitable cases, the farm can use all the produced energy for heating and covering the farms's electricity need. Small-scale upgrading units are also available enabling vehicle fuel production.

4.1.2 Farm cooperative biogas plant

Farm cooperative biogas plant is a considerable option when there are several farms within short distance of each other. Instead of building many small plants, one large plant has lower investment costs in relation to the biogas produced. For the same reason, it may also be possible to include more advanced technology. The basic construction in the farm cooperative biogas plant is similar to the farm-scale plant (Figure 8).

There are both more challenges and possibilities in a farm cooperative biogas plant compared to a farm-scale plant. First of all, straightforward production of heat and electricity might not be economically feasible. Only the main farm closest to the plant can use the electricity, while the rest of the electricity is sold to the grid. In Finland, if the power output of the plant is more than 100 kVA, it is possible to join feed-in tariff system and have the guaranteed price for the electricity sold. However, this option is more likely in the larger production scale with centralized co-digestion plants. It may also be challenging to find user for the heat, unless the plant is located near a district heating network or some other installation requiring a lot of heat (e.g. industry, greenhouse). Upgrading biogas to biomethane is also one option to utilize the biogas.

Logistics of manure and digestate between the partner farms and the biogas plant needs to be planned carefully. One solution to cut down the transportation costs is to remove water from manure or digestate by separation. When manure is separated into liquid and solid fractions, the liquid fraction can be used as a fertilizer on the partner farm and only the solid fraction is transported to the biogas plant. The same strategy can be used with the digestate. Still, when using wet process technology, sufficient part of the feed must be e.g. slurry to ensure dry matter content below 14% or the feed needs to be diluted. The co-operation between the partner farms may enable to divide the digestate between the farms optimally.

An example of a farm cooperative biogas plant is Bioson Oy in Juva. It is owned jointly by several farms and a greenhouse (http://www.ilmase.fi/site/?page_id=1105). The biogas production started in 2011. The volume of the reactor tank is 1 700 m^3 and the volume of the post-digestion tank 2 000 m^3. Cattle slurry (13 000–14 000 m^3/a), solid chicken manure (2 000 t/a) and vegetable waste (1 000–2 000 t/a) are used as substrate. Heat (2 000 MWh/a) and electricity (1 400 MWh/a) produced from biogas are used in Turakkala greenhouse which is located on the same slot as the biogas plant.

4.1.3 Centralized co-digestion plant

Centralized co-digestion plants are usually working on industrial scale and owned by companies. The technological solutions are more complex, e.g. the process is fully automated. The basic feed may still be from agricultural origin but also various industrial side-streams are used as substrates. Depending on the substrate, an additional hygienization (70°C, 1 h) and other pre-treatment steps might be needed.

In addition to the energy production, the role of a centralized co-digestion plant may also be waste treatment. In this aspect also part or even the main income may be a gate fee for the received biomass. In planning of this kind of activity it should be noted how to handle the digestate rich in nutrients. The total nutrient load is the same in substrate and digestate. To avoid the problem of concentrating nutrients locally, the digestate needs to be processed to various fertilizer products, which can be then transported to a longer distance and used where they are needed.

Biovakka Finland Oy in Vehmaa was the first rural centralized co-digestion plant in Finland (http://www.biovakka.fi/vehmaan-biokaasulaitos). The biogas production was started in 2005. The plant has an environmental permit to treat waste streams from agriculture (pig manure) and food industry up to 120 000 t/a. The biogas produced is converted to electricity and heat and the total power output is 4 MW. In addition to energy, the plant produces concentrated nutrient products, which can be used as organic fertilizers, but also in the industry e.g. to replace urea and phosphoric acid.

4.2 Aspects of biogas plant feasibility

The profitability of a biogas plant is always case-specific and consists of several aspects. Aspects related to feedstock, plant investment, energy production and digestate utilization are shortly described here. The most important factor in biogas plant feasibility is, however, the constant and predictable cash flow. Incomes associated with the biogas process may contain revenues from energy, gate fees from treatment of waste materials and revenues from selling the digestate, while the operational costs usually consist of costs of the feedstocks, service and maintenance costs and other costs (e.g. personnel costs, insurances, marketing, administration). The net income must be positive to allow feasible operation.

4.2.1 Feedstock

The energy value of a feed material is related both to the amount and type of organic matter. For example, energy content in 1 tons of cattle slurry is about 200 kWh, while in 1 ton of slaughterhouse waste it is about 2000 kWh. Some examples of properties of different feedstocks are shown in Table 4.

Table 4. Properties of some typical biogas plant feedstocks (www.biokaasulaskuri.fi)

SYÖTE	Total solids (TS)	Volatile solids VS/TS	CH_4-pot.	CH_4-pot.
	(%)	(%)	(m^3/tVS)	m^3/t fress weight
Cattle slurry	5-14	75-85	120-300	5-36
Cattle solid manure	17-25	68-85	100-250	12-53
Pig slurry	4-10	75-86	180-490	5-42
Pig solid manure	20-34	75-81	162-270	24-74
Poultry solid manure	32-65	63-80	150-300	30-156
Grass silage (hay)	20-40	90	213-360	38-130
Slaughterhouse waste	20-31	90	200-910	36-254
Municipal biowaste	27	90	400	97
Municipal sewage sludge	3-50	70	200-400	4-140
Biological sludge from pulp and paper mill wastewater treatment	20	70	100	14
Primary sludge from pulp and paper mill wastewater treatment	20	70	300	42

As biogas plants usually are operated as continuous mode, constant availability of the feedstock throughout the year is important. Important aspects related to feasibility are also the transport distance and storing of feedstock. Furthermore, supply of some feedstocks cause costs (e.g. cultivation of energy crops), while gate fee is obtained from some feedstocks as a compensation of taking care of waste management. In addition to the gate fee, additional feedstocks may foster incomes by increasing the energy yield of the plant. Currently, most co-digestion plants base their economy to the gate fees. Legislation sets requirements for the treatment technique of some feedstocks, which may increase the investment costs of a biogas plant. In rural areas, the availability of suitable waste materials in surroundings of biogas plants is, however, often limited. Furthermore, some actions in Finnish agri-environmental support system do not favor processing manure in biogas plants (Marttinen et al. 2013).

4.2.2 Biogas plant investment

Biogas plant size and costs depend on the amount and type of feedstocks and the technique used. For example the digestion of energy crops usually need a longer retention time than manure, which in turn increases the need of reactor volume. Hygienization and other pre-treatment steps may increase the investment cost in plants processing waste-based materials. Typically investment includes basic equipment, buildings, piping and electrical works, and other equipment, such as cleaning systems. Also project costs including development costs, such as loans must be included in investment costs.

Investment cost of a biogas plant is rather high, though usually the unit cost of biogas installation decreases with increasing reactor volume. Farm-scale plants that cannot join the feed-in tariff system can have investment support. Investment support can also be given to big biogas plants upgrading biogas to biomethane. An estimation of the investment costs at farm-scale can be calculated with a tool available on a webpage: www.biokaasulaskuri.fi.

4.2.3 Energy

Biogas can be utilized as various energy products. At farm scale, the most typical choices are either production of heat in a boiler or combined heat and power production (CHP). At farm-scale biogas plants where the operation is based solely on agricultural feedstocks, the only solid income is usually the revenues from energy, which makes feasible operation challenging. The energy income is the highest, when the biogas producer can use all the produced heat and power on his own farm for replacing commercial energy. In that case the revenue consists of the price of the electricity avoided (electricity sales, electricity distribution, and in some cases taxes) and the costs avoided of the alternative fuel for heating.

If the producer sells electricity to the grid, the revenue is the price of electricity sale negotiated with the supplier, which is less than half of the total price of electricity bought. In Finland electricity from small scale production can be sold to the grid, but not directly to the final user. Electricity is usually produced in CHP plants, producing also heat. Heat could be sold directly to the customers, but the challenge usually is to find a buyer sufficiently closely located. Biogas producer can also sell the biogas as such for a buyer who produces the energy. Another option is to upgrade biogas to biomethane and sell it to customers for vehicle fuel or to the natural gas grid operator.

Taxation of small-scale electricity production may have an effect on the profitability of biogas plant. Plants with electricity production unit smaller than 50 kW can use the produced electricity for example in farming activities without paying electricity tax. At biogas plants, however, the power output is often higher than that. If the electricity power output is higher than 50 kW and part of the produced electricity is sold to grid, the electricity tax must be paid also of the electricity used in the farm. This may dramatically decrease the revenues obtained from energy.

Larger biogas plants, where the electrical power output is more than 100 kVA, can have a guarantee price for electricity sold to the grid. Guarantee price is 83.50 €/MWh and the additional heat premium is 50 €/MWh if 50% of heat is utilized (75% in plants >1 kVA). Furthermore, the support system contains some limitations, eg. no second-hand parts are allowed.

In August 2014, there were nine biogas upgrading plants in Finland with upgrading capacities of 10–1100 Nm^3/h (Huttunen & Kuittinen 2014. There are few companies, also Finnish ones, already on the market providing technology also for small-scale upgrading. In rural areas, biomethane can be sold as a vehicle fuel in a distribution station on the farm or to the natural gas grid if the farm is located in the close proximity.

Effect of substrate on energy gain of a biogas plant

The energy content of the substrate(s) affects the net energy gain of a biogas plant. In the production process, the substrate needs to be heated to the processing temperature

(+37°C in a mesophilic process). Substrates, which contain a lot of water, consume a lot of heating energy, but have a low methane production potential. In addition, due to the low methane production potential of this type of substrates, also larger volume of the reactor tank is needed for the same biogas production, which increases the electricity consumption in mixing. Slurry, which is in other terms suitable substrate for biogas production, has a relatively low methane production potential. In experiments at MTT Maaninka biogas plant operated with cow manure, methane production increased by 50% when the feed contained 10% of the fresh weight grass silage (Luostarinen et al. 2013).

Part of the biogas energy is used for heating the feed materials and to compensate for the heat loss from the reactor as well as covering the power need of the equipment. The share of heat and power the plant itself consumes of the energy it produces depends on the scale, substrates and technical design. For example, in MTT Maaninka farm-scale biogas plant the heat consumption is about 15–26 % of the total energy production (Luostarinen et al. 2013c). Typically, the higher the dry matter concentration of the substrates is, the lower share of the total energy production is consumed by the plant itself. Dry fermentation is operated in higher solids concentration than a slurry process and may need less energy for feedstock heating and mixing, but this technology is not reviewed in this report.

Challenge between biogas energy production and the energy demand of the farm

The electricity and heat demands on the animal farm are not synchronized. While electricity demand is usually more or less constant throughout the year, the heat demand is highest during winter. For example with cow house electricity consumption, more electricity is needed for lightning during the winter, while during the summer the ventilation demands more electricity. These electricity consumptions counteract each other and the electricity need remains similar throughout the year. On the other hand, the energy needed for heating depends on housing choice and the outside temperature.

An example farm-scale biogas plant, with 4 300 t/a cattle slurry and 150 t/a grass silage as feed, produces all the heat and almost all the electricity needed on the farm. The total energy production is higher in the winter, because during the summer the cows are partly on the pasture and this part of the manure is lost. The grass silage feed is constant because only silage left over is used. Fig. 9 shows the electricity production and consumption on the farm. During summer, either some electricity needs to be purchased or more co-substrate needs to be fed in the biogas reactor.

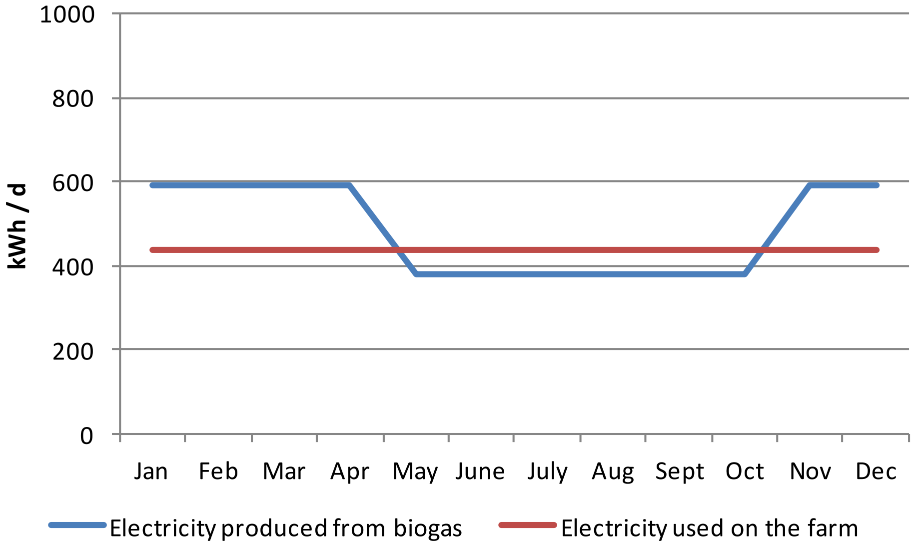


Figure 9. Example of the net electricity production from a farm-scale biogas plant and electricity used on the same farm. The lower electricity production in summertime is due to pasturing.

Fig. 10 shows the heat production and consumption on the farm. During summer, the heat is produced multiple times what it is needed, even if the electricity production during the same time is somewhat below the consumption of the farm. It would be important to find some use for the excess heat, because it is not possible to adjust the produced heat/electricity-ratio of a CHP-unit.

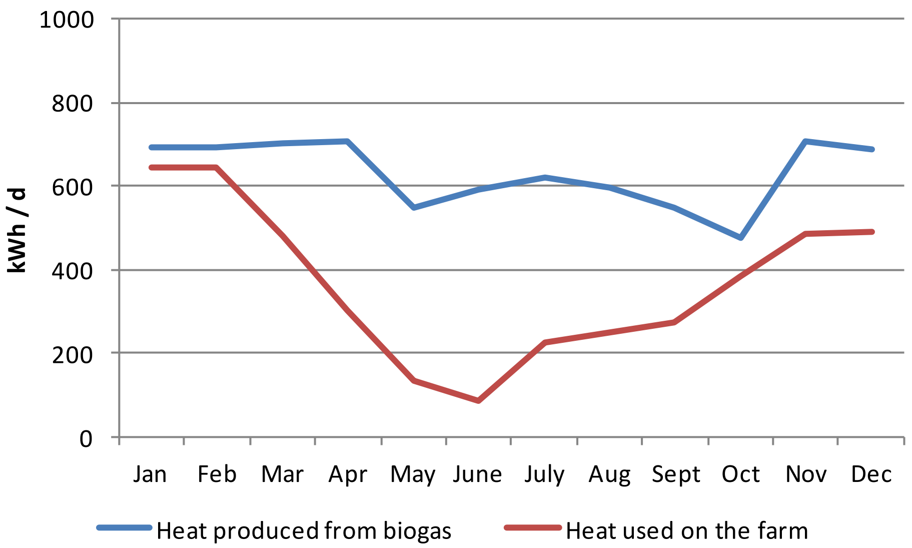


Figure 10. Example of the net heat production from a farm-scale biogas plant and heat used on the same farm.

4.2.4 Digestate

Biogas plant digestate contains all the nutrients of the feedstock. The value of nitrogen is improved, because part of organic nitrogen is solubilized to ammonia which is immediately available for plants. Digestate can be used as fertilizer in agricultural fields as such, but often some kind of post-treatment is done to decrease the water content of the digestate or to separate nitrogen and phosphorus to different fractions. The reason behind these is lowering the transportation costs of the digestate.

Especially in intensive animal production areas, where large amounts of manure is produced, the past and present manure inputs may have raised the soluble P level in field soils meaning that addition of P is not allowed. Separation of digestate to liquid and solid fractions allows transportation of the P-rich solid fraction to areas with actual need for P. For farm-scale simple solutions are needed, while in larger biogas plants more sophisticated post-processing technologies may become feasible. For example, liquid fraction may be processed in stripping unit, where nitrogen is separated and collected as concentrated ammoniumsulphate, which have uses in both agriculture and industry. Solid fraction may be processed, for example, in thermal processes to dry pellets with high phosphorus content.

Although nutrients in digestate obviously have value and can be used to replace mineral fertilizers, no revenues are currently obtained from selling digestate-based products for fertilizer use. Organic digestate-based fertilizers need more storage capacity than mineral fertilizers and their spreading is more time consuming with current machinery in addition to being less precise and not necessarily in the nutrient ratios the crop requires. This decreases farmers’, especially on crop farms, interest to use such fertilizers. Currently, some digestate-based nutrient products are sold to industrial purposes.

Digestate may have the status of being applicable for organic production, if it meets requirements stated in legislation, which may increase the monetary value of the digestate. Some digestate-based products, for example concentrated nitrogen liquid, may be used also in industrial purposes. However, these applications usually require that the digestate is further prosessed, which, in turn, is costly. At this moment, the driver to post-processing of digestate, is usually the need to transport nutrients further distances from the biogas plant, not the revenues obtained from the product. However, it’s commonly expected, that in future digestate will have higher role in biogas plant revenues (Marttinen et al. 2013)

Biogas process also sanitizes raw materials, reduces the number of animal and plant pathogens and destroys some of the seed germination of weeds. Hygienization is the more effective the higher temperature is used. For example the complete destruction of the salmonella typically requires using a separate hygienization unit (70°C, 1 hour).

The biogas process also effectively reduces the smell of manure and thereby reduces odors from manure application. Currently, the manure smell may even prevent the enlarging the farm installation.

5 Environmental aspects of biogas

Biogas technology allows utilizing both energy and nutrient content of biomass. Also, reduction in greenhouse gas (GHG) emissions can be achieved, depending on the choices made in the entire management chain. The emission reduction potential of a biogas plant should be estimated throughout its life cycle starting for example from storage of manure or other waste materials or from cultivation of grass to be used for biogas production. In the end of the management chain is the use of the energy produced from biogas and the use of the digestate as fertilizer or in other solutions. The total emission reduction potential is evaluated by summarizing the total emissions and emission credits (avoided emissions as compared to a management chain without biogas technology) together throughout the life cycle.

Management chains of, and thus emissions from, materials being processed in biogas plants vary case-specifically. For example in biogas plants processing manure, GHG emissions can be formed in manure storage prior to the biogas process as well as during loading, mixing and actual transport of manure from a farm to a biogas plant. It is important to ensure that methane emissions are minimized in each management stage as methane has a high climate warming potential. A crucial step is to ensure sufficiently long retention time for the substrates processed under gas-tight conditions. At farm scale, this is usually done in unheated post-digestion tanks from which the residual biogas is collected and utilized in energy production. Failure to collect this residual biogas might result in high methane emissions and also significant loss of energy potential. Emissions are also formed in the agricultural use of the digestate, as with any other fertilizer.

As compared to traditional manure management (long storage, direct fertilizer use), biogas plant may decrease GHG emission of manure management via e.g. avoiding emissions from manure storage. In addition to decreasing GHG emissions, significant GHG emission credits/savings can be achieved by replacing fossil fuels with biogas-based renewable energy and by replacing mineral fertilizers with the digestate. Life cycle analysis (LCA) of manure processing biogas plants will be presented in forthcoming report of the authors.

Rural biogas technology may also have other positive environmental effects than merely GHG mitigation. The air quality is affected by a lower level of different pollutants, such as ammonia, particulate matter, nitrogen oxides, carbon monoxide, and carcinogenic hydrocarbons when biogas-based energy is used instead of fossil fuels.

The biogas process can be used especially when aiming at closed nutrient and energy cycles (Fig 11). All the nutrients in the substrates of a biogas plant can be recycled via using digestate as fertilizers or in different industrial applications. The plant-availability of nitrogen is typically improved by 15–50% when agricultural materials are used, due to part of the organic nitrogen being converted to soluble ammonium nitrogen during digestion. When digestate is spread on growing crops, the crops can take up more of the nitrogen immediately as compared to using e.g. raw manure. This may also reduce nutrient leaching to water. On the other hand, the risk for ammonia evaporation increases due to higher ammonium nitrogen content. In order to reduce harmful ammonia emissions and loss of valuable nitrogen, it is recommended to store digestate in covered storages and spread it at a proper dose on growing crops or prior to sowing using injection and/or mulching. Recycling of nutrients via biogas processes reduces the use of mineral phosphorus and energy consumption of fertilizer manufacturing. The digestate also contains organic matter, which is vital to the maintenance of soil carbon stock.

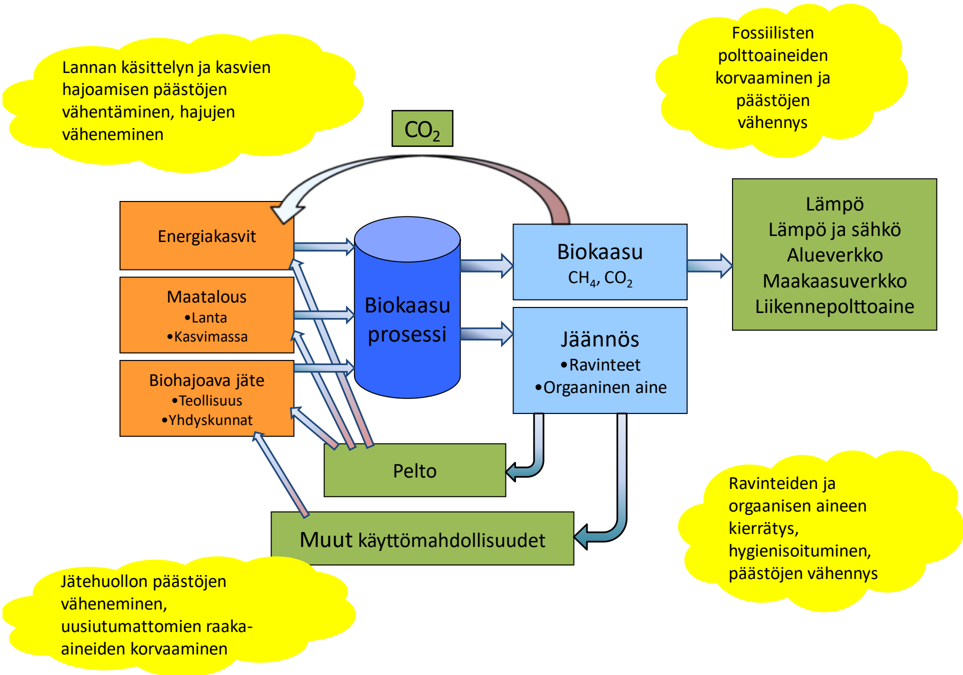


Figure 11. Cycles and environmental aspects related to biogas technology.

6 Extended summary and visions for the future

The theoretical biogas potential in Finland is 24 TWh and techno-economical potential 10 TWh. The distribution of potential between different feedstocks is shown in Figure 12. Both the theoretical and techno-economical biogas potentials are compared with current production and targets set in Fig. 13.

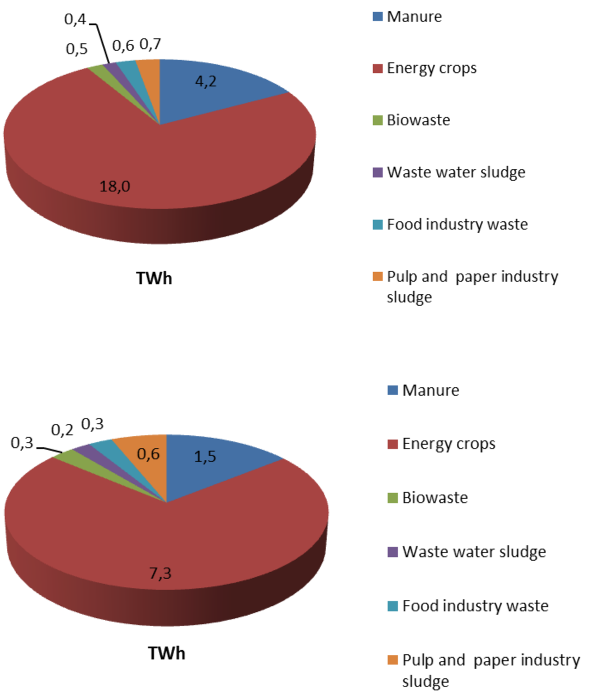


Figure 12. The theoretical (left) and techno-economical (right) biogas potential of different feedstocks.

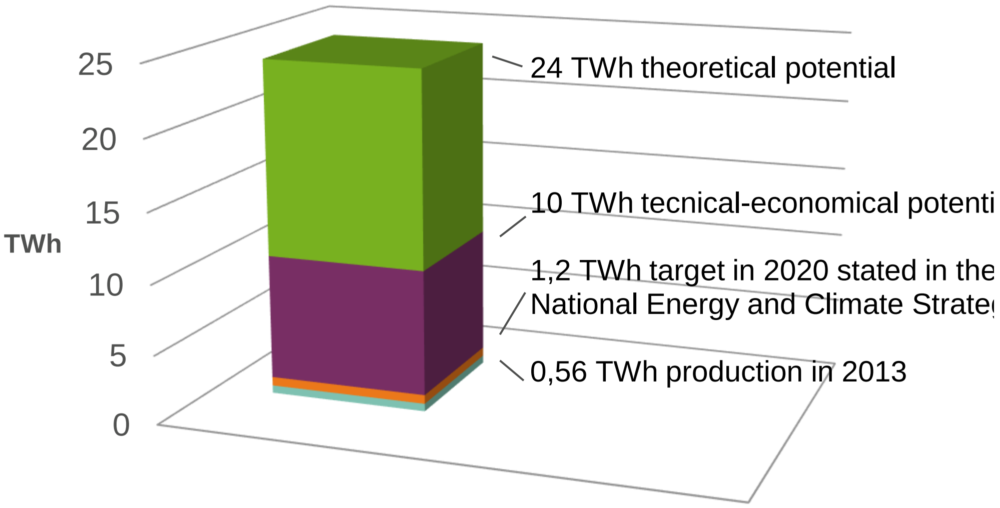


Figure 13. Finnish theoretical and techno-economical biogas potentials, target for 2020 and production in 2013.

Figure 14 shows the energy production potential, if the entire techno-economical potential would be transferred to heat and power at CHP plants or upgraded to biomethane to be used as vehicle fuel. Biogas-based electricity and vehicle fuel potentials are compared with the total consumptions in Fig. 15.

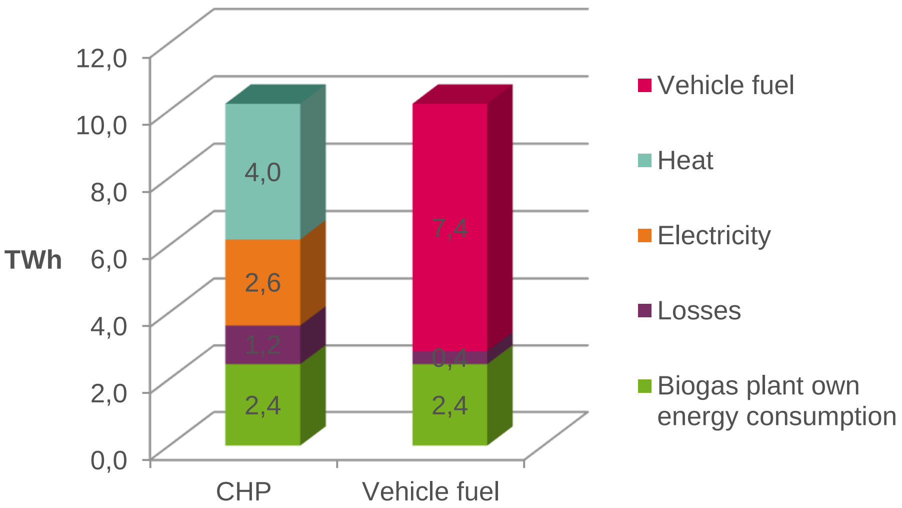


Figure 14. Energy potentials in two cases: the techno-economical biogas potential (10 TWh) is completely transferred to heat and power (CHP) or upgraded to biomethane (Vehicle fuel). (Current production from biogas: 0.064 TWh of electricity, 0.19 TWh of heat, and 0.008 TWh of mechanical energy; Huttunen & Kuittinen 2014).

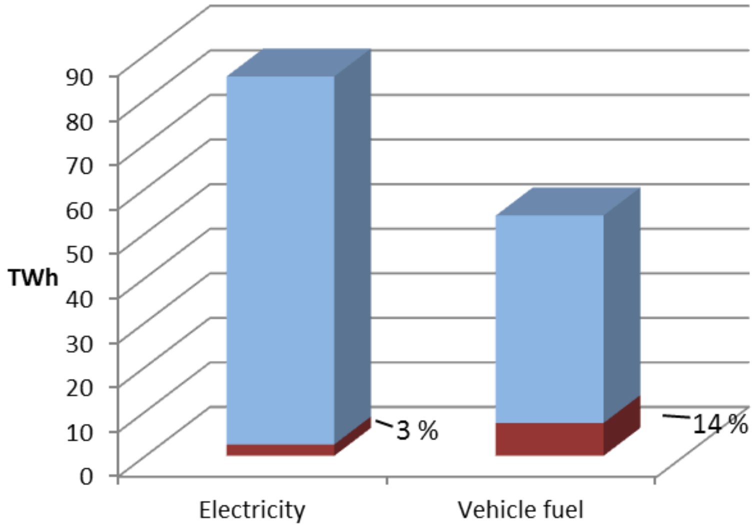


Figure 15. Total electricity and transport energy consumption in Finland 2012 and the amount which could be produced from biogas (■ techno-economical potential)

There has been a high interest among farmers in establishing biogas plants already for several years in Finland. General attitude towards biogas is positive and its environmental benefits are widely acknowledged. Also, support systems exist. However, poor profitability and high investment costs are the main reasons for the few rural biogas plants in Finland. The main income comes usually from energy, though in large plants also from gate fees of receiving external substrates for treatment. The price of electricity sold to grid is low and it is often challenging to find user(s) for the heat. In most profitable cases, all the electricity and heat produced can be utilized on farm and there is no need to sell the surplus. Production of transport fuel is limited by the low number of gas-driven cars in Finland. Gas-driven tractors are, however, currently available, which and this can increase farmers interests to produce own fuel. In the future, production of high-quality nutrient products from the digestate could offer additional incomes. Incentives and barriers for manure energy use are more closely discussed in reports of Marttinen et al. (2013) and Luostarinen (2013b).

Farmers often see the biogas plant as “a missing piece” of the energy and material cycles in their farm (Marttinen et al. 2013). According to interview of the rural biogas entrepreneurs (Marttinen et al. 2013) the most common motivations establishing a biogas plant are the following:

- biogas plant would support and diversify their other businesses
- own energy production would lower the farm’s dependency of commercial energy, which is supposed to be more expensive in the future
- biogas plant would improve the nutrient recycling in the farm

Support systems and taxes will highly influence on the increase of biogas plants number. Current tax system related to own electricity consumption in the farm is regarded unfair among rural biogas entrepreneurs (Marttinen 2013). If the electricity power output is higher than 50 kW and part of the produced electricity is sold to grid, the electricity tax must be paid also of the electricity used in the farm. Processing manure in biogas plants is an option to obtain greenhouse gas (GHG) emission reductions in agriculture, which could be one driver in supporting biogas plants. As the operation time of a biogas plant is long, the related strategies, support systems and legislation should be predictable.

In future, there could be regions which are self-sufficient in terms of energy. On those areas short-distance transfer and selling of electricity could be allowed. On those areas biogas could be part of the energy portfolio.

The share of energy crops in the total biogas potential in Finland is high, but currently very few plants use them as feedstock. For example, utilization of grass biomass from water protective zones would offer also environmental benefits (Luostarinen 2013b). In Finland, the use of water protective zones is often limited due to no use for the produced biomass. In case where biogas plants were available, the grass could be directed to digestion providing a win-win situation (manure use would become more efficient and protective zones would become more attractive). Economy of harvesting and logistics of these materials is challenging and to be developed further. Furthermore, new raw materials, like algae, could offer additional biogas potential.

Investment cost of a typical biogas plant using slurry process is high. Dry fermentation technology and new cheaper technological solutions for slurry fermentation could increase biogas investments.

In Baltic Manure-project a comprehensive study of rural biogas state-of-art and best practices in Baltic Sea Region was made. The key recommendations for manure-based biogas were (Luostarinen 2013a)

- Solutions for solid manure are required
- Profitability can be sought using co-substrates for manure-based biogas
- Proper management of the digestate is vital for environmental benefits
- Biogas energy use should be adjusted according to regional needs
- Stable and clear incentives are needed to boost manure energy use

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