abowe

Implementing Advanced Concepts for Biological Utilization of Waste

Heat and electricity production from biodegradable waste

Case studies: Lithuanian and Estonian target areas

Integrated report considering outputs: O.2.2 and O.2.6

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1. Introduction

Waste-to-energy systems are favored in European waste-to-energy policy mostly due to reduce GHG emissions and to increase resource efficiency. Therefore, biogas electricity system was assessed in this *Abowe* project work package 2 in West-Lithuanian and Estonian target areas. Feasibility of a dry digestion system was assessed by using a regional model to give feedback for potential investors and Savonia University of Applied Sciences for business modeling. Dry digestion system from Ostfalia University of Applied Sciences was piloted in Lithuanian and Estonian farms and offered parameters for modeling. In addition, local experts from target areas were used to estimate correct input parameters.

Lithuania and Estonia favor European waste policy by using taxation to prevent landfilling of biodegradable waste and by giving incentives for biogas electricity production. In addition, in European emission trading system (ETS) most of the largest combustion plants could reduce the need to buy CO_2 emission allowances from the system by using zero emission fuels as biogas (2003/87/EC). Thus, feedstock potentials and economically sustainable biogas electricity production was optimized in these target areas by using a regional model.

Lithuania aims to increase its biogas electricity production from 50 GWh/year in 2010 up to 413 GWh/year in 2020 [1]. To increase investments in biogas electricity sector, a biogas electricity production system was modeled in the Lithuanian target area which considers Telšiai, Šiauliai, Taurage, Klaipeda, Panevežys provinces. By using the model the most cost efficient waste-to-energy solutions were found for the biogas CHP system. Household biowaste and sewage sludge were considered as feedstock for the system having sanitation while cattle solid manure was considered as feedstock for systems without sanitation process. Public data sources were used to derive operational income, personnel demands, annual material and energetic production rates, saved GHG emissions and the most cost efficient plant and feedstock selections for systems. Public data included information about field areas and locations, district heating plant locations and energy production rates, sewage sludge production and locations, population in geographical origins, number of domestic animals in agricultural facilities as well as published information about biogas heat and power production costs.

Household biowaste was considered as potential feedstock in Estonian operational environment. Even Estonia has not given any target for biogas electricity production [1]; Estonian 2020 target in renewable electricity production would be achieved by increasing biomass usage in electricity production from the level in 2005 of 33 GWh/year up to 346 GWh/year by 2020. Still, increasing tax from municipal solid waste landfilling would cause pressure to degrease waste generation and to prevent landfilling. Thus, household biowaste was considered as potential feedstock for biogas electricity production. In addition, agricultural waste biomass potential was estimated.

1.1 Emission trading system, ETS

The goal of the European emission trading system is to reduce GHG emissions by trading emission allowances in an auctioning system (2003/87/EC). Annual allowances are decreased by 1.74 % from the annual average mounts that member states have set in their national plans for 2008-2012. Due to solidarity in European ETS Lithuania and Estonia receive 46 % and 42 % more emission allowances that it would get from ETS system, respectively (2003/87/EC). Lithuania and Estonia receive a relative amount of allowances that is proportional to the amount of its GHG emissions in 2005 of the total GHG emission in EU in 2005.

In heat and power production sector only large plants producing GHG emissions are included into the ETS, but there are some exceptions. GHG emissions gases that belong to the emission trading system are Carbon dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Hydrofluorodarbons (HFCs), Perfluorocarbons (PFCs), Sulphur Hexafluoride (SF_6). District heating plants as well as plants that follow directive (2004/8/EC) about efficient co-generation of heat or cool would receive emission trading rights without payment (2003/87/EC). In addition, waste incineration plants are excluded from the system. Still, plants that have nominal thermal production power more than 20 MW belong to the system.

1.2 Outlook for biogas production in Lithuania

It seems that biogas technology is coming more and more common in Lithuania, but in the current status it seems that only few biogas plants exists. Currently biogas is produced at least in waste water treatment plants in Kaunas and Utena, in one pig farm and one food industry enterprise in Rokiskis [2]. Total volume of operating bioreactors comprises 24 000 m^3, and annual production of biogas is about 6.3 million m^3 per year (3.4 ktoe) [2]. It was also reported that sewage sludge treatment plant in Klaipeda has biogas plant [3]. In 2008 Klaipeda's plant produced in 7175 t/year of sewage sludge while in the region it was estimated that 13.6 t DM/inh of sewage sludge is produced annually.

Guaranteed prize for biogas electricity in Lithuania is the most favorable for small scale plants [4]. National Control Commission (NCC) for Prizes and Energy sets the tariff prizes in every three months which are guaranteed for 12 years. Plants that have biogas nominal electricity production power less than 10 kW shall have guaranteed prize set by NCC. A guaranteed prize is paid for plants that produce electricity from renewable energy sources no more than 50 % of the total during a calendar year. For example, in the second quarter of 2013 guaranteed prize for plants having nominal RE electricity capacity less than 10 kW was 0.55 LTL/kWh which is approximately 0.16 €/kWh (1 LTL = 0.29 €). In the same second quarter of 2013 tariff prizes for plants that had nominal electricity production power more than 10 kW had the following structure:

- Installed capacity from 10 kW to 500 kW: 0.51 LTL/kWh (~0.148 €/kWh)
- Installed capacity from 500 kW to 1000 kW: 0.48 LTL/kWh (~0.139 €/kWh)
- Installed capacity from 1000 kW to 2000 kW: 0.46 LTL/kWh (~0.133 €/kWh)
- Installed capacity exceeding 2000 kW: 0.44 LTL/kWh (~ 0.128 €/kWh)

1.3 Outlook for biogas production in Estonia

So far, only three biogas plants are producing biogas in Estonia [5]. Terts AS (Ltd) produces heat and electricity from biogas in Pääsküla Landfill (Tallinn). Tallinna Vesi AS produces biogas from sewage sludge in its wastewater treatment plant (WWTP) in Paljassaare (Tallinn). It uses its biogas to run the aeration compressors in the WWTP. Saare Economics OÜ (Ltd) produces biogas heat and electricity from swine slurry. Other biogas producers are landfill biogas producers that flare their biogas. In 2010 Estonia produced 71.8 GWh of biogas heat and 43.1 GWh of biogas electricity [5]. Most of the biogas heat of 44.7 GWh was produced in landfills while 19.3 GWh and 7.8 GWh were produced from sewage and slurry gas, respectively.

In Estonia, premium tariff and investment support can be given for biogas electricity production plants. Still, it should be also taken into account that Estonian Government is going to reform its inventive mechanisms in becoming years since Estonia seems to achieve its 2020 faster than it was expected. At the moment, biogas electricity producers can receive bonus price of 53.7 €/MWh on top of the selling price when production capacity is less than 10 MW. For example, medium size industries had in 2011 electricity costs of 61.6 €/MWh [6] which means that biogas electricity producer would receive electricity prize of 115.3 €/MWh from the target group. Grid operator is obligated to pay the bonus price in 21st of each month to the electricity producer. In addition, renewable electricity producers must inform in 5th of each month grid operator with data about sold electricity from renewable energy resources. Bonus prices are valid for 12 years [4]. Still, it is been under of discussion to decrease feed-in tariff levels from renewable electricity production [5]. Decision about reformed feed-in tariff system is expected in becoming years.

Investment support for heat and electricity production from biomass is available for farmers that get at least 50 % of their incomes from processing and selling agricultural products. The amount of support can vary from 40 % to 60 % of the total investment costs when maximum amount is 0.512 million €. Based on public calls, farmers should apply the support from Estonian Agricultural Register and Information board. Supports are funded from European Agricultural Fund for Rural Development. [4]

Estonian taxation system in becoming years could reinforce actors in waste management sector to take in use new ways of handling household biowaste and municipal waste. In 2009 landfill tax rates for basic non-hazardous waste, including residual household biowaste waste was [7]:

- 10.0 € per ton on compliant landfills
- 20.0 € per ton on non-compliant landfills
- 30.1 € per ton on old non-compliant landfills

In addition landfill tax for non-hazardous waste including municipal waste, will be increased up to 29.84 €/t after 1.1.2015 [7].

2. Biogas CHP model

There are several factors which have effect on the operational income of the biogas electricity production system. The biogas CHP system considers feedstock transportation to the plant, digestate transportation and spread as well as heat delivery to the end user as it was previously reported [8]. Produced electricity is assumed to be used in the production site. Because municipal biodegradable waste is considered as feedstock for the plant there is considered feedstock sanitation for household biowaste and sewage sludge. Due to thermal losses there is considered auxiliary reactor heating. Biogas entering from the reactor is used in heat and electricity production in the CHP unit which is considered to produce electricity and heat for the plant's own consumption (Section 2.2). Additional heat is sold to the district heating network.

For finding to most cost efficient biogas CHP production systems, algorithm which maximizes operational income over the whole production chain within the model restrictions was used [9]. When operational income is maximized in all possible plant locations, only the most cost efficient plants remain which would take feedstock that would otherwise be used in plants that are not as cost efficient.

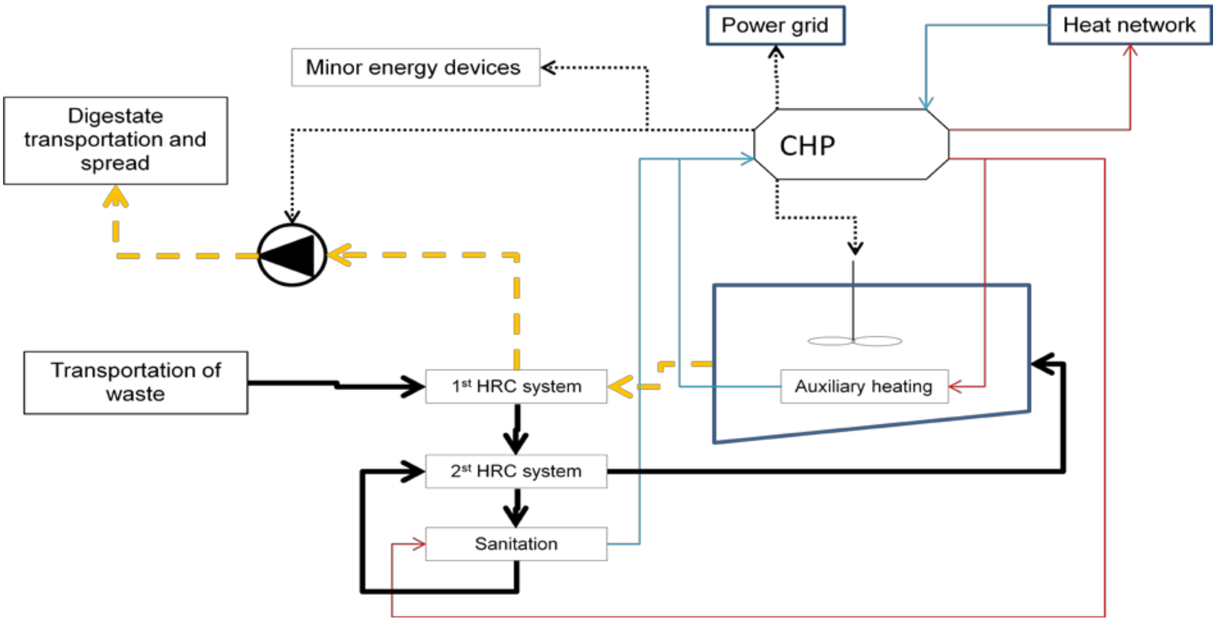

Figure 1. System boundary in Lithuanian case includes biogas CHP production system.

2.1 Operational income in the biogas CHP system

Operational income per processed mass unit seems to have growing trend when electricity production and digester volumes are increasing, but local costs in feedstock transportation, heat delivery as well as utilization of digestate would give the final form for plant economics. When costs from CHP unit and digester investments, personnel and maintenance were considered, it seems that annual operational income per ton of feedstock have growing trend versus reactor volume and electricity production power (Figure 2). Annual shortening for investment loan was determined from ten years of payback time and annual load rate of 5 %.

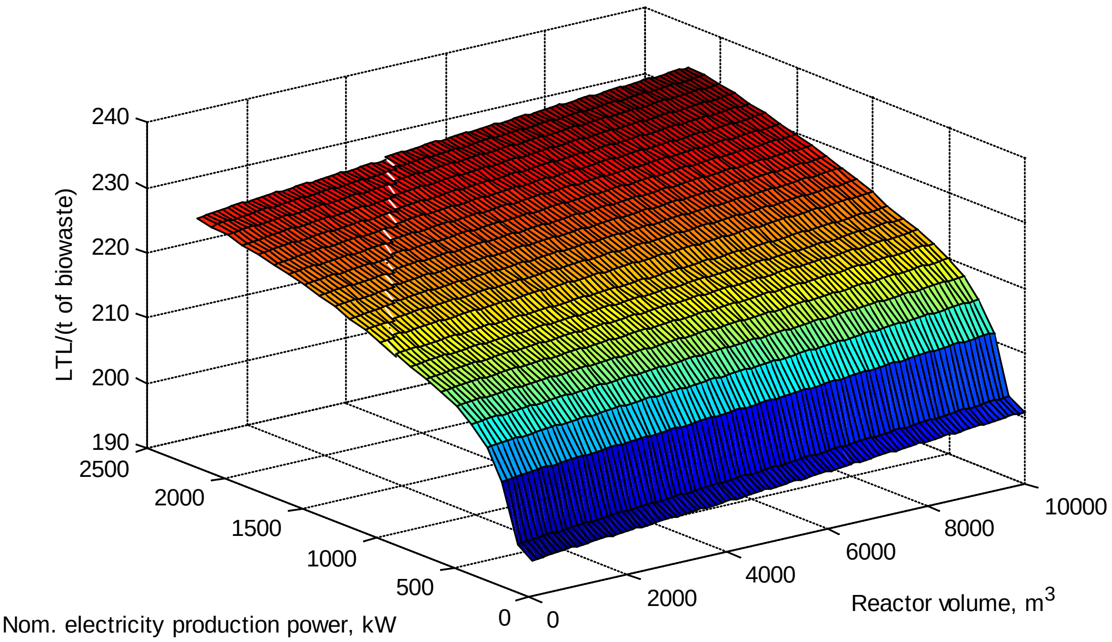

Figure 2. Operational income per ton of household biowaste versus reactor volume and the plant electricity production power is shown when costs from feedstock delivery, heat delivery and digestate handling are not considered.

Costs in heat and power production consist of CHP investment cost, maintenance, personnel as well as anaerobic digester investment costs. In generally speaking it can be deduced from the cost data that the larger is the CHP unit and digester the smaller are the costs per ton of processed feedstock. CHP investment and maintenance costs are considered for systems that have electricity production power from 100 kW to 2000 kW [10]. Personnel costs per electricity production power of the plant are assumed to be the smaller than the larger is the personnel hourly basis labor demand [11]. The investment cost for the digester is assumed to be same as it was estimated for Finnish wet digesters [9] which has also slightly decreasing cost trend per reactor volume when digester volume is increasing.

Incomes are considered from heat and electricity sell as well as from fertilizer sell and gate fees (Table 4). It was assumed that fertilizer would be transported and spread to the nearest fields. Heat loss and electricity consumption were considered in the heat delivery process which had significance especially if there was need to deliver heat very far from the plant. Heat and electricity consumption in the plant was fulfilled by the heat and electricity which was produced in the plant. Electricity consumption in mixing, pumping and operational devices was estimated at 51 MJ/(t FM), 0.5 MJ/(t FM) and 9 MJ/(t FM), respectively [12].

2.2 Heat consumption in the plant

Heat consumption in the biogas plant is the sum of the heat need in sanitation process and auxiliary heat need. Auxiliary heating is needed when heat losses from the reactor surface occur when temperature of surroundings is less than reactor temperature of 37 °C. The larger the reactor is the smaller are the surface heat losses of the feedstock mass unit. It can be stated that surface heat losses increases to the power of two thirds when the volume of the digester is increased. It was calculated that surface heat loss coefficient in the an aerobic digester is 0.67 W/(m^2·K).

The heat need in the sanitation process consists of the heat need in the system where feedstock heat content is first increased by two heat exchanger after it is heated up to the sanitation temperature. At first feedstock receives heat from the digestate which is leaving the reactor and after that it receives heat from the feedstock that has just passed by sanitation at 70 °C. The effectiveness of the heat exchangers for incoming feedstock is estimated to be 41 %. The heat needed in sanitation process depend on the temperature difference of the feedstock before and after the sanitation process as well as the heat capacity of the feedstock which consists of the feedstock mass and specific heat capacities of the feedstock. The model considers different specific heat capacities for total solid material of 1.2 kJ/(kg·K) and 4.19 for water kJ/(kg·K).

2.3 Biogas heat and power production

Heat and electricity production by spark ignition engines is considered in this study [9]. Roughly speaking the larger the feedstock input power of the methane fuel the higher is the electricity production efficiency. In contrast, the larger is the methane fuel input power the lower is the heat production efficiency. Heat and power production efficiencies of 57 production unit are used as input data for the model in this study [13].

2.4 Feedstock transportation

It is assumed that feedstock is transported with a delivery truck with load capacities, energy consumption and costs mentioned in Table 4. Due to the road network the actual distance was estimated to be 1.4 of the Euclidean distance considering driving to the feedstock origin and transportation to its destination [14]. Transportation distances and waste masses for household biowaste, sewage sludge as well as for cattle solid manure were calculated from GIS data bases (Table 2 and Table 3).

Costs in feedstock transportation were estimated based on local waste collection costs. According to Klaipeda University a Lithuanian waste management company have municipal solid waste collection have costs of 42.4 €/t [15]. When estimated average waste transportation distance was 30.4 km the specific costs in MSW collection are 1.40 €/(t*km) which was also used as input value in this model. It is also reported that MSW collection costs are in a level of several tents of € per ton [16].

2.5 Digestate management

Digestate transportation was considered to the fields which have the lowest impact on transportation costs (Table 4). Digestate transportation and spread model follows strictly the model which was used to assess energy consumption in farm scale biogas production [12]. Costs in digestate transportation are increasing exponentially when transportation distance to the field block increases. Total cost is the sum of costs about work done in the field and in road transportation between biogas plant and the field block. Transportation distances were calculated from field area data base and heating plant locations (Table 2 and Table 3).

2.6 Model restrictions

Biogas plant locations, end product end users and feedstocks were optimized in target areas by setting techno economical limits as well as feasible amounts of biogas electricity and heat for the production system. Techno economical limits considered the demands amount positive operational income as well as positive net energy balance of the system. Maximum limit for heat and electricity production was based on keeping the heat production lower level than the regional heat consumption is. In addition, maximum organic loading rate of 12 kg VS/(m^3·d) with hydraulic retention time of 30 days was considered in the biogas plant (Table 4).

3. Input data to the biogas CHP model

Input data to the model consists of feedstock properties data (Table 1) and GIS data sets (Table 2 and Table 3). Model and its parameters is describer more in deeply in the Section 2. . Feedstock mass and origins as well as district heating plant locations and arable land areas for digestate spread were derived from public data sources (Table 2 and Table 3).

Table 1. The properties of waste fractions in Lithuanian case.

Feedstock	MPR, $Nm^3CH_4/(t\ TS)$	ρ_{ij}, kg/m^3	TS_{ij}, % ww	VS of TS, %	N of TS, %	P of TS, %
Solid cattle manure	181.8 [9]	992.7 [17]	20 [a]	81.45 [a]	5.45 [12]	0.9 [12]
Household biowaste	300 [9]	850 [9]	33 [18]	75 [19]	2.0 [19]	0.4 [19]
Sewage sludge	205 [9]	900 [9]	26[a]	69 [19]	4.0 [19]	2.5 [19]

[a] Estimated value.

3.1 Lithuanian input data

Reasonable amounts of sewage sludge, household biowaste and cattle solid manure from the region was considered as feedstocks for the system. Energy potential of feedstocks was calculated as reported previously [9]. Total biogas energy potential of sewage sludge was 8 GWh/year. Instead, household biowaste have biogas energy potential of 33 GWh/year if 27 kg per inhabitant of the waste could be utilized. Cattle solid manure has biogas energy potential of 146 GWh/year if 20 % of the total cattle solid manure potential could be utilized.

Table 2. Feedstock data for Lithuania was mostly derived from public data sources.

GIS data sets in LKS-94	Description	Reference
Household biowaste	Number of people in 1 km x 1 km grids	[20]
Sewage sludge	WWTP statistics	Table 5
Livestock manure	Number of domestic animals	[21]
Background maps	EBM_100LT-1005 map	[22]
District heating plants	Lithuanian district heating association	[23]
Arable land areas	Corine Land Cover 2006	[24]

3.2 Estonian input data

Household biowaste was considered as feedstock for modeling biogas electricity production in Estonian area. In digestate utilization, the fields that contributed lowest costs were considered as input to the model. Digestate fertilizing was considered for non-irrigated arable land (211) and pastures (231).

Heat delivery and consumption data was based on national statistics. Maximum average district heat price for consumer in Estonia in 2013 was 68 €/MWh [25]. CHP plant locations were retrieved from Erkas which is based on Estonian Land Board data base. In 2012 heat consumption was in totally 3 953 GWh/year [26]. In the end of 2012 population in Estonia was 1286479 [26]. Thus, the average heat consumption power in 2012 was 350.76 W/inh.

Table 3. Feedstock data for Estonia was mostly derived from public data sources.

GIS data sets in EST97	Description	Reference
Household biowaste	Number of people in 1 km x 1 km grids	[20]
Background maps	Administrative boundaries	[27]
District heating plants	Erkas' data base	[28]
Arable land areas	Corine Land Cover 2006 (211&231)	[24]

Table 4. Parameters of the model.

Target area specific data	Target area variable	Unit	Lithuania Value	Lithuania Ref.	Estonia Value	Estonia Ref.
Annual average temperature of surroundings	1	°C	7,60	[29]	5,6	[26]
Average heat consumption power	2	W/inh.	209,34	[30]	350,76	[26]
MSW production	3	kg/inh.	347,00	[3]	399	[31]
Biodegradable waste fraction of the total MSW mass	4	%	39,00	[19]	36.6	[32](2005)
Availability of biodegradable waste of the maximum	76	%	20,00	Estimation.	20	Estimation.
Cattle manure production (TS of 10 %)	77	t/cattle unit	16,00	[9]	16,00	[9]
TS of cattle manure solid fraction	78	% of FM	20,00	Estimation.	20,00	Estimation.
TS of cattle manure liquid fraction	79	% of FM	5,50	[17]	5,50	[17]
Availability of cattle solid manure of the maximum	80	%	20,00	Estimation.	20,00	Estimation.
Plant specific parameters						
Minimum reactor volume	5	m^3	150,00	Estimation.	150,00	Estimation.
Maximum reactor volume	6	m^3	11 000,00	Estimation.	11 000,00	Estimation.
Maximum feedstock intake capacity of the plant	43	kt/year	500,00	Estimation.	500,00	Estimation.
Maximum TS concentration of digestate	71	%	10,00	Estimation.	10,00	Estimation.
Maximum organic loading rate (OLR)	7	kg VS/(m^3·d)	12,00	Ostfalia	12,00	Ostfalia
Hydraulic retention time	8	d	30,00	Estimation.	30,00	Estimation.
Heat exchanger effectiveness of sanitation unit	56	%	41,00	[33]	41,00	[33]
Heat exchanger 1. effectiveness	9	%	41,00	[33]	41,00	[33]
Heat exchanger 2. effectiveness	55	%	41,00	[33]	41,00	[33]
Mixing energy consumption	10	MJ/(t FM)	51,00	[12]	51,00	[12]
Pumping energy consumption	11	MJ/(t FM)	0,50	[12]	0,50	[12]
Electricity consumption from minor energy devices	12	MJ/(t FM)	9,00	[12]	9,00	[12]
Temperature of feedstock in the digester	49	°C	37,00	[9]	37,00	[9]
Sanitation temp. for household biowaste and sewage sludge	57	°C	70,00	[9]	70,00	[9]
Minimum heat consumption in the plant heat network	42	kW	25,23	Estimation.	5	Estimation.
Thermal input power of feedstock at the beginning of iteration	44	kW	7 425,00	Estimation.	7 425,00	Estimation.
Minimum electricity production power	45	kW	100,00	Estimation.	10	Estimation.

Target area specific data	Target area	Unit	Lithuania Value	Lithuania Ref.	Estonia Value	Estonia Ref.
Heat delivery						
Mean velocity of heat transfer fluid	58	m/s	1,00	[8]	1,00	[8]
Inner radius of the heat transfer pipe	59	mm	24,15	[8]	24,15	[8]
Outer radius of the heat transfer pipe	60	mm	24,65	[8]	24,65	[8]
Outer radius of the insulation core	61	mm	80,00	[8]	80,00	[8]
Temperature difference between incoming and out coming heat transfer	62	K	50,00	[8]	50,00	[8]
Temperature of the heat transfer fluid	63	°C	120,00	[8]	120,00	[8]
Pumping energy consumption of the total head	67	%	65,00	[8]	65,00	[8]
Thermal conductivity of the heat transfer pipe steal (at 400 K; AISI 304)	64	W/(m·K)	16,60	[33]	16,60	[33]
Thermal conductivity of urethane in the heat transfer pipe	65	W/(m·K)	0,026	[33]	0,026	[33]
Maximum heat delivery distance	41	m	5000	[8]	5000	[8]
Surface heat loss from the real scale plant						
Reactor inner steal core thicknesses	50	mm	4,50	Estimation.	4,50	Estimation.
Thickness of polyurethane around reactor	51	mm	200,00	Estimation.	200,00	Estimation.
Reactor outer steal core thicknesses	52	mm	3,00	Estimation.	3,00	Estimation.
Thermal heat conductivity of the steal	53	W/(m·K)	17,30	[33]	17,30	[33]
Thermal heat conductivity of polyurethane	54	W/(m·K)	0,029	[33]	0,029	[33]
Test reactor height	14	m	8,00		8,00	
Test reactor width	15	m	8,00		8,00	
Test reactor length	16	m	40,00	Estimation.	40,00	Estimation.
Economic data of the real scale plant						
Electricity prize for the plant	18	€/MWh	125,60	[34]	61,6	[6] (Without VAT. 20%)
Feed-in tariff from electricity	47	€/MWh	128,00	Estimation	115,3	[4] [6]
Heat sell prize for the plant	19	€/MWh	40,00	Estimation	56,75	[35] (Without VAT; avg.2013)
Fertilizer prize for the plant (Agro 16-7-13)	20	€/t	410,00	[36]	324	[37](Ammonium nitrate: 34.4%N without VAT.)
Salary for personnel in the plant with side costs	72	€/hour	20,00	Estimation	6,25	Estimated according to [26].
Personnel side cost factor	73	[1]	1,00	Estimation	1,5	Estimation.
Amount of working hours per person in the plant per month	75	hour	160,00	Estimation	160	Estimation.
Gate fee for household biowaste	81	€/t	20,00	Estimation	1,5	[38]
Gate fee for sewage sludge	82	€/t	20,00	Estimation	20	Estimation.
Gate fee for cattle solid manure	83	€/t	0,00	Estimation	0	Estimation.
Magnitude factor for sensitivity analysis	46	[1]	1,00	Estimation	1,00	Estimation.
Currency	74	Currency/€	3,45	LTL /€; Estimation	1,0	Euro

Target area specific data	Target area variable	Unit	Lithuania Value	Lithuania Ref.	Estonia Value	Estonia Ref.
Transportation						
Energy consumption (Large delivery truck with full load)	24	MJ/(t·km) (load of 9 t)	1,000	[39]	1,1	[39]
Transportation cost	26	€/(t·km)	1,40	Estimation	1,40	Estimation
Distance factor	48	[1]	1,400	[Han Song]	1,40	[14]
Digestate spread						
Fertilizing requirement	27	(t TS digestate)/(ha*year)	2,22	Estimation	2,22	Estimation
Pumping capacity of slurry pump	28	t/min	6,00	[12]	6,00	[12]
Fuel consumption of the tractor	29	kg diesel/hour	28,00	[12]	28,00	[12]
Spread width	30	m	12,00	[12]	12,00	[12]
Driving speed in the road	31	km/h	25,00	[12]	25,00	[12]
Driving speed in the field	32	km/h	5,00	[12]	5,00	[12]
Digestate spread cost	33	€/hour	50,00	Estimation	50,00	Estimation
Load of the digestate spread tank	69	t/load	17,00	[12]	17,00	[12]
Maximum digestate transportation distance	68	km	50,00	Estimation	50,00	Estimation
Constants						
Specific heat capacity of water	34	kJ/(kg·K)	4,19	[40]	4,19	[40]
Specific heat capacity of dry matter	35	kJ/(kg·K)	1,20	[40]	1,20	[40]
LHV of diesel combustion	36	MJ/kg	43,00	[40]	43,00	[40]
LHV of methane combustion, MJ/kg.	37	kWh/Nm^3	9,20	[12]	9,20	[12]
Density of water	38	kg/m^3	998,00	[33]	998,00	[33]
Density of methane at NTP	39	kg/m^3	0,72	[40]	0,72	[40]
Density of carbon dioxide at NTP	40	kg/m^3	1,97	[40]	1,97	[40]
Friction factor in heat transfer fluid pumping	66	[1]	0,02	[8]	0,02	[8]

4. Biogas potential in Lithuania

Biodegradable waste-to-energy potentials have been represented in many studies, but most of them lack of information about geographical origin. Havukainen represented biodegradable waste-to-energy potentials in Lithuania with their fertilizing properties [19]. Largest biodegradable waste-to-energy potential in Lithuania comes from livestock manure and municipal biodegradable waste which will be shown more detail with geographical locations in this report.

4.1 Manure production

Most of the Lithuanian livestock biogas energy potential arises from cattle and pig farms [41]. Still in 2010, quite large amount of energy potential of 390 GWh/year lies in small farms that have less than 20 cattle units while total potential is 960 GWh/year (Figure 3). In contrast, pig farms that have more than 5000 pigs had the largest energy potential of 300 GWh/year of the total potential of 440 GWh/year (Figure 4). Distribution of the manure biogas energy potential is assumed to be same as cultivated field [24] where manure is used as fertilizer (Figure 5).

Manure production and its energy potentials were assessed in more detail level in a Baltic Sea region project, Baltic Manure. It was estimated that total manure energy potential in Lithuania could vary from 2.69 TWh/year to 5.69 TWh/year [41]. As a comparison, short calculation in this paper show roughly total manure energy potential of 1.58 TWh/year. Still, it is admitted in the Baltic Manure research that determining the actual manure biogas energy potentials needs further research about how much there is produced manure in farms. Current estimations about manure production are mostly based on estimations arising from the number, age and type of domestic animals and best available knowledge about construction recommendations of manure storages. Remarkable notation in Baltic Manure research was that cattle solid manure production was 67 % of the total while its energy potential was even 77 % of the total energy potential. It was suggested that cattle solid manure could have biogas energy potential from 1.98 TWh/year to 4.54 TWh/year.

In this model, only cattle solid manure is considered since cattle manure is dispersedly located (Figure 3). Solid fraction is selected, because it can be transported longer distances more cost effective way than liquid fraction which contains remarkably amounts of water. Utilization of pig manure is not considered in this report since, large pig farms seem to have enough feedstock potential to start biogas production (Figure 4). In the model, the total TS concentration of cattle manure is assumed to be 10 % while liquid and solid fractions are assumed to have TS concentrations of 5.5 % and 20 %, respectively. This actually means that solid fraction energy potential is 62 % of the total potential. Based on Lithuanian manure statistics [21] the total cattle solid manure potential is 1960 GWh/year when manure production per cattle unit is assumed to be 16 t/year, methane production of 181.8 Nm^3 CH_4/(t TS) [9].

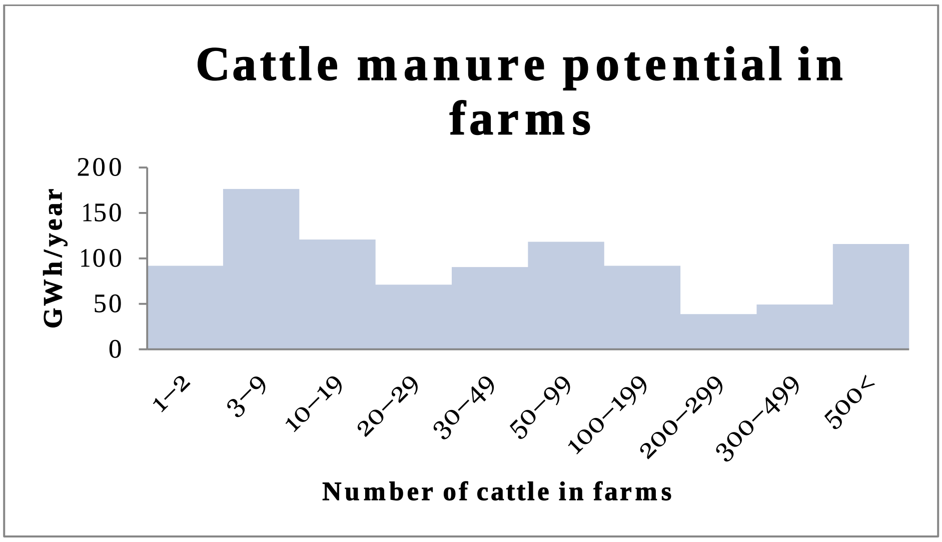

Figure 3. Energy potential of cattle manure is based on estimated methane potentials [8], manure production of livestock unit of 1 TS t/year [42], number of livestock units [43] in farms [29] and methane energy content of 9.2 kWh/year [12].

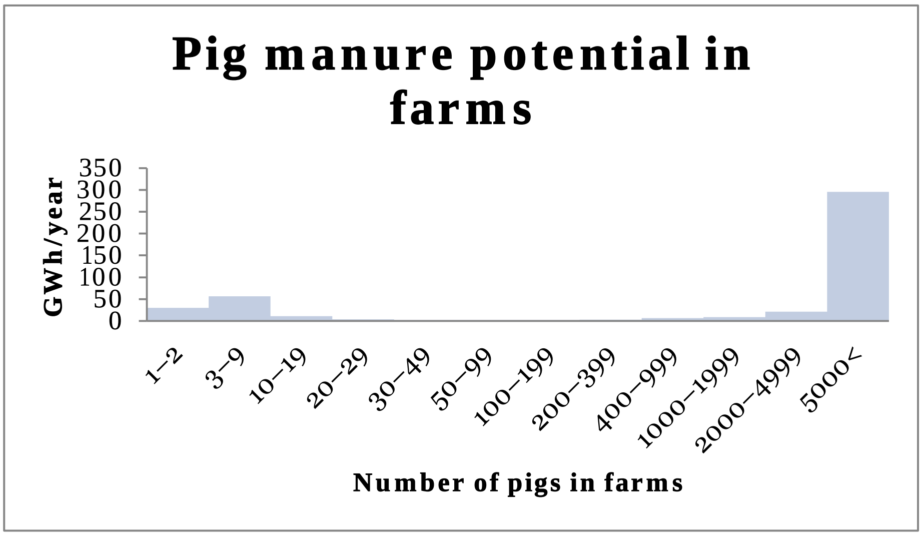

Figure 4. Energy potential of pig manure is based on estimated methane potentials [8], manure production of livestock unit of 1 TS t/year [42], number of livestock units [43] in farms [29] and methane energy content of 9.2 kWh/year [12].

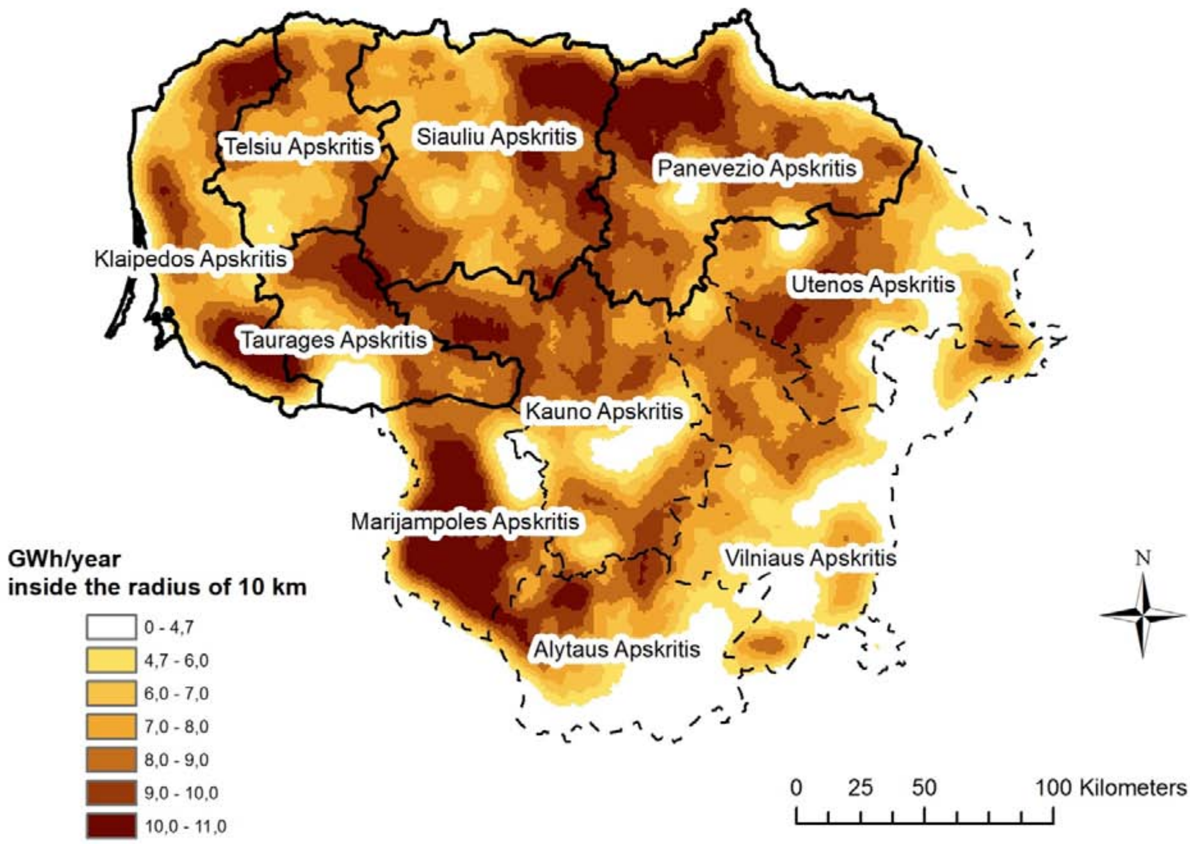

Figure 5. Distribution of biogas energy potential from livestock manure is calculated inside the radius of 10 km when it is assumed that manure distribution is similar to the distribution of cultivated field areas [24] and the biogas manure energy potential is based on number of livestock units [43], estimated methane productivity [8], manure production of livestock unit of 1 TS t/year [42] and methane energy content of 9.2 kWh/year [12].

4.2 Municipal based biodegradable waste

In Western Lithuania the largest biodegradable energy potential of about 127 GWh/year arises from biodegradable fraction in municipal solid waste while sewage sludges in the region would contribute about 7.8 GWh/year of energy (Table 5). In Lithuania it is reported that biodegradable fraction mass share 39 % of the total mixed municipal solid waste mass which is also assumed in this study [19]. Annual generation of municipal solid waste (MSW) in West Lithuania was reported as 347 kg/inh [3]. As a comparison, in Lithuania the MSW production was reported as 441 kg/inh in 2012 [44]. Biodegradable waste energy potential in Lithuania is 471 GWh/year when methane production of biodegradable MSW is assumed to be 99 Nm^3/(t ww) [9], LHV of methane is 9.2 kWh/(Nm^3 CH_4) and the total population in Lithuania is 3 million [45]. As a comparison, in Western Lithuania about 1 million people would result biodegradable waste energy potential of 127 GWh/year [3]. Due to centralization of population [20] the largest energy potential is around biggest cities (Figure 6). A research suggests that it would be possible to collect 22 % of the biodegradable fraction in MSW separately [19].

Table 5. Wastewater sludge production and their calculated energy potentials are based on Environmental Ministry of Lithuania statistics.

Company	Mass, t FM/year	Energy potential, MWh/year
Klaipėdos r. sav. (A	5 357	2 592
Kretingos r. sav.	88	42
Neringos sav.	263	127
Palangos m. sav.	52	25
Skuodo r. sav.	316	153
Šilutės r. sav.	366	177
Akmenės r. sav.	458	222
Joniškio r. sav.	3 183	1 540
Kelmės r. sav.	214	103
Pakruojo r. sav.	125	61
Radviliškio r. sav.	343	166
Šiaulių r. sav.	2 471	1 195
Šilalės r. sav.	528	255
Mažeikių r. sav.	1 013	490
Plungės r. sav.	689	333
Rietavo sav.	5	2
Telšių r. sav.	608	294
Total	16 078	7 778

A) Biogas plant exists in Klaipeda wastewater treatment plant [3].

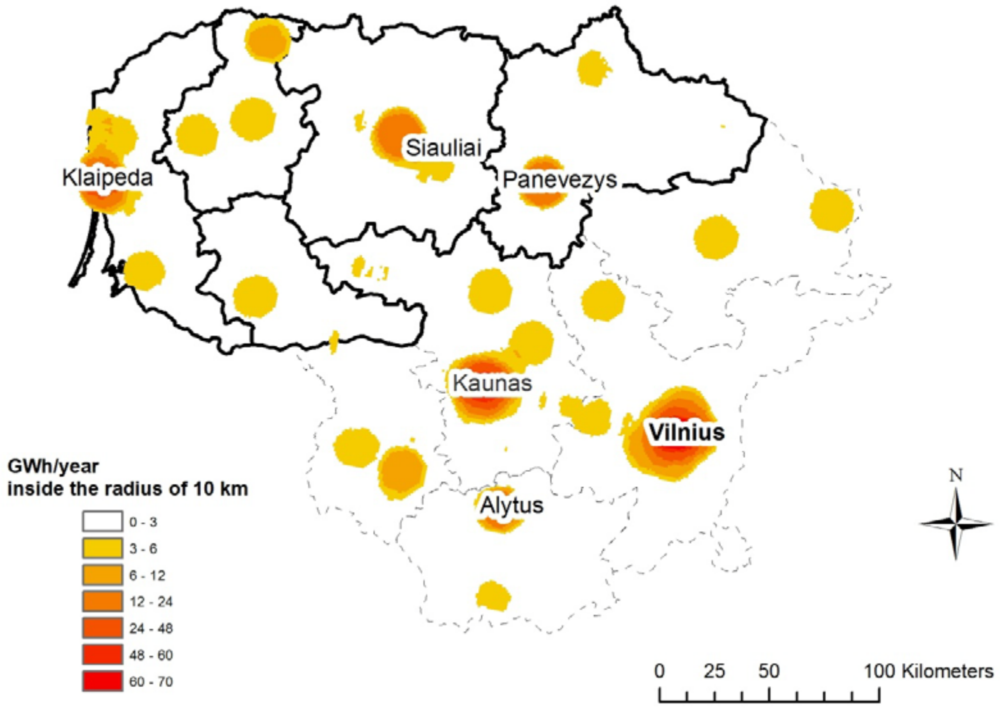

Figure 6. Distribution of household biowaste energy potential is based on number of inhabitants [20], methane productivity of household biowaste of 99 Nm^3 CH_4/(t ww), LHV of methane of 9.2 kWh/(Nm^3CH_4) and household biowaste production of 135 kg per inhabitant.

5. Optimized Lithuanian biogas electricity production system

Model results show that two of the most cost efficient biogas electricity production plants could be located next to UAB Kretingos šilumos tinklai and UAB Radviliškio šiluma district heating plants with anaerobic reactor capacities of 1000 m^3 and 1700 m^3, respectively (Figure 7). With estimated household biowaste availability of 27 kg per inhabitant, biogas electricity productions in Kretingos' and Radviliškio's plants are 6 GWh/year and 10 GWh/year (Table 6). Operational incomes for the biogas electricity production system of 3.6 million LTL and 6.1 million LTL were estimated for Kretingos' and Radviliškio's plants. Labor demands of three and five person per year are needed to run these plants in Kretingos and Radviliskio, respectively. In total, saved GHG emissions in ETS are 8800 t of CO_2 eqv./year which would have annual market value of 130 thousand LTL per year if the prize of one ton of CO_2 eqv. remains at 15.3 LTL.

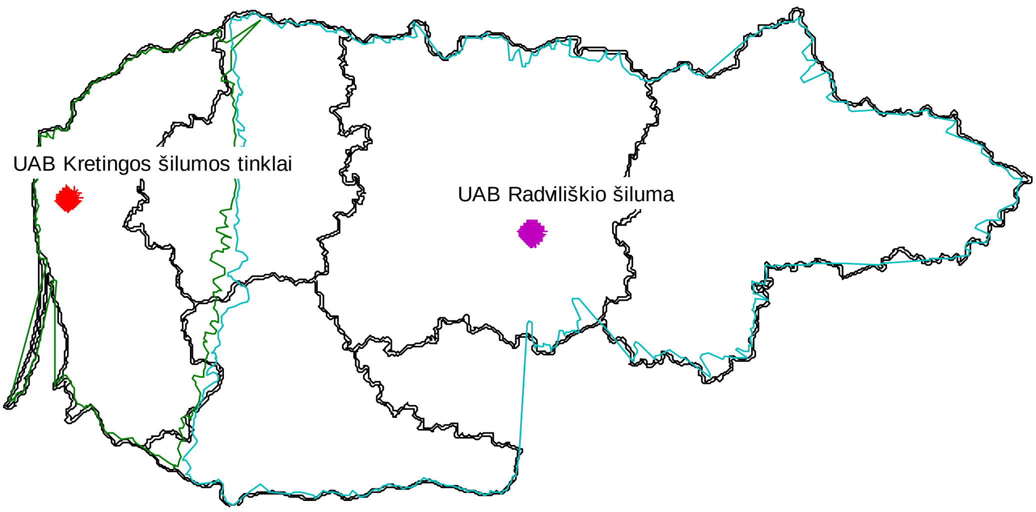

Figure 7. The most cost efficient locations for the biogas electricity production system utilizing household biowaste and sewage sludge was derived with feedstock collection areas around plants.

Utilization of cattle solid manure in biogas electricity production system would result decentralized electricity production in the target area. The most cost efficient locations for plants were found from Baisogalos, Kupiškio, Pasvalio, Akmenės, Kelmės, Šilalės and Skuodo (Figure 8). Total electricity and heat productions in those plants were 41 GWh/year and 44 GWh/year, respectively (Table 7). Operational incomes in these plants are 15 million LTL/year when incomes and outcomes are 29 million LTL/year and 14 million LTL/year, respectively. Incomes result from electricity sale of 18 million LTL/year, fertilize sale of 5 million LTL/year and heat sales of 6 million LTL/year. Outcomes consists capital and operation costs of 10.3 million LTL/year, digestate management costs of 1.7 million LTL/year and cattle solid manure transportation of 2.3 million LTL/year. Direct labor demands in those seven plants are 31 employees per year. District heating plants that belong to the ETS would have total benefits as saved CO_2 evq. emissions of 16900 ton which would have market value of 260 thousand LTL per year if the prize of CO_2 evq. ton remains at 15.3 LTL.

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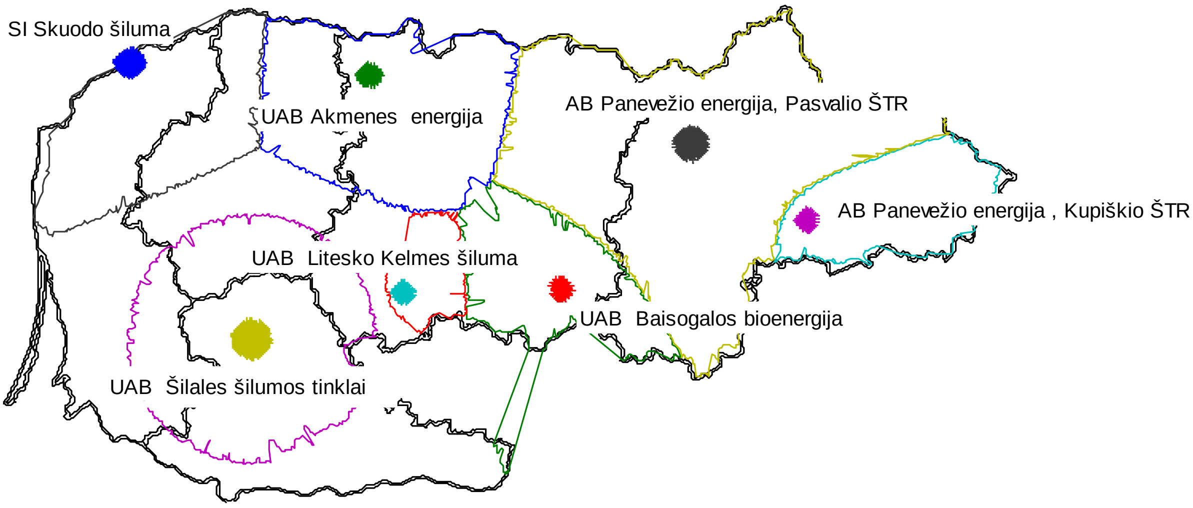

Figure 8. The most cost efficient locations for the biogas electricity production system utilizing cattle solid manure was derived with feedstock collection areas around plants.

Table 6. Results are calculated for biogas electricity production from household biowaste and sewage sludge.

Closest district heating plant	UAB Kretingos šilumos tinklai	UAB Radviliškio šiluma	In total
Total feedstock, kt/year	20.6	31.7	52
Sewage sludge, kt/year	8.7	7.4	16
Household biowaste, kt/year	12.0	24.,3	36
Nitrogen potential, t/year	169	237	406
Phosphorus potential, t/year	72	80	152
Reactor volume, m^3	1 032	1 674	2 705
Electricity, GWh/year	5.5	9.7	15.2
Heat, GWh/year	5.6	9.6	15.2
Nitrogen fertilizer, million LTL/year	0.2	0.3	0.6
Electricity sales, million LTL/year	2.4	4.3	6.7
Heat sales, million LTL/year	0.8	1.3	2.1
Gate fees, million LTL/year	1.4	2.2	3.6
Incomes in total, million LTL/year	4.8	8.0	13.0
Digestate management, thous. LTL/year	64	95	160
Feedstock transportation, thous. LTL/year	170	430	600
Plant costs, thous LTL/year	980	1 500	2 500
Tot. Cost, million LTL/year (inc. Operat. & inv.)	1.2	2.1	3.3
Operational income, million LTL/year	**3.6**	**5.9**	9.7
Labor demands (160 hour/month):			
Plant site, man months/year	15	23	38
Feedstock transportations, man months/year	15	39	54
Digestate management, man months/year	2	3	6
Labor demands in total, man months/year	33	66	98
Labor demands in total, in men/year	**3**	**5**	**8**
Saved GHG emissions in ETS, t CO_2 eqv.	**3 200**	**5 600**	**8 800**

Table 7. Results are calculated for biogas electricity production from cattle solid manure.

Closest district heating plant	UAB Baisogalos bioenergija	AB Panevėžio energija , Kupiškio ŠTR	AB Panevėžio energija , Pasvalio ŠTR	UAB Akmenės energija	UAB Litesko Kelmės šiluma	UAB Šilalės šilumos tinklai	SĮ Skuodo šiluma	In total
Total feedstock, kt/year	26	18	86	39	11	110	58	353
Nitrogen potential, t/year	290	200	940	430	130	1 200	630	3 800
Phosphorus potential, t/year	50	30	160	70	20	200	100	640
Reactor volume, m^3	970	670	3 200	1 500	430	4 200	2 200	13 000
Electricity, GWh/year	2.8	1.9	10.1	4.3	1.2	13.7	6.6	41
Heat, GWh/year	3.3	2.4	10.5	5.2	1.5	13.7	7.3	44
Nitrogen fertilizer, million LTL/year	0.4	0.3	1.3	0.6	0.2	1.8	0.9	5
Electricity sales, million LTL/year	1.2	0.8	4.4	1.9	0.5	6.1	2.9	18
Heat sales, million LTL/year	0.5	0.3	1.4	0.7	0.2	1.9	1.0	6
Incomes in total, million LTL/year	2.1	1.4	7.2	3.2	0.9	9.7	4.8	29
Digestate management, thous. LTL/year	94	68	440	150	43	640	260	1 700
Feedstock transportation, thous. LTL/year	130	110	710	270	33	670	390	2 300
Plant costs, thous LTL/year	830	590	2 400	1 200	390	3 200	1 700	10 000
Tot. Cost, million LTL/year	1.1	0.8	3.6	1.6	0.5	4.5	2.4	14
Operational income, million LTL/year	**1.0**	**0.6**	**3.6**	**1.6**	**0.4**	**5.2**	**2.4**	15
Labor demands (160 hour/month)								
Plant site, man months/year	9	7	24	13	4	33	17	107
Feedstock transp., man months/year	12	10	64	24	3	61	36	209
Digestate management, man months/year	3	2	16	6	2	23	9	61
Labor demands in total, man months/year	24	19	104	42	9	117	62	378
Labor demands in total, in men/year	**2**	**2**	**9**	**4**	**1**	**10**	**5**	**31**
Saved GHG emissions in ETS, t CO_2 eqv.	**<20 MW**	**<20 MW**	**5 800**	**2 500**	**700**	**7 900**	**<20 MW**	**16 900**

6. Biogas potential in Estonia

Distributions of agricultural waste and biogas potential of household biowaste were assessed. Biogas electricity production system was optimized with respect to economical performance. Labor demands, operational incomes, feedstock mass flows and savings in ETS are introduced.

6.1 Manure biogas potential in Estonia.

Estonian manure potential is concentrated mostly on cattle solid manure which is mostly produced in large farms that arguably are located in Estonian agricultural areas (Figure 9). Especially, until 2010 agricultural structure was changed from smaller farms to larger. Cattle farms that have more than 300 cattle had cattle population of 61 % of the total population [46]. About 86 % of the cattle population was located in farms that had more than 50 cattle [46]. The distribution of pig population is even more dramatic. About 91 % of the total pig population was located in farms that had more than 2000 pigs [46]. In addition, 95 % of the total poultry potential was located in farms that had more than 1000 poultry units. Among sheep farms, 58 % of the total sheep population was located in farms that had more than 100 sheep [46].

Cattle solid manure biogas energy potential is at least several hundreds of GWh per year. When total manure TS concentration is assumed as 10 % as well as its liquid fraction TS concentration of 5 % and solid fraction TS concentration of 25 % the solid manure TS is 62.5 % the total manure TS. It is assumed that manure production per cattle unit is 16 t FM [9]. According to the Estonian agricultural census the number of cattle units in 2010 was 241 025 [46]. When methane productivity per FM ton is estimated at 10 N m^3 CH_4 and LHV of methane at 9.2 kWh the total cattle solid manure biogas energy potential is 222 GWh/year. Still, even higher cattle solid manure biogas energy potential from 453 GWh/year to 1 040 GWh/year is reported [41].

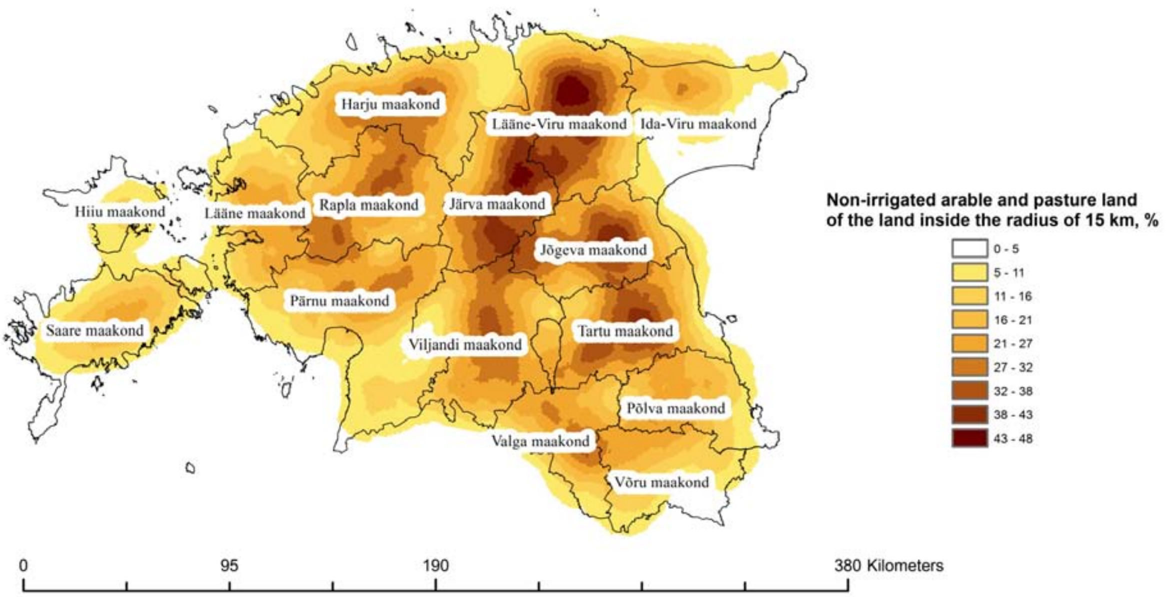

Figure 9. Estonian agricultural areas reflect also the availability of agricultural feedstock.

6.2 Municipal biodegradable biogas energy potential in Estonia

Significant unutilized biogas energy potential lies in municipal solid waste (MSW) biodegradable fraction which is located in the most populated areas (Figure 10). Annual MSW production in Estonia in 2011 was 399 kg/inh [31]. When population in Estonia in 2011 was 1 336 107 the MSW production in 2011 was 533.106 kt [47]. It was reported that during 2007 and 2008 biodegradable part in MSW was 36.6 % of the total mass of MSW when kitchen waste was 80 % of the biodegradable waste generation [32]. Representative of Tallinn waste management center Kertu Tiitso estimated that municipal solid waste would contain 30 % biodegradable fraction of the total MSW mass. When biodegradable faction of total MSW is estimated at 36.6 % of total, methane production of 100 Nm^3 CH_4/(t FM) the biodegradable fraction has biogas energy potential of 180 GWh/year. In practice, only part of this maximum amount of 180 GWh/year is utilized. In this model it was estimated that 20 % of total is utilized in current status. It would results annual household biogas energy potential of 35 GWh. In terms of fresh mass, 20 % of total estimated available household biowaste is 39 kt FM/year.

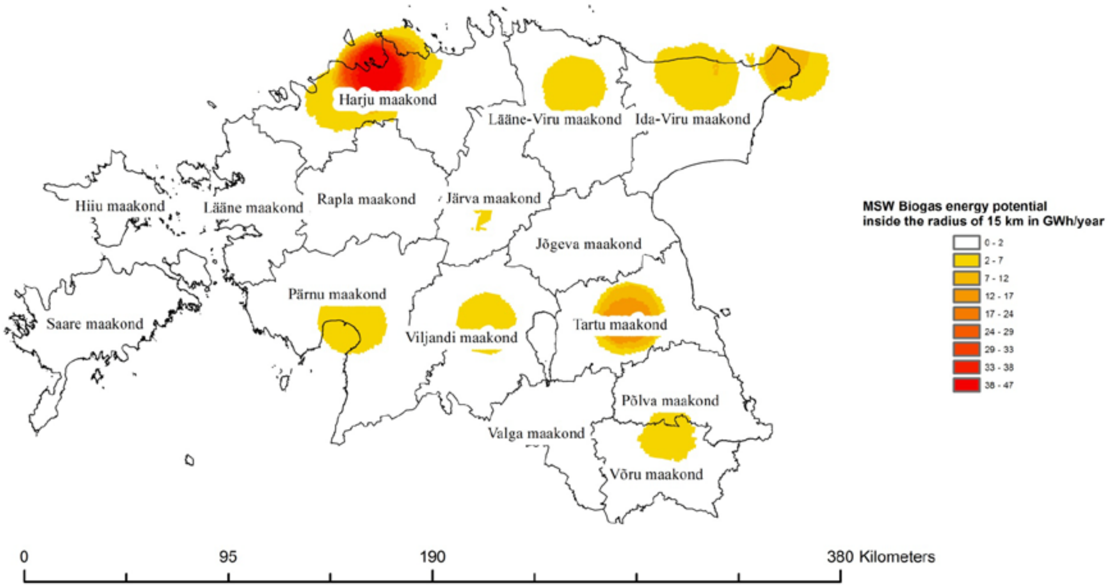

Figure 10. Estonian biodegradable municipal solid waste biogas energy potential is derived from population grid data base [20].

7. Optimized Estonian biogas electricity production system

Model results show that efficient household biowaste collection area for biogas electricity production plants follow Estonian population density (Figure 11). Results are based on Estonian specific data and parameters (Table 3 and Table 4). Among others, biowaste collection costs of 1.4 €/(t*km) would result into three biogas plants in Tallinn region and one in Tartu region. It shows that attention should be paid on efficient waste collection systems. Another important factor effecting on plant locations is biowaste availability of 30 kg per inhabitant which results Estonian wide household biogas energy potential of 35 GWh/year. In terms of mass total amount of estimated collected household biowaste is 39 kt FM/year. However, model shows that it would be cost efficient to have biogas plants utilizing 19 kt FM/year of household biowaste (Table 8). It is 50 % of the total estimated amount of biowaste that is separately collected in current status. These city centralized biogas electricity systems would offer job for about ten Estonian workers. Next, local implementation of dry digestion technology should be done to find about actual co-operative partners in plant operation point of view as well as in feedstock delivery and residue handling.

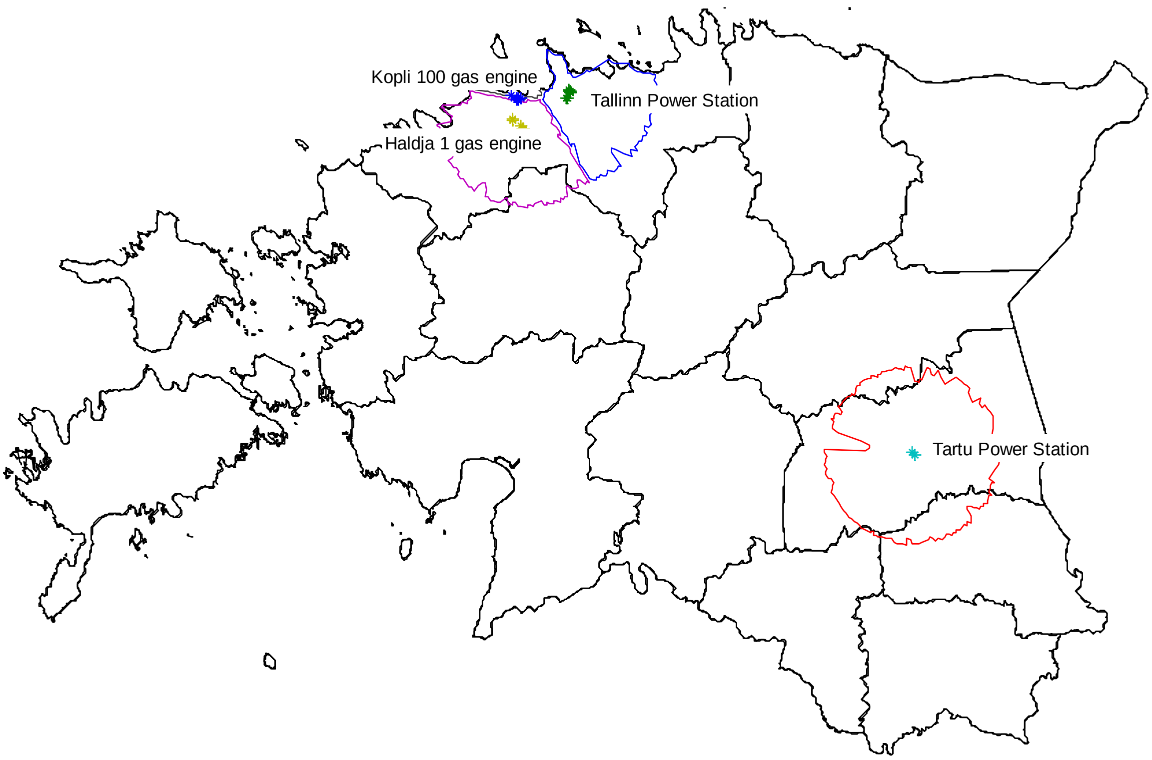

Figure 11. Household biowaste collection areas are shown in Estonian biogas electricity production scenario where labeled current heating plant locations were considered as heat buyers from biogas CHP plant.

Table 8. Mass flows, operational income and labor demands were calculated in Estonian case.

Closest district heating plant	Tallinn Power Station	Tartu Power Station	Haldja 1 gas engine	Kopli 100 gas engine
Household biowaste, kt/year	5.7	4.1	6.3	3.2
Nitrogen potential, t/year	37	27	41	21
Phosphorus potential, t/year	7.5	5.4	8.3	4.2
Reactor volume, m^3	320	233	353	179
Sales:				
Electricity, GWh/year	1.8	1.3	2.0	1.0
Heat, GWh/year	1.9	1.4	2.1	1.1
Nitrogen fertilizer, k€/year	12,1	8.8	13,4	6.8
Electricity sales, k€/year	210	150	230	120
Heat sales, k€/year	110	80	120	60
Gate fees, k€/year	8.5	6.2	9.4	4.8
Incomes in total, k€/year	**340**	**240**	**370**	**190**
Overall costs, k€/year (inc. Operational & investment)	**150**	**120**	**170**	**80**
Digestate spread & transportation, k€/year	3.6	1.9	4.8	3.0
Feedstock transportation, k€/year	49	46	61	15
Plant costs, k€/year	97	75	105	61
Operational income, k€/year	**190**	**120**	**200**	**110**
Labor demands (160 hour/month)				
Plant site, man months/year	6.4	5.1	6.9	4.2
Feedstock transportations, man months/year	32	31	40	10
Digestate spread & transportation, man months/year	0.4	0.2	0.6	0.4
Labor demands in total, man months/year	39	36	48	15
Labor demands in total, in men	3	3	4	1
Saved GHG emissions in ETS, CO_2 t	**1 000**	**700**	**1 100**	**600**

8. Conclusions

Cost efficient biogas electricity production solutions are found in the scale of one province. Provincial scale actors in waste, municipal, farms and energy sector would be the key players when grass root level solutions to invest on the biogas electricity production system utilizing are done. Biogas electricity production systems would guarantee incomes for some tens of persons in waste-to-energy sector that operate at least in the area on one province which guarantees safe feedstock availability.

Contracts about feedstock delivery and practical level operations would be the next step in the areas where biogas electricity production was found to be the most cost efficient. Most of the heating plants in this study belong also to the emission trading system which could support their interest to invest on systems which have safe and sustainable background in European Energy policy sector. Results about plant locations and feedstock mass flow represent situation in free competition which can be different in reality. Situation will be changed if someone opens the game and starts to collect feedstocks from large areas.

At the moment it is hard to forecast how incentive schemes will develop in target regions, but still methods and tools to predict tariff prizes are needed. Because biogas plants have also quite high investments, several millions of €, it is more secure to consider free competition and constant prize for electricity in economical calculations, unless more predictable methods and tools to estimate becoming electricity prize and gate fees does not exist. In future perspectives, the tool in this study could be used in different applications to assess the feasibilities of different anaerobic digestion systems.

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