MTT REPORT 53

From Waste to Traffic Fuel (W-fuel)

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MTT

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Tallinn University of Technology
Stockholm Environment Institute Tallinn Centre
MTT Agrifood Research Finland
HSY Helsinki Region Environmental Services Authority

Project report to the INTERREG IVA
Southern Finland – Estonia Sub-programme

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Abstract

The EU directive on the promotion of the use of energy from renewable sources (Directive 2009/28/EC) sets a mandatory minimum target for the use of fuels produced using renewable energy sources of 10% of total petrol and diesel consumption in the transport sector by the year 2020. In addition, it states that production of renewable fuels should be consistent with sustainable development and must not endanger biodiversity. In the INTERREG IVA Southern Finland – Estonia Sub-programme, efforts towards finding solutions to the tasks set by the EU were undertaken in co-operation with Finnish and Estonian researchers.

The purpose of the "From Waste to Traffic Fuel" (W-Fuel) project was to promote the sustainable production and use of biogas using locally-sourced biodegradable waste materials from the food and beverage industry and the agricultural and municipal sectors. The ultimate aim of the project was to upgrade the biogas (produced based on anaerobic digestion of biodegradable wastes, sludge, manure, slurry and energy crops) to biomethane with a methane content similar to natural gas, to be further used as transport fuel with the aim of reducing traffic-borne emissions, in particular CO_2. The project combined waste, energy and traffic solutions in order to decrease emissions, costs and the use of materials.

Six case areas in southern Finland and northern Estonia were selected. The two case areas in Estonia were the counties of Harju and Lääne-Viru in northern Estonia. The project aimed to promote waste and sludge prevention and to commence biogas production and its subsequent upgrading to biomethane for use as a renewable fuel. The project promoted regional businesses and employment in waste treatment and 'green energy' production. On basis of the gathered data, the biogas potentials and prerequisites of each case county were analysed. Furthermore, the environmental, economic and other regional effects of the different options were compared. By developing research-based feasibility plans, the project partners provided solutions for public and private companies, local governments and research institutes.

The project was implemented in close co-operation with municipal waste and sewage companies as well as stakeholders in industry and the agricultural and transport sectors. This report presents the project results for Estonia.

Keywords:
Biowaste, sludge, manure, energy crops, biogas, biogas plant, biogas upgrading methods, biomethane, transport fuel, waste prevention, environmental and economic impact assessment, cost-benefit analysis, vehicle fuel, public transport, greenhouse gases

Contents

Ülo Kask, Janita Andrijevskaja, Livia Kask, Priit Heinla, Meeli Hüüs (Chapters 1, 2, 4, 5, 6) - Tallinn University of Technology

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List of abbreviations

BAU	Business as Usual scenario - assumes continuing the present practice
CHP	combined heat and power plant
CH_4	methane
CO_2	carbon dioxide
DM	dry matter
ha	hectare
EEIC	Estonian Environment Information Centre
EARIB	Estonian Agricultural Registers and Information Board
FM	fresh mass
TS	content of total solids
VS	content of volatile solids
ww	wet weight

1. Introduction

According to the EU targets for renewable energy that were adopted in 2009, the percentage of renewable energy in the energy consumption of the EU should be increased by 20%, energy efficiency improved by 20%, and greenhouse gas emissions reduced by 20% by the year 2020. The mandatory minimum target for the use of fuels produced using renewable energy sources is 10% of the total consumption of petrol and diesel fuel in transport by the year 2020. The target concerns all EU countries (Directive 2009/28/EC).

The EU directive on the promotion of the use of energy from renewable sources notes that production of renewable fuels should be consistent with sustainable development and must not endanger biodiversity (Directive 2009/28/EC). The EU commission has set a requirement that renewable fuels should yield savings of at least 35 % in greenhouse gas emissions during their life cycle compared to traditional fuels. In addition the raw material should not be harvested from either high biodiversity areas or areas with large amounts of bound carbon (Pitkän aikavälin ilmasto- ja energiastrategia, 2008).

In the long-term climate and energy strategy approved by the Council of State it is said that Finland is committed to achieving the EU target of having 10% of transport fuels made from renewable energy sources by 2020. According to the strategy, by 2020 the amount of liquid biofuels would be approximately 6 TWh, most of which would be used as transport fuels.

Biomethane is increasingly considered as a potential biofuel and its pioneering use is being stepped up in many European countries. Biomethane can be produced from several different types of feedstock including waste and agricultural materials. In addition to serving as a biofuel, the produced gas can also be used in power and heat production, which is the more traditional way of using gas. Many studies have concluded that biomethane is one of the most sustainable biofuels available today. This is partly because the technology can employ waste materials and the treated materials can in many cases be used as fertilisers, thus enabling the recycling of nutrients.

Various type measurements are needed to ensure the more efficient introduction of biomethane, as is the case with any other new technology in society. Systematic analysis and planning of regional biomass resources and of technological implementations as well as the evaluation of impacts provide one way of developing sustainable and economic biomass utilisation and energy production.

1.1. W-Fuel project objectives

The main objective of the W-Fuel project was to promote biogas production and use as traffic fuel and to promote sustainable use of biomass waste and by-products in the target regions. Available biowaste, sludges, agroresidues and energy crops were considered as feedstock for biogas production. Another aim was to determine the environmental and economic impacts of biogas production and its traffic use. In order to assess the environmental and economic impacts of promoting biomethane production and utilisation, a methane case and base case were defined for the year 2020 on the basis of the forecasts for feedstock availability and biomass treatments in the year 2020. In order to compare possible future developments, the impacts of potential biowaste prevention measures in the year 2020 were also studied.

For all case regions a Biowaste and sludge prevention plan and a Biogas production forecast and plan for biomethane use as transport fuel were drawn up.

The two case areas in Estonia were Harju County and Lääne-Viru County.

Harju County is the largest county in Estonia in terms of population (523,277 inhabitants on 01.01.2008, incl. Tallinn 397,617) and the second largest by land area (4 333.13 km²). It is situated in northern Estonia and covers the coastal region of the Gulf of Finland from the Gulf of Keibu to the Gulf of Eru and stretches up to 56 km inland from the sea. The centre of the County is Tallinn, which is also the capital of Estonia. At present there are 26 municipalities in the County of Harju (**Figure 1**).

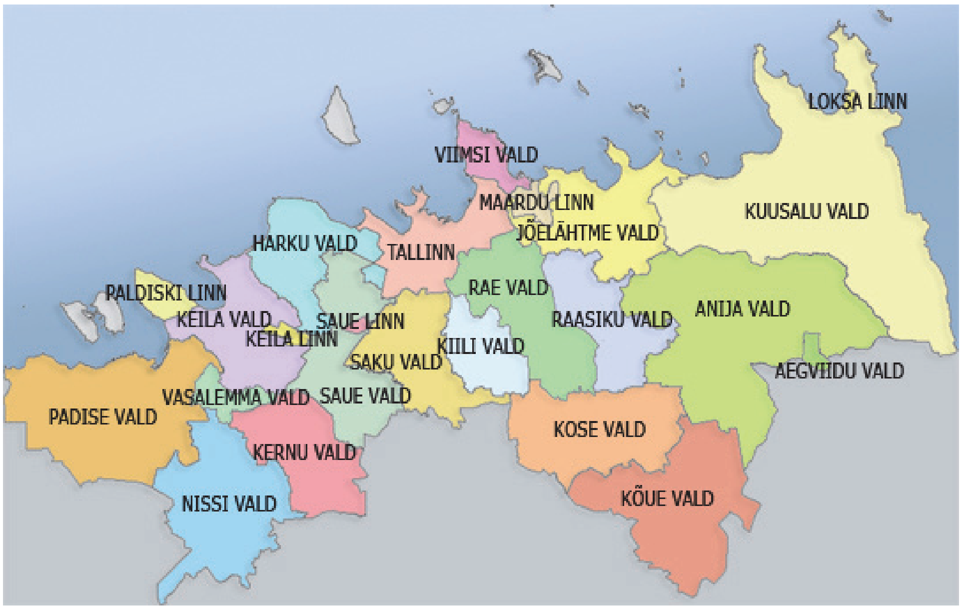

Figure 1. Map of Harju County and municipalities

Lääne-Viru County is the fifth largest county in Estonia in terms of population (66,996 inhabitants on 01.01.2010), a quarter of which live in the administrative centre of the county Rakvere. There are 15 municipalities in Lääne-Viru County: 2 urban municipalities (Rakvere and Kunda towns) and 13 rural municipalities (**Figure 2**). Important industries include meat and food processing, furniture, cement and construction materials, forestry and wood-processing, clothing, processing of agricultural products, distilleries, breweries, dairies, and bread and pastry production.

Figure 2. Map of Lääne-Viru County and municipalities

The Harju and Lääne-Viru counties were chosen as the pilot areas for the project as they produced the highest amounts of biowaste and sludge in Estonia in 2006 and 2007 (when the project was being prepared). In 2007, Harju and Lääne-Viru produced 52% of all biowaste and 62% of all sludge in Estonia combined.

1.2. Waste prevention

Waste is often considered to be sustainable feedstock for energy production. However, the prevention of waste is the first priority e.g. in the EU-legislation related to waste management. In the waste directive

(2008/98/EC) the term prevention is defined to mean “measures taken before a substance, material or product has become waste that reduce:

- the quantity of waste, including the re-use of products or the extension of life span of products;
- the adverse impacts on the environment and human health of the waste generated; or
- the content of harmful substances in materials and products.”

The following waste hierarchy shall apply as a priority order in waste prevention and management legislation and policy:

(a) prevention, (b) preparing for re-use, (c) recycling, (d) other recovery, e.g. energy recovery, and (e) disposal.

In practise, the prevention of food waste means diminishing the production and consumption of food. For instance, it has been estimated that in Finland about 10 % of food products end up as waste (Katajajuuri & Vinnari, 2008) and are therefore produced unnecessarily. Decreasing this unnecessary consumption would also have multiplicative effects on waste generation in the food industry and primary production. Rough estimates with the ENVIMAT- model show that a 10% decrease in food consumption in Finland would lead to a decrease of 420 000 tCO_2-eq in domestic GHG-emissions, if it is assumed that the food production decreases by the same volume; furthermore, domestic resource consumption would diminish by 1.3 Mt and land use by 140 000 ha. At the same time, however, this would lead to the unemployment of 8000 persons and GDP would decline by 300 M€. On the other hand, the monetary savings could be allocated to creating new jobs and land could be used more efficiently and productively, and thus the total effects of diminishing food production are complicated (Mattila et al., 2011).

EU member states have to prepare national waste prevention plans either as part of national waste plans or as separate plans. In Estonia prevention plan will be part of national waste plan to be prepared in 2012-2013. Earlier national waste plan (2008-2013) did not include a plan for waste prevention.

The overall target of preventing the amount and the harmfulness of waste and sludge is included in the legislation of both the EU and its member states, but quantitative targets and effective measures are almost non-existent. Targets and measures, if any, are set mainly only to promote the recovery and recycling of waste.

1.3. Biogas production

Biogas (main components: methane and carbon dioxide) is produced by micro-organisms from biodegradable organic material under anaerobic conditions from materials such as biowaste, sludges, manures, agro residues and energy crops.

Anaerobic degradation of organic matter is a balance between the activities of different groups of micro-organisms and occurs as a sequence of four steps: hydrolysis, acidogenesis, acetogenesis and methanogenesis (**Figure 3**). During hydrolysis, hydrolytic micro-organisms produce extracellular enzymes that degrade complex organic compounds into their monomeric and dimeric components, i.e. proteins into amino acids, carbohydrates into simple sugars and lipids into long chain fatty acids. Acidogenic bacteria then degrade these components further into volatile fatty acids, such as acetic, propionic, butyric and valeric acids and alcohols. During acetogenesis, these intermediary compounds are converted to acetic acid, hydrogen and carbon dioxide, from which methanogenic bacteria produce methane and carbon dioxide as end products.Biogas processes are typically operated at 30-40°C, referred to as a mesophilic process, or at 55 to 60°C, a thermophilic process. The pH value should range from neutral up to low alkaline (Mata-Alvarez, 2003).

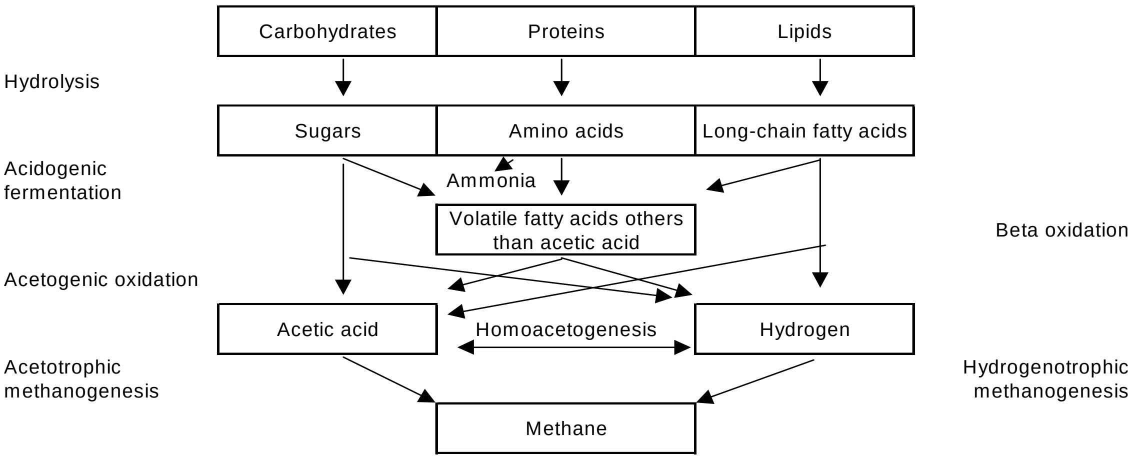

Figure 3. Anaerobic degradation of organic matter (Mata-Alvarez, 2003)

Digested material – referred to as digestate – can be used as fertiliser or soil conditioner. During the digestion process the nutrients in the feed materials remain in the material and nitrogen is converted to ammonium, which is more available for the plant. The digestion process lowers the C:N ratio and total solid content of the organic material and makes it more homogenous.

In comparison to other EU countries, Estonia is a very small biogas producer and consumer per inhabitant. In 2009, the average biogas consumption for energy purposes in the EU was 16.7 toe per 1000 inhabitants. The equivalent figure for Estonia was 2.1 toe per 1000 inhabitants.

In Estonia, biogas for energy production is produced from manure, sewage sludge and landfill waste. The first biogas plants were put into operation in the Soviet period. These were located on the pig farms near the city of Pärnu and at the Linnamäe collective farm. After eight years of operation, production at Linnamäe had to be terminated due to cracks in the concrete digester and the Pärnu plant ended in bankruptcy. All equipment at the plants was dismantled.

Today there are six companies producing biogas for energy purposes in Estonia. Terts AS (Ltd) produces biogas from the Pääsküla Landfill (Tallinn) and distributes heat and electricity to the local district heating network and the national grid, respectively. Tallinna Vesi AS produces biogas from sewage sludge at its sewage water treatment plant in Paljassaare (Tallinn) and uses the gas to run the compressor engines of its aeration tanks. Saare Economics OÜ (Ltd) produces biogas from pig slurry and uses it for heat (self-consumption only) and electricity production distributed to the national electricity grid. Other producers of energy from biogas include the Rääma landfill site, the Tallinn landfill site (Tallinn Recycling Centre) and the Kuressaare wastewater treatment plant.

The Estonian Institute of Economic Research (EIER) has published a comprehensive study (Review of Estonian Bioenergy Market in Year 2010) on biogas production and consumption in Estonia. Some of the key tables, figures and explanations presented in the above study are given below.

Table 1. Biogas production in Estonia, million m^3

	2007	2008	2009	2010	Development '10/'09 ±%
Total production	12.54	11.85	13.59	13.13	-3.5
From: sewage sludge	2.64	2.84	2.69	2.96	10.1
pig slurry	0.57	0.39	0.59	0.85	43.6
landfill gas	9.34	8.62	10.32	9.32	-9.7
- Share of biogas from sewage sludge	21.0	23.9	19.8	22.5	2.8
- Share of biogas from pig slurry	4.5	3.3	4.3	6.5	2.1
- Share of landfill gas	74.5	72.8	75.9	71.0	-4.9

Source: (Ülevaade.., 2011)

As **Table 1** shows, the total biogas production declined in 2010, but further growth can be expected if all biogas plants being constructed or planned are commissioned. Landfill gas production also decreased in 2010. The decrease was caused by the decommissioning of the Pääsküla landfill in accordance with European requirements, after which gas fermentation dropped. Despite this decline, landfill gas remains the biggest contributor to biogas production. The share of biogas produced from pig slurry and cattle manure is, however, likely to grow rapidly in the near future.

Table 2. Biogas production and consumption in Estonia, million m^3 (reserves not taken into account)

	2007	2008	2009	2010	Development '10/'09 ±%
Biogas production, total	12.54	11.85	13.59	13.13	-3.5
Imported	-	-	-	-	-
Exported	-	-	-	-	-
Domestic consumption	12.54	11.85	13.59	13.13	-3.5
power production	3.76	3.18	2.04	2.75	34.7
heat production	4.47	4.12	3.16	3.16	-
flared off	3.78	3.80	7.87	6.16	-21.7
technological use	0.62	0.75	0.52	1.05	102.7
Consumption, total	12.54	11.85	13.59	13.13	-3.5

Source: (Ülevaade.., 2011)

As **Table 2** shows, the consumption of biogas differs by sector. Consumption levels for power and heat production as well as for technological use have been variable, whereas flaring (burning off as waste) has been on a near constant increase. This reflects the closure of landfills and the construction of gas extraction systems. Most Estonian landfills are small, and installing energy production facilities on site is not cost-effective. Consequently, most landfill gas is flared off. One positive exception regarding biogas use is the Tallinn Sewage Treatment Plant (Paljassaare), where biogas from sewage sludge is used industrially to operate Otto engines, which generate mechanical energy for compressors supplying air to the sewage water aeration tanks.

According to the EIER's assessment, 71.8 TJ of heat and 42.1 TJ of electricity (power) were produced in 2010 from biogas. Heat and power production increased in 2010 compared to 2009 at 48.3% and 34.7%, respectively.

1.4. Biomethane as transport fuel

There are over 14 million gas vehicles in the world and over 1 million in Europe. Italy is the leading country in Europe with almost 800 000 gas vehicles, followed by Germany (over 90 000 vehicles), Bulgaria (over 60 000) and Sweden (over 40 000). In Finland there are almost 1000 gas vehicles, of which 75 are busses, whereas Estonian numbers are almost ten times smaller: 110 gas vehicles of which 7 are buses (NGVA, 2011). The vehicles mainly use natural gas, but can also use biomethane (upgraded biogas) with no technical modifications (Persson et al., 2006).

Biogas can be purified to biomethane using several different purification technologies. Purification may consist of several units with the aim of enriching methane and removing carbon dioxide, hydrogen sulphide, ammonia, particles and water. Biomethane may have a methane content above 96-98%. Biomethane can be distributed via the natural gas grid or local gas grid or using a local on-site fuelling station. The major difference between biomethane and natural gas is that the former is produced from renewable energy sources, while natural gas is a fossil fuel (Gustafsson & Stoor, 2008).

A challenge of biomethane deployment is that the constraints of the refuelling network limit growth in the number of methane-fuelled vehicles and vice versa. Building biogas production overcapacity leads to a substantial increase in the production costs of biomethane. Therefore the production and consumption of biomethane should be balanced, especially in areas without a gas grid.

According to NGV's statistics (2011) the growth rate of methane-driven vehicles has been rapid in recent years; however this is mainly due to the low initial number of such vehicles. For example in Switzerland the number of methane vehicles has grown 35-fold and in Sweden and Finland 20-fold within the last ten years. In Italy, which is a leading country in Europe in terms of the number of methane vehicles, the amount has grown 128% within the same time period (NGVA, 2011). However, access to methane refuelling is still very limited.

The trend in methane vehicle numbers correlates positively with refuelling infrastructure. As the number of refuelling stations grows, so does the amount of methane vehicles per station. This results from the better availability of methane, which makes changing over to such a vehicle more attractive. Italy represents a market where the amount of methane vehicles per refuelling station has remained at around 900 during the last ten years. In Finland there were 44 methane vehicles per station. These figures can be compared to the mature state market for liquid fuel refuelling in Finland, where there are an average of 1000 vehicles per station (NGVA, 2011).

1.5. Environmental and economic impact assessment

An impact assessment aims at identifying the potential economic, social and environmental consequences of a given action. The EU defines an impact assessment as a set of logical steps that prepares evidence for political decision-makers on the advantages and disadvantages of possible policy options by assessing their potential impact (EU, 2012).

In order to be able to assess the impacts of biogas production and use, a comparison with an alternative scenario must be made. Outlining an alternative scenario to biogas production and use requires the identification of the ways in which biogas raw materials would otherwise be handled, as well as defining alternative uses for biogas other than for use as transport fuel, i.e. uses of biogas for production of electricity and heat. The figure below shows a pathway of raw materials to their alternative use in comparison to their use as biogas.

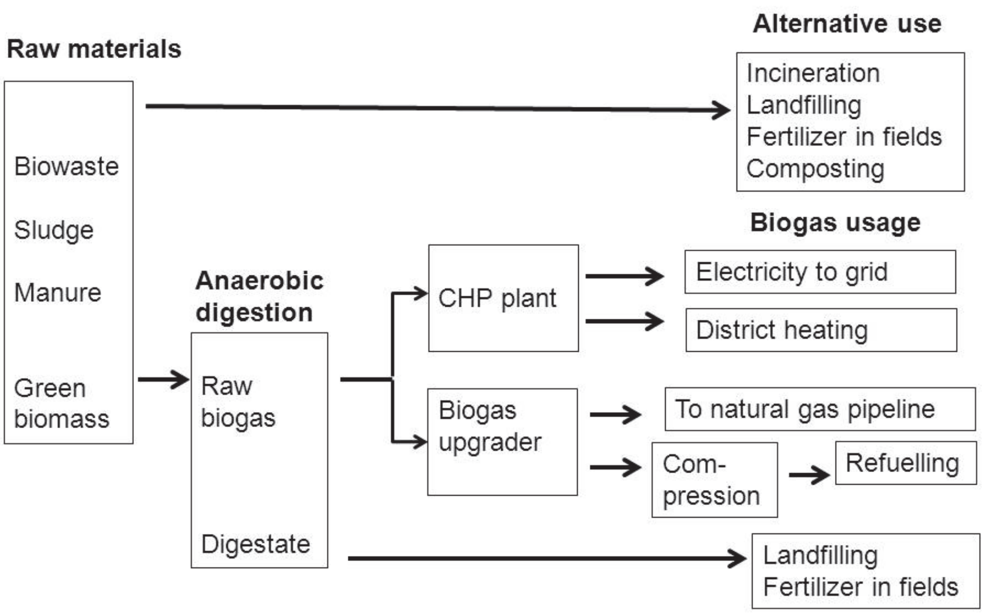

Figure 4. Schematic diagram of raw materials in alternative and biogas usage

The uppermost arrow indicates the alternative use of raw materials that are inputs in biogas production. These include incineration of waste, use of sludge and manure as landfill or fertilizer. The lower arrow leading from the raw materials shows two biogas options: either production of electricity and heat or upgrading to natural gas quality, i.e. biomethane. In the first step, the production process is identical – raw biogas is produced during anaerobic digestion. After completion of the digestion process, raw biogas leaves the digester. As a second step of production the raw gas enters either a combined heat and power (CHP) plant or a bio-gas upgrading unit. In the CHP option, electricity is fed to the grid and heat is directed to the district heating network. In the upgrading option, the raw biogas is upgraded to biomethane which is fed into the natural gas network or transported to a filling station where it is used as a vehicle fuel. The digestate is the residue from the anaerobic process. High quality digestate can be used as fertilizer, either as-is or mechanically separated into liquid and solid fractions.

The environmental impact assessment follows the potential environmental interactions throughout the biogas production process: from biomass production and the biomass digestion process, in which emissions can be released from the digester, to the CHP plant or upgrading unit and through to application of the digestate onto the field as fertilizer, the use of electricity and heat, and the use of biomethane as a vehicle fuel.

The economic impact assessment identifies the investments and running costs needed for producing biomethane and the potential revenues from sales, and compares this to the costs and revenues of the alternative options. Since the production and use of biogas has further goals than just commercial impacts, such as impacts on economic welfare and the environment, the overall economic impacts are assessed in a cost-benefit analysis (CBA). The basis of a CBA is to appraise whether the costs of an action contribute to economic welfare. This implies a need to appraise the positive and negative impacts that go beyond the financial results of those who receive income and those who pay the costs.

2. Data and methods

2.1. Origin of data on feedstock for biogas production

Biowaste

The study focuses on biowaste as defined in EU directive 2008/98/EC, according to which biowaste includes biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises and comparable waste from food processing plants. In this study, tissue paper is also considered as biowaste, as this is a good raw material for biogas production. Tissue paper constitutes approximately 4% of mixed municipal waste in Estonia (Moora, 2008).

The study deals with biowaste from households, industries (food processing industries and pulp and paper industries) and private and public services (shops, restaurants, health care, children day care, education).

The majority of the statistical data on biowaste is sourced from the database of the Estonian Environment Information Centre (EEIC). In addition to statistics, data from several interviews were also used in the study (see appendix for full list of organizations interviewed): the 14 largest biowaste producers, 3 schools, 2 kindergartens, 2 nursing homes. The main interview topics included the amount and properties of the biowaste (e.g. content of total solids (TS), volatile solids (VS), nutrients and harmful substances; although only a few companies had access to chemical analysis results) and waste treatment procedures. The largest producers of biowaste were also asked about their interest in biogas production.

In addition to waste producers, several experts on waste management were interviewed from the following organizations: the Association of Waste Managers, Ministry of Environment, Lääne-Viru Waste Station, Tallinn City Environment Board, and local municipal governments.

Sludges

The statistical data on municipal and industrial sludge originates from the database of the EEIC. The EEIC collects and records the data submitted by companies in their annual water reports. The sludge data used in the present study dates from the period 2007-2008.

In addition to statistical data, the four largest sludge-producing companies were interviewed: Tallinna Vesi AS and Horizon Tselluloosi ja Paberi AS in Harju County; and Estonian Cell AS and Rakvere Vesi AS in Lääne-Viru County.

The main interview topics included the amount and properties of the sludge (e.g. TS, VS, nutrients, harmful substances), sludge treatment procedures, and interest in biogas production.

Manure

Data on the numbers of animals and farms were obtained primarily from the Estonian Agricultural Registers and Informational Board (EARIB)[1] and, to a lesser extent, also from the Estonian Statistical Office.

To calculate manure production levels, the following data were used (**Table 3**). To determine the amount of manure from beef cattle over 12 months old, the average amount was calculated based on two categories of animals: 12-24 month old and over 24 month old animals.

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[1] EARIB provides data on agricultural farms that applied for agricultural support. EARIB does not disclose data on farms managed by natural persons.

Table 3. Approximate manure production by animal type

Animal type	Liquid and semi-liquid manure, t/y	Solid manure, t/y
Dairy cow	21	12
Beef cattle, >24 months	15	9
Beef cattle, 12-24 months	7.5	4.8
Beef cattle, 0-12 months	3.6	2.0
Sow with piglets	5.7	4.0
Fattening pig (10-120 kg)	1.6	0.7
Horse		9.0
Sheep		1.5
Laying hen		0.05
Broiler		0.015

Source: Keskkonna.., 2004

To estimate the amount of manure that can be realistically used for biogas production, only those amounts were taken into account which originate from farms where the number of animals exceeds the limit value for a mandatory waste permit:

1. Pig farms with more than 1,000 pigs or 300 sows;
2. Cattle farms with more than 300 dairy cattle, 400 beef cattle or 600 ca young cattle;
3. Chicken farms with more than 40,000 chickens.

Energy crops

The data on cultivated and abandoned land were obtained from the EARIB. To calculate the amount of land suitable for growing energy crops, the following percentages were used (proposed by the Estonian Biogas Association):

- 5% of cultivated land can be used for growing energy crops,
- 20% of abandoned land can be used for growing energy crops.

In the present report, two types of energy crops are recommended for biogas production:

- reed canary grass (päideroog, *Phalaris arundinacea*). Average annual yield: 9 tDM/ha (2 harvests) (Rohtsete .., 2007). TS 28%, VS/TS 90%, methane yield 300 m^3/tVS or 76 m^3/tFM (MTT, Chapter 2.2).
- clover (ristikhein, *Trifolium pratense*). Average annual yield: 9 tDM/ha (2 harvests). TS 12.7%; VS/TS 90.3%; methane yield: 335 m^3/tVS or 38m^3/tFM (Põllumajanduses ..., 2005).

Both clover and reed canary grass has been cultivated in Estonia for many years. The yields of these crops are high and it is possible to harvest 2-3 crops per year.

When calculating forecast estimates of energy crops for 2020, it is assumed that reed canary grass and clover cover equal land areas.

Landfill gas and biogas from sewage sludge treatment

The amounts and properties of landfill gas and biogas recovered from sewage sludge treatment were obtained from Statistics Estonia reports, the Estonian Environment Information Centre, and from interviews with wastewater treatment plants in each case area. Information on future developments in landfill gas recovery was obtained through interviews with waste management companies.

In Harju County, biogas is collected and used for energy production at two landfill sites (Pääsküla and Jõelähtme landfills). In Lääne-Viru County, biogas is collected at the Ussimäe landfill. The landfill was closed in 2009 and final covering was completed in autumn 2011. The biogas is not collected for energy generation.

2.2. Estimated methane yields

Several data sources for biomass methane yields were used in this report. The main source used was MTT Agrifood Research Finland (lead partner of the W-Fuel project), see **Table 4**.

Table 4. Biomass methane potential

Biomass	Biomass Type	CH_4	CH_4	TS	VS/ TS	C	N	P
		m^3/tVS	m^3/t ww	%		%TS	%TS	%TS
Biowaste	Biowaste from industry	400	97	27	90	48	2	0.4
Biowaste	Biowaste from private services	400	97	27	90	48	2	0.4
Biowaste	Biowaste from public services	400	97	27	90	48	2	0.4
Biowaste	Biowaste from households	400	97	27	90	48	2	0.4
Biowaste	Biowaste from ferries	400	97	27	90	48	2	0.4
Biowaste	Fish processing waste	520	119	27	85	40	10	0.2
Biowaste	Bakery waste	400	238	66	90	45	2.3	0.2
Biowaste	Milk waste (whey)	420	18	6	70	45	5	1
Biowaste	Fat waste	800	288	40	90	73	0.4	0
Biowaste	Slaughter waste	600	216	40	90	56	8	1
Biowaste	Vegetable waste	400	97	27	90	45	1.6	0.2
Manure	Stable manure	250	48	32	60	45	2.5	0.9
Manure	Slaughterhouse manure	250	18	10	70	40	8.3	1.95
Manure	Solid cattle manure	200	23	19	60	46	2.4	0.8
Manure	Liquid cattle manure	200	10	6	80	45	5.5	0.9
Manure	Solid pig manure	300	58	24	80	43	2.5	1.5
Manure	Liquid pig manure	300	10	4	85	30	11	3
Manure	Solid chicken manure	300	81	38	71	38	3.1	1.5
Sludge	Food industry sludge	300	42	20	70	35	4	2.5
Sludge	Paper and pulp mill sludge, biol.	100	14	20	70	46	1.5	0.3
Sludge	Paper and pulp mill sludge, primary	300	42	20	70	25	1.2	0.1
Sludge	Municipal ww-treatment sludge	300	42	20	70	35	4	2.5
Energy crops	Straw	230	178	85	91	46	0.5	0.1
Energy crops	Vegetable tops	300	28	11	85	40	2.2	0.2
Energy crops	Silage	350	104	35	85	47	3.4	0.6
Energy crops	Rape straw	250	207	90	92	44.5	1.6	0.1
Energy crops	Reed canary grass	300	76	28	90	48	1.8	0.2

Notes: TS Total solids
VS Volatile solids
ww wet weight

Another source of methane yields used in this report was the publication "Põllumajanduses kasutatavate biogaasiseadmete gaasitootlus" (2005, Mecklenburger Gesellschaft mbH) and for some substrates, methane yields were obtained from interviews with experts from Tallinn University of Technology, Department of Chemistry.

For more precise methane yields, additional tests of biogas substrates have to be made.

2.3. Base and methane case scenarios for 2020

The amounts of waste materials were calculated using two different scenarios. In the calculations for Option A, the amount of waste in 2020 was calculated using same efficiency for separate collection of biowaste as in year 2009 (**Table 5**). In option B, it was assumed that the amount of household biowaste has decreased as described in the waste prevention plan (chapters 3.2 and 4.2).

Table 5. Two scenarios used for year 2020

Option A - Base Case 2020	Option B - Methane Case 2020 (average percentage for both counties)
Municipal biowaste: treatment as at present or as currently planned in Estonia (e.g. incineration at the Iru power station)	Municipal biowaste: 33% anaerobic treatment / remainder treated as at present (waste prevention also considered)
Industrial biowaste: treatment as at present	Industrial biowaste. Animal tissue waste: 90% anaerobic treatment / remainder treated as at present Waste from spirit distillation: 33% anaerobic treatment / remainder for animal breeding
Municipal sludge: treatment as at present	Municipal sludge: 100% anaerobic treatment
Forest industry sludge: treatment as at present	Forest industry sludge: 100% anaerobic treatment or alternative energy generation
Manure: traditional treatment for field application, partly anaerobic digestion (Vinni biogas plant)	Manure. Pig slurry: 90% anaerobic treatment / remainder: traditional treatment for field application Beef and dairy cattle slurry: 40% anaerobic treatment / remainder: traditional treatment for field application Chicken solid manure: 80% anaerobic digestion / remainder: traditional treatment for field application
Energy crops: not cultivated for energy production	Energy crop cultivation on 5% of cultivated agricultural land and on 20% of abandoned land / remainder cultivated as at present

2.4. Impact assessment of biogas production and use as a transport fuel

The Methane Case has been implemented in the design of two pilot biogas plants: one at the Hinnu pig farm in Harju County, and one adjacent near to the Rakvere sewage treatment plant in Lääne-Viru County. The environmental and economic impacts of these pilot plants were assessed by comparing their operations to the Base Case in 2020. For each pilot plant there are two options:

B_1 – Biogas is used to produce electricity and heat in a CHP regime

B_2 – Biogas is upgraded to biomethane, i.e. natural gas quality, and used as vehicle fuel.

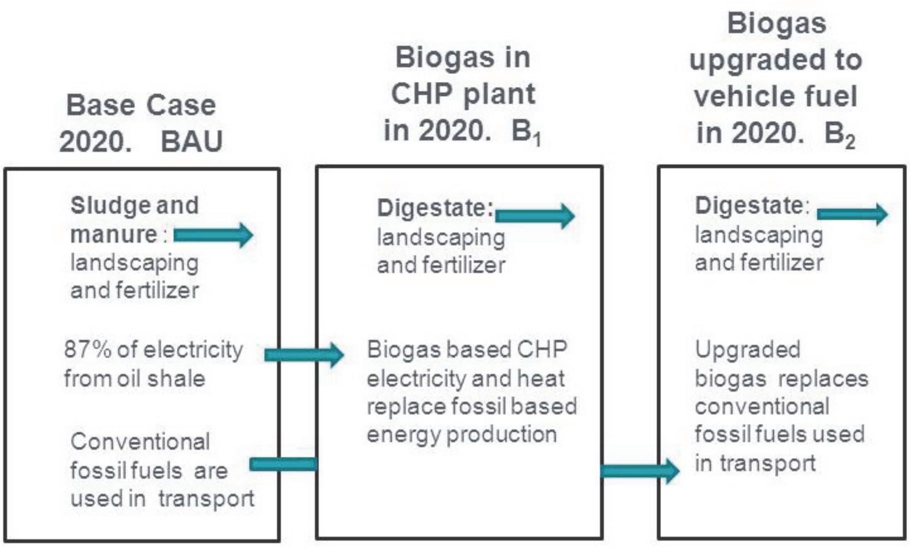

Figure 5. Base Case (BAU) compared with biogas options B_1 and B_2 in 2020

In the environmental impact assessment, a Life Cycle Assessment (LCA) was used as the guiding principle for detecting environmental impacts from biogas production and usage. Based on data from literature, environmental impacts were accounted for as far as possible according to their physical quantities. In the case scenarios these impacts were not possible to quantify, and were therefore assessed qualitatively. The table below shows the environmental impacts during production.

Table 6. Environmental impacts during production

		Sources
Nitrogen leakage		
Energy crops fallow land, N-leakage	+10 kg/ha	Börjesson & Berglund, 2003
Digestate replaces manure, N-leakage	-7.5 kg /ha	Börjesson & Berglund, 2003
Emissions from covered digester		
CH_4, NH_3, N_2O and VOC	1-2% of production	Thomtén, 2011
Odour		
digestate less odorous than manure	Reduction of butanoic and valeric acid	Hansen et al., 2004
Upgrading plant (methane slip)		
Water absorption	~1%	Peterson &Wellinger, 2009
Amino wash	<0.1%	Peterson & Wellinger, 2009

The impacts during the use of biogas need to be compared to alternative sources of electricity, heat and vehicle fuels. The assumption of the Base Case is that electricity generation follows the average Estonian electricity mix with 87% oil shale electricity in 2020. Sensitivity analyses assume that biogas replaces marginal electricity produced from natural gas. The Base Case assumes conventional petrol and diesel as transport fuels in 2020.

The economic assessment is based on cost benefit analysis (CBA) and follows the EU guidelines on economic analysis by applying an assessment period of 30 years and an interest rate of 5.5% (Guide .., 2008). The CBA includes all impacts, i.e. both environmental and economic. In order to compare impacts, these need to be expressed using a common unit of measure (in the present study the euro). Monetary impacts, e.g. investments, running costs and revenues are already expressed in monetary terms. Since environmental impacts have no market price, the CBA uses shadow prices, e.g. damage costs. The European project ‘Harmonised European Approaches for Transport Costing and Project Assessment’ (Heatco, 2006) proposes damage costs of electricity production and transport for 25 EU countries. In the CBA, the Estonian values of the damages are applied to the environmental impacts that arise during biogas use. The CBA applies 2011 prices. The emission values were converted to 2011 prices using the consumer price index, see table below.

Table 7. Air emission values for Estonia*

	Electricity EUR_{2011}/ tonne	Transport, EUR_{2011}/tonne
CO_2 (2020-2029)	0**	46
MVOC	713	713
NO_X,	1,997	1,997
PM	4,280	38,522
SO_2	1,712	1,712

*Consumer price index IA02 of Statistics Estonia was used to determine 2011 prices.
**Default value. Sensitivity analyses use €46/tonne.
Source: Heatco, 2006, see Tables 6.2 and 6.5

It is assumed that the EU Emissions Trading Scheme (EU-ETS) will be operational in 2020. The EU-ETS includes most electricity generation plants. For this reason, biogas electricity that replaces fossil electricity is given a zero value of CO_2 emissions. Several authors note that once the EU-ETS becomes operational, the effectiveness of all other policies to reduce CO_2 emissions of the participating sectors becomes zero because the EU-ETS sets a binding carbon emissions cap (Morthorst, 2003, Sijm, 2005, Frondel et al., 2010). When CO_2 emissions are reduced by substitution of fossil fuels with renewable energy, the producer of fossil energy can sell its emission allowances to another sector, which then can increase emissions. Sensitivity analyses were carried out to determine the range of impact of this assumption.

Information about economic impacts was collected from literature. Estonian sources were used as far as possible and complemented with international literature as needed. The table below shows the assumed costs and revenues of biogas production.

Table 8. Costs and revenues of biogas production

	In 2011 prices		Source
	Hinnu	Rakvere	
Investment			
Biogas plant (incl. CHP)	2.0 M€	3.76 M€	€3,000/kW_{el} (Edström et al., 2008)
of which CHP	0.5 M€	0.94 M€	Maaelu, 2008
Upgrading equipment			
Water absorption	1.145 M€		Tartu, 2011
Amino wash and H_2S treatment		1.82 M€	de Hullu, 2008
Connection to electricity grid	0.2 M€	0.376 M€	10% of investment
Connection to natural gas net	0.6 M€	0.25 M€	€500/m (Kuningas & Kärki, 2011)
Refuelling and compression	0.12 M€	0.12 M€	Grontmij, 2009
Running costs per year			
Labour (2 h/day 365 days)	7,848 €	7,848 €	2011 3rd quarter: €10.75/h (stat.ee)
Green biomass	116,090 €	-	Cost per tonne €32.5 incl. transport
Other raw materials	0 €	0 €	Assumption
Running cost CHP	77,000 €	144,760 €	3.5% of investment
Running cost upgrading	100,000 €	179,000 €	de Hullu, 2008
Revenues			
Electricity	46.29	46.29	€/MWh, Konkurentsiamet, 2011
Feed-in tariffs (FITs)	54.00	54.00	€/MWh, Electricity Market Act
Heat	35.00	35.00	€/MWh, (Latõšov, 2011)
Biomethane	455.46	455.46	€/1000 m^3 net of taxes, Eesti Gaas

3. Harju County: project results and scenarios

3.1. Biowaste, sludge and agricultural biomass: history and trends

Biowaste

Harju County produces almost half of all municipal waste in Estonia (2008). The area's high population density, high business concentration and massive tourist flows each contribute to the large amounts of waste produced.

The amount of biowaste in Tallinn and Harju County are presented in **Table 9** and **Table 10**. The largest industrial biowaste producers in Tallinn and Harju County are: AS Tallegg, Saku Brewery, Eesti Munatooted AS, Maseko OÜ, Spratfil AS and others. The largest producers of municipal biowaste include the companies Karlskroona, Rigual, Prisma Peremarket and Green Marine, as well as the street maintenance services, households and others. Most of the companies named and other larger companies were interviewed during the project.

Biowaste from the companies interviewed comprised 81% of the food and beverage industry biowaste in Tallinn and 82% of the food and beverage industry biowaste in Harju County (excluding Tallinn). The share of in non-household municipal biowaste from the companies interviewed was 6% in Tallinn and 14% in Harju County.

Table 9. Biowaste and sludge production in Tallinn 2006-2008, tonnes

Type of waste	2006 total	2007 total	2008	
			Total	… of which households
Biowaste from food processing industries	123	131	618	-
Incl.: Animal-tissue waste from preparation and processing of food of animal origin	123	131	618	-
Municipal biowaste (household waste and similar commercial, industrial and institutional waste) including separately collected fractions	64 761	63 653	63 068	28 799
Incl.: Biodegradable kitchen and canteen waste	…	1 048	7 113	2 866
Cooking oil and fat	…	146	134	4
Biodegradable waste from gardens and parks	2 696	1 488	2 603	513
Biowaste in mixed municipal waste	61 426	60 243	52 623	25 416
Waste from markets	639	728	595	-
BIOWASTE TOTAL	64 884	63 784	63 686	28 799

Explanations in the tables:
… data not available; - magnitude nil

The figures in **Table 9** show that the amounts of certain biowaste in Tallinn change significantly over the years. For example:

Biowaste from food industries in Tallinn increased almost 5-fold from 2007 to 2008. The statistical data were influenced by several fish-industry companies who reported large amounts of biowaste in 2008 (production increased due to the favourable exporting conditions).

Source-separated kitchen waste grew from negligible amounts in 2006 to over 7000 t in 2008 in Tallinn. This fast growth has resulted from the introduction and promotion of source-separation, which has been stimulated in recent years in order to comply with the limits of the EU directive on the share of biodegradable waste to be deposited in landfill.

Table 10. Biowaste and sludge production in Harju County (excluding Tallinn) 2006-2008, tonnes

Type of waste	2006 total	2007 total	2008	
			Total	…of which households
Biowaste from food processing industries	6 029	3 078	2 688	-
Incl.: Animal-tissue waste from preparation and processing of food of animal origin	6 029	3 078	2 660	-
Waste from washing, cleaning and mechanical reduction of raw materials for alcoholic and non-alcoholics beverages	…	…	28	-
Municipal biowaste (household waste and similar commercial, industrial and institutional waste) including separately collected fractions	16 715	21 143	24 759	9 804
Incl.: Biodegradable kitchen and canteen waste	…	11	241	80
Cooking oil and fat	1	4	4	-
Garden/park biodegradable waste	652	288	324	30
Biowaste in mixed municipal waste	16 062	20 840	24 190	9 694
Waste from markets	…	…	…	-
BIOWASTE TOTAL	22 744	24 221	27 447	9 804

The study on mixed municipal waste in Tallinn districts showed that the composition of biowaste within municipal waste varies significantly across the city districts (**Table 11**). The share of soft tissue in municipal waste is approximately 4% on average for Estonia (Moora, 2008, p 18, 21).

Table 11. Share of biowaste in mixed municipal waste of three regions in Tallinn, % by mass

Waste	City centre	Nõmme	Haabersti
Biowaste total	32.7	35.8	35.8
Food and kitchen waste	25.3	28.3	35
Garden waste	6.5	6.4	2.5
Other biowaste	1	1.1	1.2

Notes: Haabersti - high-rise district
Nõmme - single-house garden district

The main waste management companies involved in biowaste treatment in Harju County are: Tallinn Landfill (in Jõelähtme) and waste management companies such as Ragn-Sells Ltd., Veolia Environment, Adelan Prügiveod and Prügivedu Grupp OÜ.

Jõelähtme Landfill is a relatively new landfill site – it was opened in 2003 as a replacement for the old landfill in Pääsküla (Tallinn suburb). The Jõelähtme landfill receives waste from Tallinn and the neighbouring municipalities. The main biowaste brought to the landfill are: spoiled fruits and vegetables from storehouses, garden waste, eggshells, spoiled fish, products that have exceeded the expiry date.

It should be noted that to avoid overestimation of the resources available for biogas production, the amounts of biowaste in further calculations of the biogas potentials (see part 3.3.2.1) are taken into account excluding Tallinn. This is because all waste from Tallinn (incl. biowaste) is planned to be used by a new waste fuel plant (commissioned October 2011) and by the Jõelähtme landfill. There is also a future plan to construct a biowaste separation unit at the new waste fuel plant.

Sludge

The annual sludge production in Harju and Tallinn are presented in **Table 12**. The largest sludge producer in Harju County and Tallinn is Tallinna Vesi AS (wastewater treatment plant); the company was interviewed during the project. The sludge from Tallinna Vesi AS accounted for 100% of the total sludge production registered in Tallinn in 2008. The average total solids (TS) content of the sludge was 25% and 15% for Tallinn and Harju County (excluding Tallinn), respectively.

Table 12. Sludge production in Harju County, tonnes

Region	2007	2008	2009
Tallinn	33,834	35,691	35,701
Harju County, excluding Tallinn	5,523	23,420	20,395
Harju County including Tallinn	39,357	59,111	56,096

In Tallinn, 99% of the population has access to the sewerage system. In Harju County (excluding Tallinn), the percentage is lower, at 93% (EEIC, 2010).

Tallinna Vesi AS treats most of the municipal wastewater and stormwater from Tallinn and its suburbs; 60% of sludge in Harju County is produced by Tallinna Vesi AS. After mechanical and biological purification, the clean water is discharged into the Bay of Tallinn. The excess sludge from purification is directed to methane tanks, where mesophilic anaerobic digestion is applied to produce methane ($2.3*10^6$ m^3 in 2009). The digestion residue is stabilized, compressed, aerated, mixed with peat and transported to a sludge collection site. Treated sludge is sold to customers under the brand 'soil for growth' (*kasvumuld*) at approximately 3.2 EUR/t. The treated sludge cannot be named 'compost', because the stabilization method is different from the national standard for making compost (e.g. 6 days at 60˚C). A total of 76% of biogas was used to produce heat, and the rest of the gas was burned off. In 2009, Tallinna Vesi sold 31,942 tonnes of processed sludge, which is two times more than in 2008.

Paldiski Linnahoolduse OÜ. The company treats wastewater from the town of Paldiski and the surrounding areas. The company's wastewater treatment equipment is relatively new (built 2005). The sludge remaining after mechanical and biological wastewater treatment is not composted, although there are plans to start composting by mixing the sludge with grass, leaves and straw, or to build a biogas plant.

Depending on the levels of hazardous substances in the wastewater, there are 8 price groups for leading off wastewater from companies situated in Tallinn. Prices average at around 2 EUR/m^3 (regulation of Tallinn Governmental Council, 30.09.2010). If the levels of hazardous substances are exceeded, the service price increases. For natural persons, the price is EUR 0.93.

To avoid overestimation of available sludge resources, also sludge production levels are calculated both inclusively and exclusively of Tallinn, as all Tallinn sludge is treated by the wastewater treatment plant of the water company Tallinna Vesi AS. The company has for a number of years been operating a biogas plant that produces biogas from sludge for its own needs as boiler fuel and motor fuel for its compressors.

Manure

This section gives an overview of livestock farms and livestock numbers in Harju County. The main data source was the Estonian Agricultural Registers and Information Board (EARIB) and partly also the database of Statistics Estonia. The data was also verified during on-site interviews. Livestock numbers were used to calculate manure production levels, based on which the theoretical biogas yield for Harju County was estimated.

According to the EARIB register, there were 233 livestock farms in Harju County in 2009; of these:

- 164 farms raised beef and dairy cattle, totalling some 16,500 animals,
- 5 farms raised pigs, totalling some 16,200 animals, the biggest being Hinnu pig farm at Allika village (*küla*), Kuusalu municipality (*vald*), with 11,205 animals.

- 80 farms raised sheep, totalling some 6,000 animals,
- 13 farms raised goats, totalling some 70 animals,
- 2 farms raised chicken, totalling some 280,200 hens – the chief producer being AS Tallegg at Loo village, Jõelähtme municipality, with 280,000 hens.

The data from the EARIB database on livestock numbers in Harju County in 2007-2009 is presented in **Table 13**. The corresponding manure production levels are also given in the table. As the table shows, the biggest sources of manure are cattle farms. These are followed by pig and chicken farms. Cattle numbers fell by about 10% and pig numbers by about 5% by 2009. The biggest decrease was in 2008, coinciding with the beginning of the economic recession. Chicken numbers remained unchanged over the period under observation.

Table 13. Number of livestock and calculated amount of solid manure (tonnes) in Harju County, 2007-2009

Animal type	2007		2008		2009	
	animals	manure	animals	manure	animals	manure
Beef cattle under 12 months	3,354	6,708	3,347	6,694	3,280	6,560
Beef cattle over 12 months	9,729	67,130	8,788	60,637	8,761	60,451
Dairy cattle	5,413	64,956	4,778	57,336	4,521	54,252
Cattle total	18,496	138,794	16,913	124,667	16,562	121,263
Fattening pigs	8,105	5,674	5,736	4,015	5,622	3,935
Piglets	7,442	3,721	8,259	4,130	8,985	4,493
Gilts	40	20	295	148	376	188
Sows	1,521	6,084	1,247	4,988	1,215	4,860
Boars	31	124	25	100	26	104
Pigs total	17,139	15,623	15,562	13,380	16,224	13,580
Chicken	280,200	14,010	280,200	14,010	280,200	14,010
Sheep	4,074	6,111	4,896	7,344	5,807	8,711
Goats	83	125	73	110	71	107
Horses	600	5,400	600	5,400	700	6,300
Manure total		180,062		164,911		163,970

Source: EARIB, Statistics Estonia

Note: Manure amounts are calculated based on the data from the source ''Keskkonda säästev sõnniku hoidmine ja käitlemine', 2004, p 9.

The cattle farms in Harju County are rather small: 56% of farms have only up to 100 animals. The distribution of the Harju County farms by livestock size is presented in **Figure 6**.

There are 11 cattle farms where the number of animals exceeds the limit value for a mandatory waste permit (see subchapter 2.1). The number of animals in these farms represents about 55% of the total number of cattle in Harju County (2009).

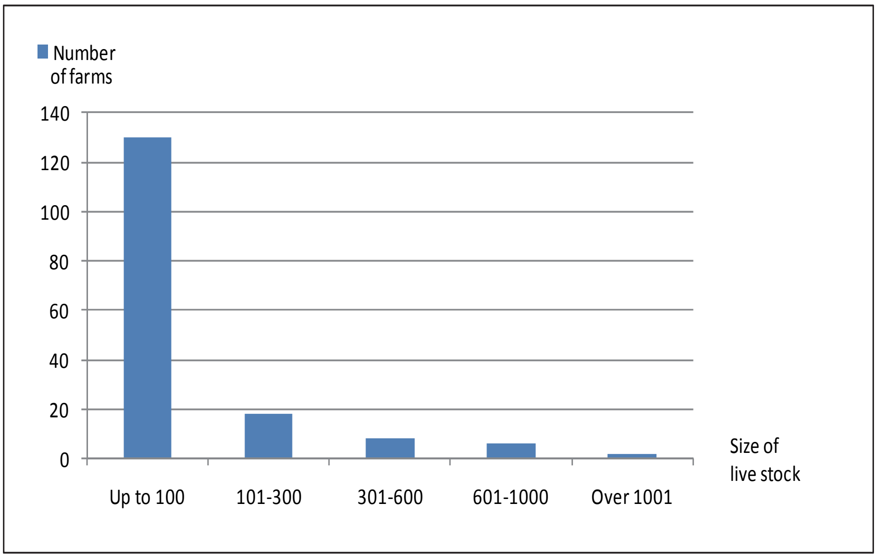

Figure 6. Farms in Harju County by livestock size: beef cattle and dairy cattle, 2009

According to the EARIB data, only four pig farms in Harju County exceed the maximum limit on livestock numbers However, these farms account for nearly 99% of all pigs in Harju County. The biggest of the farms is the OÜ Hinnu Seafarm in Allika village, Kuusalu municipality, with 11,205 head of pigs. As mentioned above, the main chicken farm is AS Tallegg in Loo village, Jõelähtme municipality, with 280,000 chickens.

Cultivated and abandoned land

According to the EARIB database, farms in Harju County held 55,033 ha of cultivated land in 2009. The area of abandoned land is smaller, but not remarkably so, covering approximately 43,400 ha in 2009 (see **Table 14**). During the period 2007-2009, the area of cultivated land in Harju County has increased 5-6% per year, but the area of abandoned land has increased at twice this rate – about 11% annually.

Table 14. Cultivated and abandoned land in Harju County in 2007-2009

Land type	Area, ha		
	2007	2008	2009
Cultivated land	49,576	51,804	55,033
Abandoned land	35,513	38,065	43,418
Total	85,089	89,869	98,451

Source: EARIB

Cultivated land is distributed between nearly 450 farms growing crops in Harju County. The majority of these, about 71%, are fairly small, with up to 100 ha cultivated (see **Figure 7**). Only 25 farms have more than 500 ha of cultivated land.

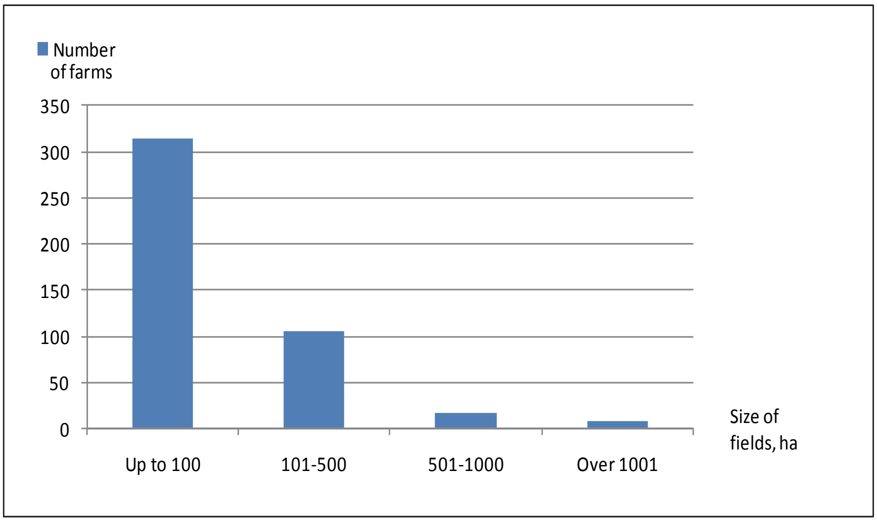

Figure 7. Harju County farms by size of cultivated land, 2009

3.2. Biowaste and sludge prevention in 2020

3.2.1. Option A – continuing the present course of development

If the current development continues and no additional waste prevention measures are applied, the annual growth rates of biowaste and sludge are expected to be the following:

I Biowaste from food and beverage industries

Animal-tissue waste from preparation and processing of food of animal origin

Tallinn: annual growth 0.3%. Fish industry waste accounts for the majority. The fish industry is highly export-oriented. Exports are expected to remain level or to grow moderately.

Harju County (excluding Tallinn): annual growth 0.5%. Companies producing chicken and eggs are the major source of this waste type in Harju County. Chicken consumption has increased in recent years and this trend is set to continue due to increasing health consciousness among consumers.

II Municipal biowaste (household waste and similar commercial, industrial and institutional waste) including separately collected fractions

Biodegradable kitchen and canteen waste, annual growth 3%

Source-separation of biodegradable waste started in 2007 in Tallinn. Collection is becoming increasingly regulated and more municipalities are forcing households and companies to use special containers for biodegradable waste.

Edible oil and fat, annual growth 0.1%

The amounts of edible oil and fat will remain relatively stable, but may increase due to improved accuracy of data collection. Previously, edible fat was often documented under other types of biowaste (e.g. biodegradable canteen waste).

Biodegradable waste from gardens and parks

Tallinn: annual growth 0.3%. This waste type derives mainly from parks and green areas. No significant change in size and number of parks and green areas is expected.

Harju County (excluding Tallinn): annual growth 1%. Waste comes mainly from vegetable processing companies. The amounts of waste may increase due to increased demand for vegetables.

Biowaste in mixed municipal waste

The amount of biowaste in mixed municipal waste has been decreasing since the start of the economic recession in 2008. Growth in this biowaste is likely to remain minimal.

<u>Households:</u> annual growth 0.5%. The amount of biowaste per household depends primarily on household income. Before the economic crisis, wages were increasing 10-20% per year in Estonia, and households' biowaste correspondingly grew more than 10% per year. Potential positive impacts on waste amounts may include public campaigns on the dietary importance of vegetables and fruit, and planned improvements in municipal waste collection. The amounts of municipal biowaste may decrease, as consumers increasingly wash biowaste from plastic packages into the sewer (source-separated plastic packages are required to be washed relatively clean by the user).

<u>Non-households:</u> annual growth 0.2%. Increase in this sector will be less than for households, as profit-oriented businesses strive to control rapidly growing waste handling costs.

Waste from markets, no growth (annual growth 0%)

Levels will remain the same. This waste type comes from the largest markets in Tallinn. The number and size of markets are likely to remain unchanged.

III Sludge

<u>Tallinn</u>: annual growth 2%. The TS of Tallinn wastewater is expected to increase.

<u>Harju County (excluding Tallinn)</u>: annual growth in 2008-2012: 2%, annual growth in 2013-2020: 1%.

The table below (**Table 15**) shows the biowaste production levels in 2020 if biowaste levels follow the growth rates discussed above.

Table 15. Estimated biowaste and sludge production in Harju County in 2020 (including Tallinn), tonnes/y

	2008	Forecast for 2020	Growth 2008-2020
Biowaste from food processing industries	3,306	3,496	5.8%
Municipal biowaste	87,827	94,272	7.3%
- households	38,603	42,043	8.9%
- non-households	49,224	52,228	6.1%
Sludge	59,111	72,716	23%
Total	150,244	170,483	

The forecast estimates are based on an average annual growth rate of the Estonian economy of 3-6%. If the growth rate is significantly different, the estimates must be revised.

The production levels of many companies in the food and beverage industry depend on export opportunities to Russia, Ukraine and the EU. Changes in exports will impact waste levels, but these changes are difficult to predict.

Changes in production technology may also influence waste production levels. These changes are not taken into account in the forecast estimates.

3.2.2. Option B - biowaste and sludge prevention

If preventive measures are applied, annual growth in biowaste and sludge will slow by 2020. The effect of prevention is difficult to predict, as it depends on which measures are selected for implementation and how successful their implementation is, and on the state of the economy. Therefore, several sub-scenarios (options) of prevention are proposed (below), the first of which (B1) is considered the most realistic, and the third (B3), the most optimistic. The results are presented in **Table 16** (for the county incl. Tallinn) and **Table 17** (for the county excl. Tallinn).

Biowaste

Scenario 1. Biowaste from the food and beverage industry remains stable, municipal biowaste decreases max. 0.3% per year.

Interviews conducted with companies in the food industry revealed that companies are already implementing efficient waste prevention measures in order to reduce landfill costs. It is therefore expected that additional preventive measures will have no significant impact on the food industry. Biowaste from households, shops and services may, however, be affected by the measures. It is realistic to assume that during the first years of implementing preventive measures, waste levels will remain relatively stable. During that period, consumer behaviour will change gradually, leading to decreasing biowaste levels at rates of, e.g., around 0.1% and 0.2% per year.

Scenario 2. Industrial and municipal biowaste decrease 15% compared to 2008.

Biowaste from households, commerce and industry decrease 15% by 2020. Due to the economic recession, biowaste levels remain stable or decrease moderately during 2008-2012. After that, preventive measures must decrease biowaste levels by at least 1.5% per year to reach a 15% reduction by 2020.

Scenario 3. Industrial and municipal biowaste decrease 30% compared to 2008.

Biowaste from households, commerce and industry decrease 30% by 2020. Due to the economic recession, biowaste levels remain stable or decrease moderately during 2008-2012. After that, preventive measures must decrease biowaste levels by at least 3.5% per year to reach a 15% reduction by 2020.

Table 16. Biowaste prevention scenarios in Harju County for 2020 (incl. Tallinn)

	OPTION B1	OPTION B2	OPTION B3
Decrease from 2008 to 2020	up to 2%	15%	30%
Biowaste production in 2008, t	91,133	91,133	91,133
Production in 2020, t	89,700	77,500	63,800

Table 17. Biowaste prevention scenarios in Harju County for 2020 (excl. Tallinn)

	OPTION B1	OPTION B2	OPTION B3
Decrease from 2008 to 2020	up to 2%	15%	30%
Biowaste production in 2008, t	27,447	27,447	27,447
Production in 2020, t	26,900	23,300	19,200

Sludge

Sewage sludge levels may increase in the coming years if more households connect to the public sewerage system. Other potential factors increasing sludge levels include the installation of waste disposal systems in kitchen sinks (placing an additional burden on the sewerage system), as well as misguided moves towards centralized wastewater management (replicating the German or Swedish models). The Estonian sewerage system is not ready for increased levels of solid matter in wastewater.

Scenario A *– sludge prevention measures are not applied*

Scenario B *– sludge prevention measures are applied*

Given the legal tendencies outlined above, improvement of wastewater treatment technologies (need for phosphorus removal, integrated use of biofilm and activated sludge etc.) and our economic opportunities, the experts provide (A. Kuusik et al., Tallinn University of Technology Institute of Environmental Engineering) the following scenarios for sludge levels in 2020:

***B1** – sludge levels remain relatively stable compared to 2008;*

***B2** – sludge levels decrease 10% compared to 2008;*

***B3** – sludge levels increase 20% compared to 2008.*

The results of these forecast estimates for 2020 are given in following tables:

Table 18. Sludge prevention scenarios in Harju County for 2020 (incl. Tallinn)

	OPTION B1	OPTION B2	OPTION B3
Sludge level decrease from 2008 to 2020	0%	10%	20%
Sludge production in 2008, t	59,111	59,111	59,111
Sludge production in 2020, t	59,100	53,200	47,300

Table 19. Sludge prevention scenarios in Harju County for 2020 (excl. Tallinn)

	OPTION B1	OPTION B2	OPTION B3
Sludge level decrease from 2008 to 2020	0%	10%	20%
Sludge production in 2008, t	23,420	23,420	23,420
Sludge production in 2020, t	23,420	21,100	18,750

The development of more accurate scenarios requires in-depth analysis of a wider range of variables than that observed here.

3.3. Biogas potential and possible biogas plants in 2020

The following chapters provide descriptions of the future biogas options in 2020. Option A represents business as usual (BAU) and includes currently planned developments as well as the current use of biomass and biowaste. Option B represents the W-fuel case study and assumes that the biogas produced in the Harju pilot biogas plant is upgraded to biomethane quality for use as vehicle fuel. A summary of the options is provided in **Table 30**.

3.3.1 Option A - continuing the present course of development

Option A (BAU - Business as Usual) assumes that the present usage of biomass, which is not oriented towards biogas production, will be continued. By the end of 2011 there were only three biogas production units in Harju County:

1) A biogas plant at AS Tallinna Vesi (Tallinn Wastewater Treatment Plant - WWTP) producing biogas from sludge for the company’s own needs as boiler fuel and engine fuel for its compressors.

2) Two landfill biogas plants - at Pääsküla (old plant with gradually decreasing biogas yield) and at Jõelähtme (new plant commissioned in autumn 2010).

At present, there are no agricultural biogas plants (based on waste such as manure/slurry and/or energy crops) in Harju County. However, there is a biogas plant project on the agenda: in 2008, biogas company *Biogaas OÜ* designed a biogas production plant for feeding a combined heat and power (CHP) plant in the Loo settlement. The CHP plant has a planned electrical capacity of 1.3-1.6 MW and is to be commissioned in 2012 (Loo Biogaasijaam …, 2011). The substrates for biogas production will be manure (chicken and cattle), source-separated biowaste, and biowaste from the food industry (brewery residues). The cattle manure supply will be provided from the nearby medium-size farms AS Aatma and OÜ Haljava, both with stock sizes of about 450 LUs (livestock units). Most of the chicken manure originates from AS Tallegg (see **Table 20**).

The intermediate product is biogas, which will be used for cogeneration of heat and electricity. The annual heat energy produced (11-12 GWh) will be used in the district heating grid of the Loo settlement, the electric energy produced (10-11 GWh) will be fed into the Eesti Energia Jaotusvõrk OÜ grid. The start of construction works for the biogas plant is planned for 2012. The size of investment is 5.1–5.8 MEUR for the project in total. (Loo Biogaasijaam …, 2011). Commissioning of the Loo biogas CHP plant is planned for the end of 2012.

Table 20. Amounts of biowaste originating from the processing units of AS Tallegg (T. Tamm, 2010a)

	District	Substrate	Unit	Value
1.	Harku municipality	Solid manure	m^3/year	19 000
		Feathers	t/year	2 200
		Animal tissue waste (feed for fur-bearing animals)	t/year	3 500
2.	Jõelähtme municipality	Solid manure	m^3/ year	7 700
		Semi-liquid manure	m^3/ year	3 500
		Biowaste from hatching and eggs	t/ year	250
3.	Rae municipality	Semi-liquid manure	m^3/ year	11 500

The planned location for the biogas plant is Maardu village (land unit Läga, land register 24504:003:0796), the planned location of the CHP plant is the Loo settlement (plot owned by AS Fortum Termest, land register 24504:002:0574). The length of the gas pipeline connecting the biogas plant and the CHP is 7 km (**Figure 8**).

According to the latest information (November 2011), financial support for *Biogaas OÜ* from the Estonian Environmental Investment Centre (EIC) has been temporarily suspended due to additional investment costs required to build the biogas pipeline to the settlement. Furthermore, the local municipality has demanded a renewal of the detail planning – a procedure which might take up to two years. Since these new developments are uncertain and the potential extra planning procedure relatively time consuming, it is assumed that the planned CHP will be carried out with some delay.

Figure 8. The trajectory of the gas pipeline (marked blue) between the biogas plant in Maardu village and the CHP in Loo settlement (Loo Biogaasijaam …, 2011)

3.3.2. Option B – using biomass for biogas production

3.3.2.1. Biomass availability for biogas production

This chapter provides an estimation of how much biogas could be produced from different biomass types in Harju County by 2020. The main resources for biogas production are biowaste, sludge, manure and energy crops. To calculate the biogas potential, first the amounts of resources are estimated, then the realistic availability of these resources for producing biogas is evaluated and, finally, the methane production is calculated (see **Table 22**).

For calculating the biomass resources for biogas production in 2020, the following assumptions and estimations were used:

Biowaste and sludge

Again, to avoid overestimation of the resource availability, the levels of biowaste and sludge for Harju County are taken into account exclusively of Tallinn. This is because all waste from Tallinn (incl. biowaste) is planned to be utilised by a new waste fuel plant (commissioned October 2011) and/or the Jõelähtme landfill. This situation also reflects the fact that source-separation of biodegradable waste, started in 2007, has not yet delivered the expected results in Tallinn. A plan is currently on the table to also construct a unit for separation biowaste at the new waste fuel plant, but this is still highly uncertain. All sludge from Tallinn is currently managed by the wastewater treatment plant of the water company Tallinna Vesi AS. The company already operates a biogas plant and produces biogas from sludge for its own needs as boiler fuel and motor fuel for its compressors.

- ***Biowaste from the food and beverage industry will remain stable***

Biowaste levels from the food processing industries in Harju County (excluding Tallinn) are relatively low (see **Table 10**). Interviews conducted with the leading biowaste producers show that companies are already efficiently reducing their biowaste production in order to minimize rapidly growing landfill gate fees. Companies are choosing new technologies, new products and new markets to minimize their waste and to profit from waste minimization. Therefore, it is expected that additional preventive measures for the food industry will have no significant impact on waste levels, which will remain stable until 2020.

- ***Municipal biowaste will decrease max. 0.3% per year***

Source-separation of biodegradable waste was introduced in 2007. Collection is becoming gradually more regulated and more municipalities are forcing households and companies to use special containers for biodegradable waste. In addition, prevention measures may affect biowaste levels from households, shops and services. It is realistic to assume that during the first years of implementing preventive measures, the quantities of waste will remain stable. During that period, consumer behaviour will change gradually, leading to decreasing biowaste levels, by 0.1% and 0.2% per year and so on.

- ***Wastewater sludge will remain stable***

The amount of sewage sludge may increase in the coming years if more households are connected to the public sewerage system, more waste disposal systems are installed in kitchen sinks (placing an additional burden on the sewerage system) or if misguided moves towards centralized wastewater management are taken (replicating the German or Swedish models). Nevertheless, given the sludge prevention measures, improvement of wastewater treatment technologies (need for phosphorus removal, integrated use of biofilm and activated sludge etc.) and economic opportunities, the experts agree that sludge production levels will remain relatively stable over the period 2008-2020 (A. Kuusik et al., Tallinn University of Technology, Institute of Environmental Engineering).

Manure

Cattle. According to the assumptions used for the forecast estimates (see chapter 2.1), 1.5% growth by 2020 is expected. Cattle numbers may increase due to growing demand for dairy products worldwide and Estonia’s ideal climate for cattle breeding. It is expected that EU support for Baltic farms will increase (at present the support is several times lower than in older EU member states).

Pigs. Expected growth 1% by 2020. Over the last few years, growing demand from Russia has led to increased exports of live pigs from Estonia. Due to instability of political relations between Russia and Estonia, the export growth potential should not be overestimated.

Chicken. Chicken numbers will remain stable in line with the trend in recent years.

Energy crops for biogas production

At present, energy crops in Harju County are not used for biogas production. The Estonian Biogas Association estimates, however, that approximately 5% of cultivated land and 20% of abandoned land can be used for growing crops for biogas, such as clover and reed canary grass.

In 2009, there were about 55,000 ha of cultivated land and about 43,400 ha of abandoned land in Harju County. Both land types are expected to increase by 2020. According to expert opinion and recent trends, cultivated land is expected to increase by approximately 0.5% per year (reaching 58,140 ha in 2020) and abandoned land by approximately 2% per year (reaching 53,980 ha in 2020).

Abandoned land has been audited since the establishment of the agricultural land register in 2004. A proportion of the land abandoned in the early 2000s may be naturally forested by 2020 and therefore unusable for immediate cultivation of energy crops. To exclude most of these land areas, only land abandoned in 2009-2020 is taken into account in this report (see **Table 21**).

Table 21. Estimated harvest of energy crops in 2020 in Harju County

Land type	2009	2020	Land for energy crops		Clover in 2020			Reed canary grass in 2020		
	ha	ha	%	ha	%	ha	VS, tonnes/ year	%	ha	VS, tonnes/ year
Cultivated	55 033	58 140	5	2 906	50	1 453	11 770	50	1 453	11 770
Abandoned	43 418	53 980 Accumulate d during 2009-2020: 10 562	20	2 112	50	1 056	8 550	50	1 056	8 550

Notes: VS – volatile solids or organic matter

In this report, two types of energy crop are recommended for biogas production: reed canary grass (est. *päideroog*, *Phalaris arundinacea*) and clover (est. *ristikhein*, *Trifolium pratense*). The average annual yield of both crops is ~8 tDM/ha (2 harvests per year) (Rohtsete ..., 2007).

Table 22 shows approximate figures for the amount of biomethane that can be produced in Harju County from different substrates in 2020. The total biomethane production potential is estimated to be about 17.3 million m3/y. The largest methane potential comes from energy crops (about 75% of the total potential), followed by slurry and manure from the agricultural sector (approx. 12%), sludge (5.6%), municipal (4.4%) and industrial (3%) biowaste.

Table 22. Biomass production and biogas yield in Harju County: W-Fuel scenario for 2020

Type of biomass resource	Production in 2008	W-Fuel scenario 2020	Can be practically used for biogas production in 2020		CH4 yield	Methane production
	tonnes	tonnes	%	tonnes	m^3/t FM	m^3/y
I Biowaste from food processing industries	2,660	2,660	-	-	-	517,104
incl. animal tissue waste	2,660	2,660	90%	2,394	216	517,104
II Municipal biowaste	24,759	24,263	-	-	-	766, 771
incl. biodegradable kitchen and canteen waste	241	236	33%	78	97	7,566
edible oil and fat	4	4	33%	1.3	288	374
biodegradable waste from gardens and parks	324	317	0%	-	-	-
biowaste fraction in mixed municipal waste	24,190	23,706	33%	7,823	97	758,831
III Sludge	23,420	23,420	100%		42	983,640
IV Manure[2]	210,326	213,152	-	-	-	2,109,158
incl. beef and dairy cattle slurry	172,457	175,044	55%[3]	96,274	10	962,740
pig slurry	23,859	24,098	99%[4]	23,857	10	238,570
solid chicken manure	14,010	14,010	80%	11,208	81	907,848
V Energy crops for biogas production	0	40,640 VS	-	-	-	12,903,200
incl. reed canary grass for biogas production	0	20,320 VS	100%	20,320 VS	300 m^3/t VS	6,096,000
clover for biogas production	0	20,320 VS	100%	20,320 VS	335 m^3/t VS	6,807,200
TOTAL						17,279,873

Notes: The method used to calculate crop, methane and manure yields is described in chapter 2.
FM – fresh matter (raw material)
VS – volatile solids (organic matter)

3.3.2.2. Proposed location and size of the pilot biogas plant in the county

The chosen location of the pilot biogas plant in Harju County is adjacent to the Hinnu pig farm. Hinnu Farm is located in a rural settlement in Allika village in Kuusalu municipality (see **Figure 9**). During the interviews with farm owners conducted in spring and summer 2010, it became evident that a potential biogas plant in Harju county should be based on pig manure. Although there are several large cattle farms and cattle manure is a more effective substrate for biogas production, there was very little or no interest among the farm owners towards introducing this technology.

The Harju county pilot project and its chosen location are based on the following assumptions:

- Hinnu Farm is the largest pig farm in Harju County (around 11,500 head). The farm is well developed and managed, and the owner is highly enthusiastic and interested in introducing biogas production using pig slurry and slaughter waste from the farm.
- Kuusalu regional sewage treatment plant is located in Allika village next to the farm. Sludge from the plant could serve as an additional valuable resource for biogas production.
- Energy crops from surrounding abandoned and cultivated land could be also used.

[2] Base year for prediction of the manure amounts is 2009
[3] Manure from the farms which must have waste permit (over 300 milk cows, over 400 mature beef cattle, over 600 young beef cattle).
[4] Manure from the farms which must have waste permit (over 1000 pigs or over 300 sows).

According to the approximate calculations, the biomethane potential of these available substrates (pig slurry, wastewater sludge and energy crops) could reach about 1.3 million m^3/y in 2020, see **Table 25**.

Figure 9. Location of the Hinnu pig farm in Harju County

Slurry

According to the data from the EARIB database, the total number of pigs at Hinnu Farm was 11,205 (in 2009). The respective slurry yield is estimated at 15,323 tonnes per year and the potential biomethane yield more than 150,000 m3 (see **Table 23**). According to the estimations of the farm manager, no remarkable growth is expected for the next 10 years, so the number of pigs is estimated to remain at around 11,500 by 2020, i.e. the same level as in 2011. Consequently, the biomethane yield from slurry will also remain stable.

Table 23. Manure and slurry production and biomethane yield at Hinnu pig farm, 2009

Animal type	Number	Factor (solid manure)	Manure, t/y	Factor (slurry)	Slurry, t/y	CH_4, m^3/t ww*	CH_4 yield, m^3/y
Fattening pigs	3 230	0.7	2 261	1.6	5 168	10	51 680
Piglets	6 993	0.5	3 497	0.8	5 594	10	55 944
Gilts	253	0.5	127	1.6	405	10	4 048
Sows	718	4	2 872	5.7	4 093	10	40 926
Boars	11	4	44	5.7	63	10	627
TOTAL	11,205		8,800		15,323		153,225

*ww - wet weight
Source: EARIB

Biowaste

Population centres in the vicinity of the potential location of the biogas plant at the Hinnu pig farm include Kuusalu, the centre of the municipality, which is located about one kilometre north of Allika village and has about 1,200 inhabitants (in 2011). Another densely populated area, Kiiu, with about 900 inhabitants, is located less than two kilometres west of Kuusalu. Assuming biowaste will be collected from households in Kuusalu and Kiiu by 2020 and transported to Hinnu, the biowaste potential of Hinnu is similar to that of Loo, i.e. biowaste from about 2,000 inhabitants in 2020, assuming no significant population changes occur.

There also some catering companies in Kuusalu village which could supply the designed biogas plant with biowaste.

Sludge

The Kuusalu regional sewage treatment plant is located in Allika village next to the pig farm. The sewage treatment plant was built in 2004 and is operated by Kuusalu Soojus OÜ. The plant uses chemical and biological treatment. The sewage treatment plant receives household wastewater from the Kuusalu and Kiiu areas as well as industrial wastewater containing phenols from OÜ Balti Spoon. The treated wastewater is directed to the Kurblu ditch in Allika village. The regional wastewater treatment plant (WWTP) in Kuusalu is a modern circular purification unit based on activated sludge technology with three bioponds for post treatment (total area 6,600 m^2). The treatment unit is equipped with biological removal of nitrogen and phosphorus, achieved by generating alternating aerobic and anaerobic (incl. anoxic) sections in the reactor. To meet effluent quality requirements, an additional chemical method for the removal of phosphorus is also applied with sedimentation of these compounds with Fe (III) sulfate.

The allowed discharge is 250,000 m^3 per year and the annual yield of residual sludge is 150 m^3. The residual sludge also contains coagulant and is pressed prior to discharge to a dry solids content of 9.9% and an organic dry solids content of 78.8%. The C/N ratio of the sludge is 7/1.

In addition, the contents of the WWTP's grease trap can be used as an input for biomethane production.

Energy crops

In previous decades, the main raw materials for biogas production were residual sludge and manure. During the last 5-7 years there has been an increase in the number of biogas plants in Europe based on green biomass. This is due to the fact that the biomethane yield of green biomass is much higher compared to sludge or manure and, thus, the process is more cost-effective. The negative impact of this substrate is its higher dry solids and fibre content, bringing about less fluidity and the need to use more efficient stirrers or different fermentation systems.

In this report, the estimates by the Estonian Biogas Association that approximately 5% of cultivated land and 20% of abandoned land can be used for growing crops for biogas (e.g. clover and reed canary grass) has been taken as the basis. According to expert opinions and recent trends, cultivated land is expected to grow by approximately 0.5% per year (reaching 58,140 ha in Harju County by 2020) and abandoned land by approximately 2% per year (reaching 53,980 ha by 2020) – see paragraph 3.6.2.1. Based on the abovementioned assumptions, it has been calculated that from the nearest agricultural land areas of the Hinnu pig farm (located in the Kuusalu municipality) about 210 hectares of abandoned land and about 230 hectares of cultivated land are suitable for growing energy crops (see **Table 24**).

Table 24. Abandoned and cultivated land in Kuusalu municipality, 2007-2009 and the forecast for 2020

Year	Abandoned land		Cultivated land	
	Area, ha	Growth, %	Area, ha	Growth, %
2007	3784.0		3870.0	
2008	4283.9	13.2	4027.9	4.1
2009	4342.9	1.4	4346.6	7.9
Forecasted increase during 2009-2020	1057.0			
20%	211.4			
Forecast 2020			4591.7	
5%			229.6	

3.3.2.3. Technological specification of the biogas plant

Grounds for selecting the biogas production technology

Considering the resources available in the vicinity of Hinnu Farm, the most viable substrates for biogas production are manure, slaughter waste, residual sludge and green biomass from both abandoned and cultivated lands. The use of manure solely would resolve the manure management problem, but the amount of biomethane produced (up to 160,000 m^3) would be moderate. Co-digestion of manure with slaughter waste (from the Hinnu Farm slaughterhouse) increases the amount of biogas produced and helps balance the C/N (carbon / nitrogen) ratio of the input. According to the literature, the recommended ratio of slaughter waste to manure is approximately 15-40% (Edström et al., 2003; Alvarez et al., 2008; Pualchamy et al., 2008; Cuetos et al., 2010). Use of residual sludge as input material would not produce as much biomethane, and further use of the digestion residue (digestate) is problematic due to its potential pathogen and pharmaceutical residue content. Therefore, the calculations and input data for the feasibility analysis are presented separately for production of biogas from manure only, from all substrates, and from all substrates except residual sludge (see **Table 25**).

The digestion of energy crops requires long hydraulic retention times (HRTs) to achieve complete fermentation with high gas yields and minimized residual gas potential of the digestate (Gemmeke et al., 2009). Therefore, the typical loading rate of organic total solids (oTS) for wet fermentation processes is only 2-4 kg oTS/(m^3*day) (Weiland, 2010). In the volume calculations for the biogas reactor for Hinnu pig farm, the reactor load was assumed to be 1.92 kg oTS/(m^3*day) (**Table 25**).

Table 25. Calculation of biogas reactor (digester) loading and volume

Parameter/ substrate	Value
Pig slurry (Hinnu pig farm)	
Reactor load (by organic total solids, oTS), kg/m^3*day (Fulhage et al., 2011)	**1.92**
Amount of slurry (by ww), kg/year	15 323 000
Volume of digester, m^3 (only pig slurry)	**743**
Annual amount of biomethane (by oTS), m^3, (based on 11,500 heads)	156 295
Slaughter waste	
Amount of slaughter waste (by ww), kg/year	78 000
Amount of slaughter waste (by oTS), kg/year	2 808
Annual amount of biomethane (by oTS), m^3	16 848
Residual sludge (OÜ Kuusalu Soojus)	
Amount of residual sludge (by ww), kg/year	150 000
Annual amount of biomethane (by oTS), m^3	3 511
Green biomass (from abandoned land near Hinnu pig farm)	
Amount of green biomass (by ww), kg/year	6 793 651
Annual amount of biomethane (by oTS), m^3	543 560
Green biomass (from cultivated land near Hinnu pig farm)	
Amount of green biomass (by ww), kg/year	7 380 952
Annual amount of biomethane (by oTS), m^3	590 550
Total amount of biomethane	
Annual amount of biomethane (by oTS), m^3	**1 310 763**
Total amount of substrates (by ww), kg/year	29 725 603
Volume of digester, m^3 (all substrates)	4225
Diameter of digester (with height of 20 m), m	16
Total amount of biomethane (without residual sludge)	
Daily amount of biomethane (by oTS), m^3	**3 582**
Annual amount of biomethane (by oTS), m^3	**1 307 253**
Daily amount of biogas(60% CH_4), m^3	**5970**
Annual amount of biogas (60% CH_4), m^3	**2 179 050**
Total amount of substrates (by ww), kg/year	29 575 603
Total amount of digestate (by ww), kg/day (Møller et al., 2009)	**40 515**
Total amount of digestate (by ww), kg/year	**14 787 793**
Volume of digester, m^3 (all substrates)	**4208**
Diameter of digester (with height of 20 m), m	16

The total amount of biomethane (100% CH_4) produced using all the substrates available is 1,310,763 m^3, and without the use of residual sludge 1,307,253 m^3. In the output, the biomethane (CH_4) content is 60% and the remaining 40% is CO_2. This quality of biogas can be directly fed into a CHP plant for production of electricity and heat or further upgraded and used as transport fuel.

Selection of biogas production technology

For energy crop digestion, two-stage digester systems are preferred which consist of a high-loaded main fermenter and a low-loaded secondary fermenter series which treats the digestate from the first stage.

Both digesters can have a similar construction enabling heating and stirring of the mixture. The reactors can have either a fixed or floating roof. If a digester has a floating roof it can also be used for gas storage. The increased energy requirement for maintaining the reactor at thermophilic temperatures (42-50°C) is not of critical importance in Option B_1, as CHPs have available surplus heat. However, with increasing sales of heat to local residential houses and industry, or injection of upgraded biogas into the natural gas grid, the thermophilic process becomes less efficient (Weiland, 2010). In Option B_2, there is no superfluous heat energy available. Thus, the appropriate digestion regime could be mesophilic (temperature 38-40°C).

The digester type is a completely mixed stirred tank reactor (CSTR). If the digester is operated at high TS, slow rotating paddle stirrers are preferred. The main components of the above biogas plant are: influent collecting tank, inlet (feed) and outlet (discharge) pipes, digester, gasholder, storage tanks, homogenization tank, gas pipe, valves, accessories, stirring facilities, heating systems, pumps and weak ring (Weiland, 2010).

The biogas production process

The operation of an anaerobic digestion facility includes the following main stages:

- pre-treatment of the waste typically including grinding, shredding, screening and mixing;
- digestion of the waste including feeding and mixing in the reactor;
- gas handling including collection, treatment, storage and utilization;
- management of the digestate (Handbook ..., 2009).

The design of the biogas plant planned for Hinnu Farm would closely resemble the plant currently operating in Bad Dürrenberg in Germany (see **Figure 10**). The substrates (green biomass and slurry) are fed into the inner area of the ring-shaped horizontal digester and fermented for 40 days at 50°C. These conditions produce about 90% of the biogas yield. Thereafter, the digested mass is directed to the outer part of digester for another 40 days (at 38 °C), and lastly to the post-digester. Due to the compactness of the digester and efficient isolation (heat transfer coefficient 0.4 W/m2K), maintaining the digestion temperature would only require 12.5–20% of the energy produced, even at an ambient temperature of -20°C. The only differences in the technology used at Hinnu Farm would be the use of a lower digestion temperature (38-40°C) and/or adding the gas purification equipment used in option B2. The process temperature classifications of the anaerobic digestion technologies are as follows: psychrophilic operation – up to 20°C; mesophilic operation – 30-40°C; thermophilic operation – 55-60°C.

As a result of the analysis, the chosen location of the pilot biogas plant in Harju County is near to the Hinnu pig farm. There are two options for biogas further use (see **Figure 5**):

- **B_1** Firstly, biogas produced at the farm could be used in a CHP plant, mainly for the farm's own needs.
- **B_2** Secondly, biogas purified (upgraded) to natural gas quality for use as transport fuel could be fed via a local pipeline into the natural gas grid passing Kuusalu village (direct distance between the farm and the grid is 1.2 km).

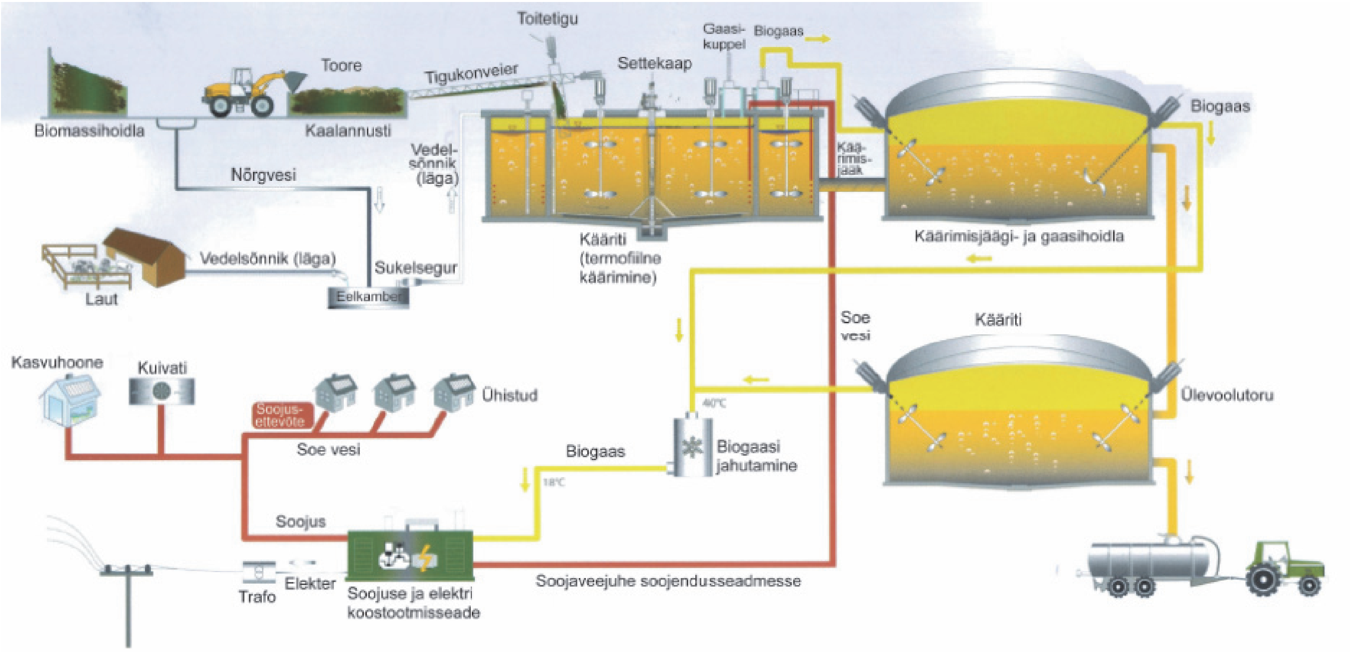

Figure 10. Schematic diagram of a biogas plant (SBBiogas GmbH, Germany) http://www.sbbiogas.de/

Option B_1
If the biogas produced at the Hinnu pilot biogas plant is used for heat and electricity production (incl. for the farm's own needs) in a CHP plant, up to 5 GWh of electricity and more than 5.2 GWh of heat can be produced (**Table 26**).

Table 26. Hinnu Farm biogas plant: CH_4 potential, electricity and heat capacity

Type of biogas raw material	CH_4 m^3/year	Electricity production kWh_{el}	Electrical capacity kW_{el}	Heat production kWh_{th}	Heat capacity kW_{th}
Pig slurry	156 295	593 546	74	630 275	79
Slaughter waste	16 848	63 982	8	67 941	8
Sludge					
(from Kuusalu WWTP) plant in Allika village)	3 511	13 333	2	14 158	2
Energy crops I					
(from abandoned land in Kuusalu municipality)	543 560	2 064 223	258	2 191 960	274
Energy crops II					
(from cultivated land in Kuusalu municipality)	590 550	2 242 673	280	2 381 452	298
TOTAL	1 310 764	4 977 757	622	5 285 787	661
TOTAL (without sludge)	1 307 253	4 964 424	621	5 271 628	659

The summarized technological specification data for the Hinnu biogas plant are presented in **Table 27.**

Table 27. Specification for the biogas plant and CHP at Hinnu Farm

No	Parameter	Unit	Value
1	Amount of substrates*	t/day	81
2	Biogas production**	m^3/day	5970
3	Electricity production	GWh_{el}	4.96
4	Electric power	kW_{el}	621
5	Heat energy production	GWh_{th}	5.27
6	Thermal power	kW_{th}	659
7	Digesters	number	2
8	Volume of digester	m^3	2100
9	Labour requirement	h/day	2
10	Area requirement	ha	0.4
11	Volume of digestate	t/year	14 788

* Total amount of all substrates except residual sludge
** Assuming a biomethane (CH_4) content of 60%

The heat energy is expected to be used mainly by the farm itself, e.g. for heating buildings, for the technological heat needs of the on-site slaughter house and for heating the biogas reactors. The surplus could be sold to the local district heating system. The latter, however, brings about additional expenses from building the grid (discussed in more detail in WP5). The surplus electricity could be sold to network as renewable electricity.

Option B2
The technological requirements for biogas purification as vehicle fuel include:

- A low pressure (up to 0.5 bar) membrane gas holder with double-walled cover (after the methane reactor);
- 1-2 digesters after the main digester to compensate the instability of biogas production, purification and usage;
- Gas purification equipment with gas compressor;
- High pressure containers;
- Biomethane filling station.

The summarized technological specification data for the Hinnu biogas and upgrading plant are presented in **Table 28**.

Table 28. Specification for the Hinnu Farm biogas and upgrading plant

No	Parameter	Unit	Value
1	Amount of substrates*	t/day	81
2	Biogas production**	m^3/day	5,970
3	Biomethane	m^3/day	3,582
4	Biomethane	m^3/year	1,307,253
5	Digesters	number	2
6	Volume of digester	m^3	2,100
7	Labour requirement	h/day	2
8	Area requirement	ha	0.4
9	Volume of digestate	t/year	14,788

* The total amount of all the substrates except residual sludge
** Assuming biomethane (CH_4) content is 60%

Usage of digestate

The digestate from anaerobic digestion of manure, slurry and green biomass can be used as a fertilizer for food crops without prior pre-treatment of the input materials. If other substrates (e.g. residual sludge) are also used, or if the substrates are mixed in no certain order, then all input materials should be pre-treated or the digestion residue should be post-treated to make the digestate usable as a fertilizer. On the opposite case the digestion residue can be used only as recultivation material in landscaping.

In a wet anaerobic process, the amount of digestate produced may be on average in the range of 0.5 tonne per tonne of wet weight of biomass (Luning et al., 2003). As no nutrients are lost during the anaerobic digestion process itself, the total nutrient content of the digestate equals the nutrient content of biomass (Møller et al., 2009). However, in the process of anaerobic digestion the physical and chemical parameters of manure, slurry and other input materials can undergo substantial changes (**Table 29**). The principal physical change is the increase in homogeneity and decrease in dry matter content, which makes the digestate more spreadable compared to manure (Tamm, 2010b). The content of mineral nitrogen (NH_4-N), which is better assimilated by plants, increases and the ratio of phosphorus and potassium is also more beneficial to plants as compared to manure (Tamm, 2010b).

Table 29. Content of total solids and nutrients of digestion residue (digestate) and slurry (Birkmose et al., 2009; Tamm, 2010b)

	Dry solids, %	N-total, kg/t	NH_4-N, kg/t	P, kg/t	K, kg/t	pH
Digestate	4.8	4.4	3.5	1	2.3	7.6
Pig slurry	5.0	4.8	2.9	1.1	2.3	7.1
Cattle slurry	7.5	3.9	2.4	0.9	3.5	6.9

Digestate is generally stored in uncovered tanks, from which several gases (CO_2, NH_3, N_2O and CH_4) are lost to the atmosphere, thus affecting the global environment and climate. Covering storage tanks helps to reduce gaseous emissions and to capture residual methane (Biofuels, 2009). Indirect emissions from agricultural use of digestate as fertilizer (transportation, spreading) are difficult to predict from the composition of the digestate alone. However, if the application of digestate contributes to increased carbon levels in the soil at the end of the considered time frame (e.g. 100 years), it will represent actual ‘long-term’ removal of carbon from the carbon cycle. This benefit is credited to the system as an avoided carbon dioxide emission. Soil improvement, improved water retention of the soil, reduced herbicide/biocide requirements, improved soil structure, and reduced erosion could also bring greenhouse gas savings (Møller et al., 2009; Tilkson, 2011).

3.3.3 Summary of future options

A summary of the three options elaborated (A, B_1 and B_2) is presented in **Table 30** below. In Option A, the current biogas production sites are included. It is also assumed that the plans for the Loo CHP will be realised, although they have currently been temporarily halted and may change as a result. The inputs at the Hinnu biogas plant will have an alternative use in Option A. The pig slurry will be used as fertilizer in the nearby fields. Slaughter waste will be processed in the rendering plant in Väike Maarja. In addition to the already planned developments and current use of biomass in Option A, Option B assumes that all of the inputs shown in

Table 25 (except residual sludge) will be used at the Hinnu biogas plant for production of biogas. The reasons for not using sewage sludge relate to its relatively modest biomethane potential and its impact on digestate quality (pathogen and pharmaceutical residue content). There are two alternatives for biogas use under Option B. Option B_1 implies a CHP plant that will provide around 5 GWh of electricity and 5 GWh of heat per year, see **Table 26** and **Table 27.**

Table 30. Future options A and B in 2020

Option	Input	Biogas production	Value added	Digestate output
A		Tallinna Vesi Landfill biogas Maardu biogas plant	Loo CHP plant	
B	Pig slurry 15,323 tonnes per year Slaughter waste 78 tonnes per year Green biomass 14,175 tonnes per year	Hinnu biogas plant	B_1 Hinnu CHP plant output, see **Table 27**	14,788 tonnes
			B_2 Hinnu biogas upgrading plant, see **Table 28**	

In Option B_2, the biogas is purified and upgraded to biomethane of natural gas quality, giving a total output of 1,307,253 m^3/ year of natural gas quality biomethane (see **Table 28**).

3.4. Biomethane use as transport fuel in 2020

3.4.1. Location of the biogas production and upgrading plant

As a result of the present study, the location of the pilot biogas plant in Harju County has been chosen to be near to the Hinnu pig farm (see **Figure 11**).

In the case of option B_2 – biogas upgrading as transport fuel – the biogas upgrading unit is proposed to be located at the same biogas production plant located near the Hinnu Farm buildings (coordinates: X:6592592 Y:580960). As the upgrading technology chosen for the Hinnu pilot biogas plant is water scrubbing, this location of the upgrading unit is also supported by the location of the Kuusalu regional sewage treatment plant in Allika village next to the farm. In option B_2, the biogas is purified and upgraded to biomethane of natural gas quality, giving a total output of 1,307,253 m^3/year of natural gas quality biomethane.

Figure 11 also shows the location of the nearest existing petrol station and the existing natural gas grid (the minimum distance from Hinnu Farm to the grid is 1.2 km).

Figure 11. Location of the Hinnu biogas plant and upgrading unit with respect to the Hinnu pig farm (at the top in the centre), and of the nearest existing petrol station at Kuusalu just off the Tallinn-Narva road (marked blue), and the existing natural gas grid (dark red).

3.4.2. Transport of biogas raw materials

As pig slurry and slaughter waste originate from the Hinnu pig farm, there are no transport costs for these substrates. One of the available resources for biogas production in Hinnu – residual sludge from the Kuusalu regional sewage treatment plant (operated by Kuusalu Soojus OÜ) – has been eliminated from the biogas production scenario due to problematic further use of the digestion residue (digestate) due to its potential pathogen and pharmaceutical residue content. If this problem were to be resolved in the future, there would be no need to transport the residual sludge as the sludge source is in the near vicinity of the biogas plant.

The only significant raw material transport cost for the Hinnu biogas plant is for green biomass, which is sourced from cultivated and abandoned land in the local Kuusalu municipality. The green biomass resource has been estimated in WP3 at about 14,200 tonnes per year. For calculating the transport costs, estimations from the study (Tartu …, 2010) have been used. According the study, the current transport price for a 10-tonne truck is about 1 EUR/km. Considering the abovementioned amount of green biomass and an average distance from the field to Hinnu Farm of 25 km, the total transport costs can be currently estimated:

14200/10*1*25=35,500 EUR (2.5 EUR/t).

As a 25-30% increase in transport costs can be assumed by 2020 (at an annual inflation of 2.5-3%), the transport costs for green biomass for the Hinnu biogas plant will reach 3.25 EUR/t or a total of 46,150 EUR/y.

In the study (Tartu …, 2010), the total costs for green biomass have been estimated as ranging widely from 300 EEK (approx. 20 EUR) to 700 EEK (approx. 45 EUR), and the share of transport costs (84 EEK/t, approx. 5.4 EUR /t) at 12-27%. Considering that in our case the transport costs are remarkably lower (mainly due to shorter distances) and the figures of the study relate mainly to semi-natural grasslands (lower yield), the total cost of green biomass for the Hinnu biogas plant in 2020 can be estimated in the range of 20-30 EUR/t.

3.4.3. Biogas upgrading method

The total annual biomethane (100% CH_4) production capacity using all substrates available to Hinnu Farm is 1,310,763 m^3, and without the use of residual sludge 1,307,253 m^3 (**Table 31**). The actual output has a biomethane (CH_4) content of 60%, the remaining 40% being CO_2. Biogas of this quality can be fed directly into a CHP plant for electricity and heat production or further upgraded for use as transport fuel.

For biogas to be effective as a vehicle fuel it must be enriched in methane. The primary goal is carbon dioxide removal, which enhances the energy value of the gas. At present, four methods are used commercially for removal of carbon dioxide from biogas either to reach vehicle fuel standard or to reach natural gas quality for injection into the natural gas grid. These methods are:

- water absorption (water scrubbing),
- polyethylene glycol absorption,
- carbon molecular sieves,
- membrane separation.

Water scrubbing is used to remove CO_2 and H_2S from biogas by absorption, since these gases are more soluble in water than methane. Carbon dioxide will therefore be dissolved to a higher extent than methane, particularly at lower temperatures (**Figure 12**). The gas leaving the scrubber therefore has an increased concentration of methane. The water leaving the absorption column is transferred to a flash tank where the dissolved gas, which contains some methane but mainly carbon dioxide, is released and transferred back to the raw gas inlet. If the water is to be recycled it is transferred to a desorption column filled with a plastic packing, where it meets a counter flow of air into which carbon dioxide is released.

Water scrubbing is the most common upgrading technique, and plants are commercially available. In 2009, 42 out of 120 biogas upgrading plants in the world used this technology (Petersson and Wellinger, 2009). Biorega AB (Sweden) has developed a water scrubber designed for small raw gas flows (12–18 Nm^3/h). In Biorega's system, carbon dioxide is desorbed by a vacuum pump connected to a desorption column.

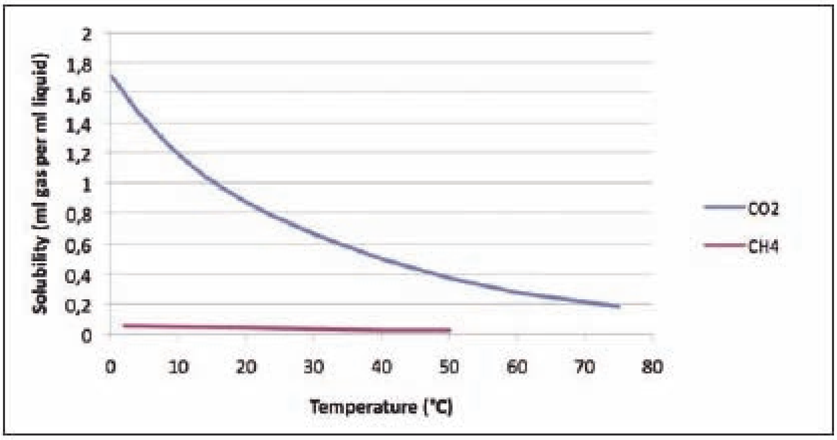

Figure 12. Solubility of methane and carbon dioxide in water (data source: Gas Encyclopaedia)

An alternative water scrubber technology has been developed by Metener (Finland). Biogas is upgraded and pressurized to around 150 bar simultaneously in batch mode. The column is then filled with water using high pressure water pumps and the carbon dioxide and sulfurous compounds dissolve in the water. After scrubbing, the clean pressurized gas leaves the column and the water is regenerated in a flash tank followed by a regeneration tank. The technology is most suitable for biogas flows of 30–100 Nm^3/h and has been demonstrated in a pilot plant with a capacity of 40 Nm^3/h in Laukaa, Finland.

The biogas is pressurized and fed to the bottom of a packed column where water is fed from above, and thus the absorption process is operated counter-currently (**Figure 13**). The water used can be regenerated by de-pressurising or by stripping with air (not in the case of H_2S) and recirculated back to the absorption column. *The most cost-efficient method is not to recirculate the water if cheap water can be used,* such as outlet water from a sewage treatment plant (Petersson and Wellinger, 2009).

Absorption in a water solution of sodium hydroxide (NaOH) enhances the absorption capacity of the water, making the absorption process thus no longer purely physical but also chemical. Sodium hydroxide reacts with hydrogen sulfide to form sodium sulfide or sodium hydrogen sulfide. Both these salts are insoluble and the method is not regenerative. Since the absorption capacity of water is enhanced, lower volumes are needed and pumping demands are reduced. The main disadvantage is the disposal of the large volumes of water contaminated with sodium sulfide (Wellinger & Lindberg, 2004).

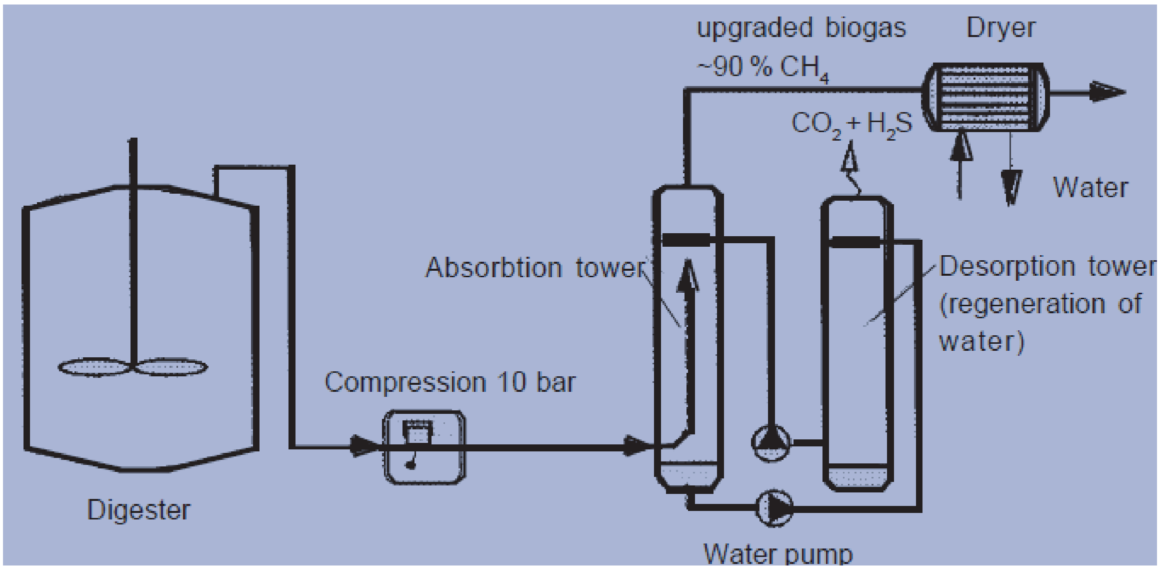

Figure 13. Schematic flow diagram of water absorption with recirculation for removal of carbon dioxide and/or hydrogen sulfide from biogas (Wellinger & Lindberg, 2004)

It is often possible to lower the methane loss, but at the expense of higher energy consumption. The upgrading costs of established techniques are dependent on the specific technology, but most importantly on the size of the plant (**Figure 14**). However, the field of biogas upgrading is developing rapidly and, thus, the cost development would also be expected to change. Today, there are commercially available plants for capacities lower than 250 Nm^3/h, while plants larger than 2000 Nm^3/h are also being built. These developments together with the fact that more plants are being built will likely lead to lower prices (Petersson and Wellinger, 2009).

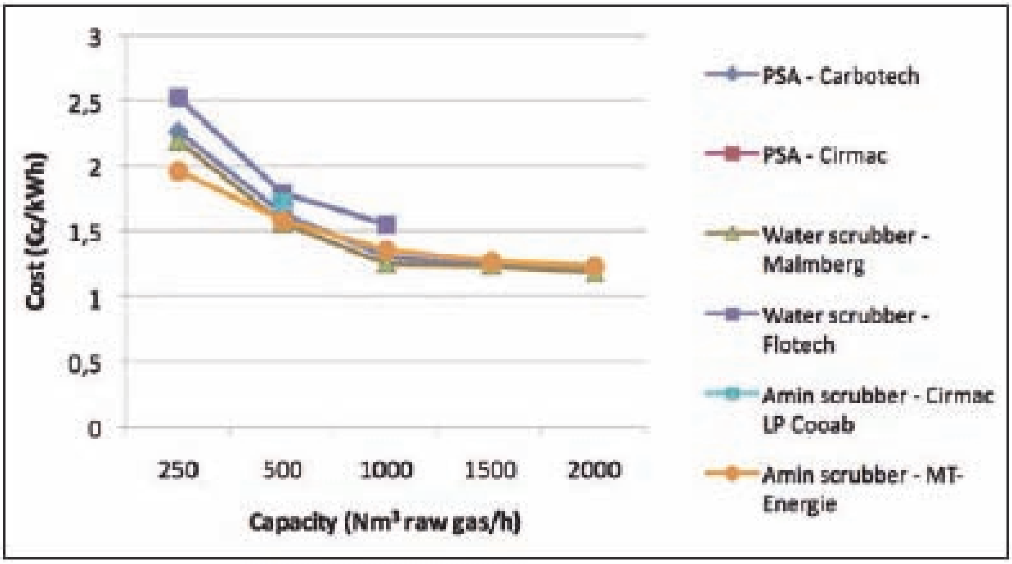

Figure 14. Estimated cost of biogas upgrading plants using different technologies (Urban et al., 2008)

The design output of the Hinnu Farm biogas plant is 249 m^3 of biogas per hour. Considering the cost of the various upgrading technologies, this level of productivity is at the threshold at which the cost levels of the different technologies begin to fall and converge (**Figure 14**). The most viable choice for the Hinnu Farm would, therefore, be a water scrubber. Due to the close location of the Kuusalu wastewater treatment facility to the farm, the purified wastewater can be easily used as process water in this upgrading process.

3.4.4. Biomethane consumption as transport fuel at Hinnu (Option B_2)

Potential users of biomethane

At present, the best technological solution for biomethane utilisation in transport is the use of compressed natural gas (CNG) vehicles, as this technology can also be used with biomethane. There are currently two CNG stations in Estonia – in Tallinn (since August 2009) and in Tartu (since March 2011). CNG buses (5) are used in the city of Tartu and also experimentally in Tallinn and have proven to be cost-effective. Other motor vehicles based in the vicinity of the biogas station are also potential users. Tallinn and Tartu have a combined total of around two hundred CNG vehicles – mostly private, but also owned by different firms and institutions (AS Eesti Post, AS Eesti Gaas, taxis etc.). As the requirement to register motor vehicles according to their owner's address has become compulsory only in the last few years, it is not possible to accurately determine the actual number of motor vehicles in any given region in Estonia.

As background data the number of motor vehicles both in Harju County without Tallinn and in Tallinn is presented in **Table 31**.

Table 31. Number of motor vehicles in Harju County, 2010

	Cars	Buses	Trucks	Motorbikes	Motor vehicles
Harjumaa	63896	334	9823	2745	76798
Tallinn	132906	1269	21599	3741	159515
Total	196802	1603	31422	6486	236313

Source: Statistics Estonia

In Harju County, including Tallinn, 236,313 vehicles were registered in 2010, about 60% of them in private use. Excluding motorbikes, the number is 229,827. It is difficult to estimate what proportion of these vehicles are convertible to CNG (thus also upgraded biogas). Based on experiences from Sweden, though, it can be estimated that by 2020 about 3% of all newly purchased motor vehicles could be CNG powered (Henriksson and Pädam, 1999). The total number of new vehicles in Estonia is about 13,000 per year (Maanteeamet, 2010), about 40% of which are purchased in Harju County (incl. Tallinn). Thus, by 2020 the number of new CNG vehicles in Harju County could increase to approximately 150 per year. As with companies, raising awareness of biomethane among private car drivers takes time, and it also takes time for consumers to adapt to new technologies such as alternative filling station networks.

Traditional biomethane users are short-distance buses, waste disposal trucks, taxis, etc. According to Statistics Estonia transport statistics, 65% of all bulk goods transportation takes place within a 50 km radius. The main potential end consumers of biomethane include transportation companies of all types, logistics companies, street cleaning companies, postal services, the police, ambulances, etc. All motor vehicles that permanently operate in the vicinity of a biomethane filling station are suitable for using biomethane.

Biogas consumption at Hinnu as transport fuel

Assuming an annual gross production of biomethane of 1,307,253 m^3, equating to a net energy output of up to 12,000,000 kWh/year, approximately 1,200 cars or 135 heavy vehicles (trucks) could be supplied annually. These vehicles could comprise trucks transporting green biomass, waste disposal trucks, vehicles of local transportation companies, private cars.

The most viable alternatives for supplying these potential biomethane consumers are threefold:

1) Building a filling station at the biogas production/upgrading plant in Hinnu.
2) Establishing a filling station (CNG station) on the Tallinn-Narva road using the existing petrol-station, see **Figure 11,** marked blue (coordinates: x:6590919 y:581413).
3) Feeding the produced biomethane into the existing natural gas grid (see **Figure 11**).

   This will become possible once the required legislative basis (standards etc.) for doing so have been introduced.

Considering the parameters of the Hinnu biogas plant and the potential market for biomethane as motor fuel in the region, option 3 – or a combination of options 2 and 3 – seem the most viable alternatives.

3.4.5. Future

Since regaining independence in 1991 Estonia has invested heavily in its transportation sector, in particular ground transportation, trucks, lorries and passenger cars. The number of passenger cars, including private cars, has risen extremely rapidly due to heavy imports of second-hand cars into the market. While the influx of second-hand cars has continued to grow steadily, the number of newly purchased cars has recently begun rising in parallel. Similar trends are being witnessed for trucks and agricultural vehicles and for vehicles and machines in the construction sector and other sectors of the economy. The share of diesel vehicles has also increased significantly during the last decade.

Fuel prices have also risen consistently in line with world oil prices and due to increased fuel excise tax based on EC requirements. Excise tax accounts for almost half of the price of fuel. Diversification of Estonia's fuel mix is being pursued. In addition to petrol and diesel, CNG has been successfully introduced in ground transportation. Gazprom is the sole supplier of natural gas to Estonia. At present there is an ongoing dispute to join the gas grid management to one compact organisation together with the main electricity grid operator Elering AS. This is likely to take place within the next 3–4 years.

AS Eesti Gaas has recently invested in CNG filling stations in Tallinn and Tartu, with further stations scheduled to be built in Tallinn, Narva and Pärnu. This covers all major routes in Estonia, and also forms a solid basis for wider CNG uptake in city transport. The three arterial routes from the capital

Tallinn to Narva in the east, Tartu in the south-east and Pärnu in the south will be the main routes around which biomethane will be introduced.

The transfer to biogas production based on a variety of raw materials features in several development plans of Estonia's two largest cities Tallinn and Tartu. The City of Tallinn is currently investigating the potential of establishing local biogas production stations. The Hinnu pig farm biogas plant could be the first of several potential production sites in Harju County.

Tartu has revised its former plans to use wastewater treatment plant sludge for CHP following positive results from five CNG buses in the city. These are encouraging signs which enable long-term forecasts of much wider biomethane production throughout Estonia to be made.

3.5. Impact assessment of the scenarios

3.5.1. Environmental and economic impacts of food waste prevention

Emission and cost savings from food waste prevention in Harju County have been estimated by generalizing the initial data gathered and the results calculated for Finland in the W-Fuel project. The results presented here should therefore be considered as indicative only, and the factors presented in **Table 32** thus also represent areas requiring further research in Estonia.

Table 32. Environmental and economic impact assessment data for Finland (averages for all sectors and case areas).

Share of food waste among biowaste	Emission savings per prevented food waste volume, tCO_2-eq/ t	Cost savings per prevented food waste volume, €/ t
81%	4.6	5932

Each of the factors in **Table 32** is dependent on the national biowaste and food waste composition which, due to the lack of data on Estonian waste composition, is assumed here to be equal with Finland. The emission savings per prevented food waste volume also depend on the national agriculture structure and imports, and include all life cycle emissions. Moreover, the cost savings per prevented food waste volume are mainly based on the national price level and are calculated from the waste generator's point of view. They include the purchase costs, usage cost (e.g. transporting, cooking and storing) and waste fees.

The environmental and economic impact analyses are conducted in three different waste prevention cases B1–B3, which are compared to a scenario in which no waste prevention has been implemented by 2020. The cases are introduced in **Table 33**.

Table 33. Compared cases.

Case	Description
Scenario A	No waste prevention measures implemented, biowaste amount increases business-as-usual
Option B1	Prevention target: biowaste reduced by 2% compared to 2008 levels
Option B2	Prevention target: biowaste reduced by 15% compared to 2008 levels
Option B3	Prevention target: biowaste reduced by 30% compared to 2008 levels

In the environmental impact analysis the emission savings value presented in Table 32 has been directly applied. The economic impact analysis, however, takes into account the lower price level in Estonia. In this paper it has been assumed that the price level in Estonia will be approximately 75% compared to the price level in Finland in 2020 (Kiander, 2012). The results are given in **Table 34**.

Table 34. Environmental and economic impacts on food waste prevention in Harju County in 2020.

Harju County	Prevented food waste volume compared to BAU in 2020, t	Emission savings in 2020, tCO_2-eq	Cost savings in 2020, M€ (in 2010 real terms)	Cost savings in 2020, €/capita* (in 2010 real terms)
Option B1	6538	30076	29	59
Option B2	16447	75656	73	147
Option B3	27520	126591	122	246

* Population forecast for Harju County is 497,113 in 2020 (Statistics Estonia; Siseministeerium 2009).

Table 34 shows that achieving the food waste prevention target will save 30,000–127,000 tCO2-eq emissions and 29–122 MEUR in 2020 depending on the target level in Harju County.

3.5.2. Environmental and economic impacts of biogas production and use as transport fuel

Careful control of the digestion process and environmentally sound management of digestate storage and application will achieve potentially smaller climate impacts than non-digested manure handling. In addition, digestate is considerably less odorous and digested manure has a higher content of nitrogen that is directly available to plants, thus enabling greater fertilization precision and reduced nitrogen leakage.

However, based on Börjesson and Berglund (2003, Table 5.3), cultivation on fallow lands increases nitrogen leakage by 10 kg per hectare, whereas the use of otherwise cultivated land does not affect the nitrogen balance. The additional leakage from energy crops planted on 210 hectares of abandoned land in the vicinity of Hinnu Farm totals 2,100 kg, i.e. about 2 tonnes per year. Replacing manure with digestate reduces nitrogen leakage by 7.5 kg per hectare (ibid). Assuming the use of 30 tonnes of manure and digestate respectively per hectare (ibid) makes it possible to replace manure on almost 500 hectares. This reduces nitrogen leakage by 3.7 tonnes. The net effect of nitrogen leakage is positive and corresponds to an annual reduction of 1.6 tonnes.

In Option B_1, the CHP electricity is used at the farm and the surplus sold to the grid. Since the district heating network of Kuusalu is located relatively far from the farm, finding users for the surplus heat may be problematic. In Option B_2, the assumption is that biomethane will be used as transport fuel. **Table 35** shows the saved emissions of the two options.

Table 35. Emissions savings Option B_1 and Option B_2 compared to BAU, Hinnu 2020

		CO_2, tonnes	HC, tonnes	NO_X, tonnes	PM, tonnes	SO_2 tonnes
B_1	CHP emissions savings in tonnes (BAU=average electricity)	3,548	n.a	5.0	1.8	28.4
B_1	CHP emissions savings in tonnes (BAU=natural gas)	1,208	n.a	3.3	0.0	0.0
B_2	Emissions savings passenger cars in tonnes	2,978	0.3	3.5	0.03	0.002

The environmental impact assessment is highly sensitive to the assumption of Base Case electricity generation. Replacement of one kWh of the Estonian electricity mix – which includes 87% oil shale electricity – with biogas achieves bigger emission savings than one kWh of biogas used as transport fuel. However, if biogas replaces marginal electricity produced from natural gas, the result is the opposite.

Instead of expressing the environmental impact in tonnes, the emissions are weighted according to their damage costs. These damage costs correspond to the air emission values for Estonia presented in Section

2.4, see **Table 7**. Assuming the European Emission Trading System (EU-ETS) is not operational, suggests that replacing Estonian electricity mix with production of electricity from biogas is better than producing transport fuel. When the EU-ETS is taken into account, the use of biomethane as transport fuel leads to a greater environmental improvement than electricity from biogas, irrespective of whether the replacement concerns average or marginal electricity. **Figure 15** below shows the monetized value of the environmental impact of biogas use at Hinnu Farm in 2020.

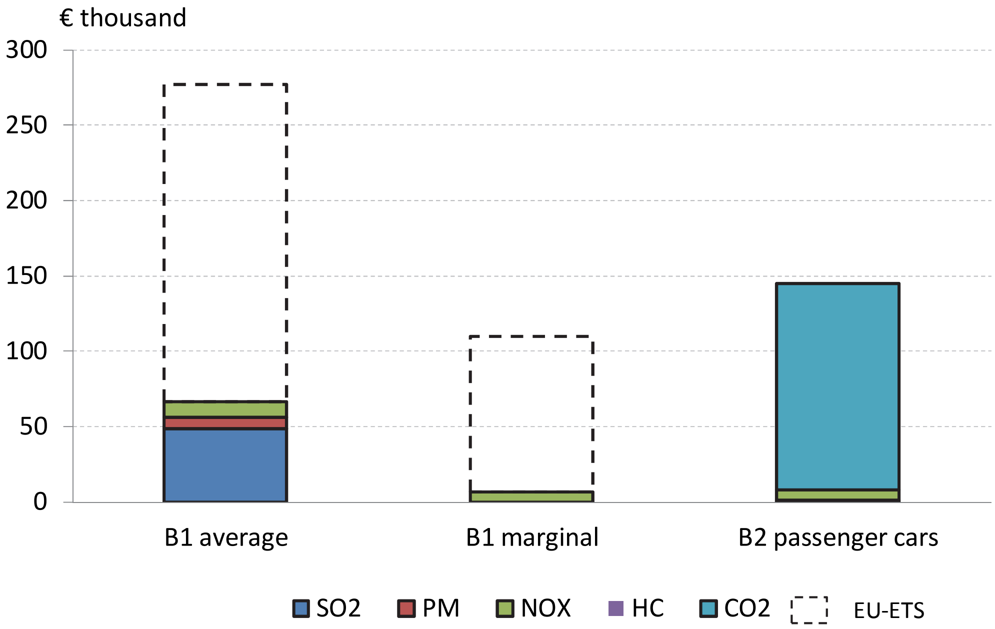

Figure 15. Savings in environmental damage costs, B_1 and B_2 (compared to Base Case), Hinnu pilot plant in 2020

Figure 16 shows the present value of the costs and revenues of biogas production at Hinnu Farm during the assessment period.

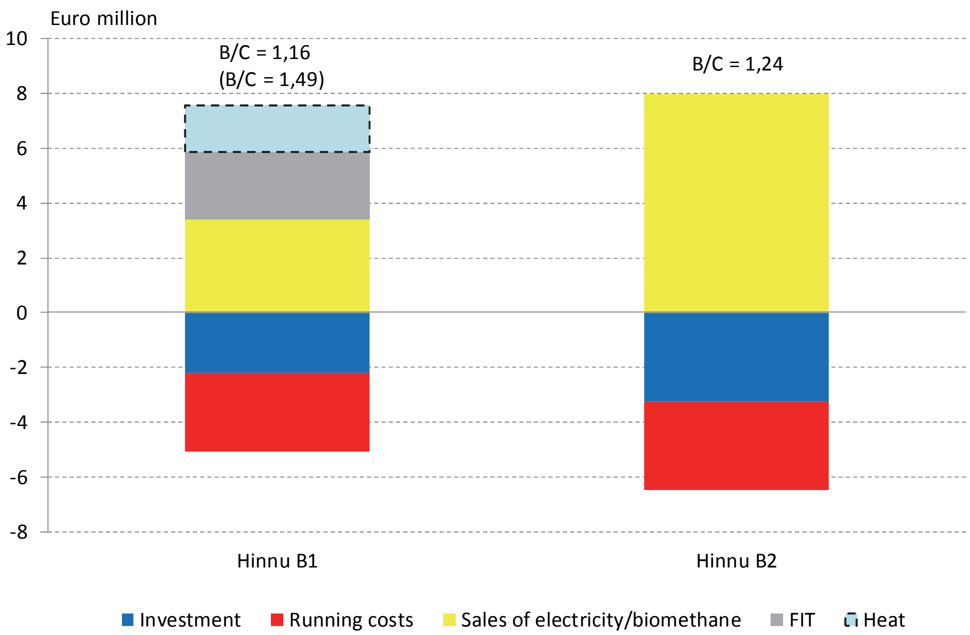

Figure 16. Costs and revenues of biogas production at Hinnu pilot plant, present value (MEUR), Option B_1 and Option B_2 (compared to Base Case)

Figure 16 shows the benefit-cost ratio (B/C ratio). A value larger than one indicates that the option is profitable. Both investment and running costs are lower if Hinnu Farm chooses to produce electricity and heat. Assuming the current levels of support for renewable fuel based electricity generation, i.e. feed-in tariffs (FITs), remain in place, the expected B/C ratio for Option B1 is greater than for Option B2 if Hinnu sells both electricity and heat. If, however, the Hinnu pilot plant does not find a market for its heat, then Option B_2 offers higher profitability.

The above figure represents commercial profitability. From the perspective of society as a whole, it is of interest to add the reduction in damage costs to the calculations. In order to present profitability from the social perspective, FITs are omitted from the resulting impact calculation. This is because the FITs cancel out, as the analysis now includes both those who pay FITs (a minus to electricity consumers) and those who receive FITs (i.e. an equally large plus to producers of renewable electricity). The figure below shows the social costs and benefits.

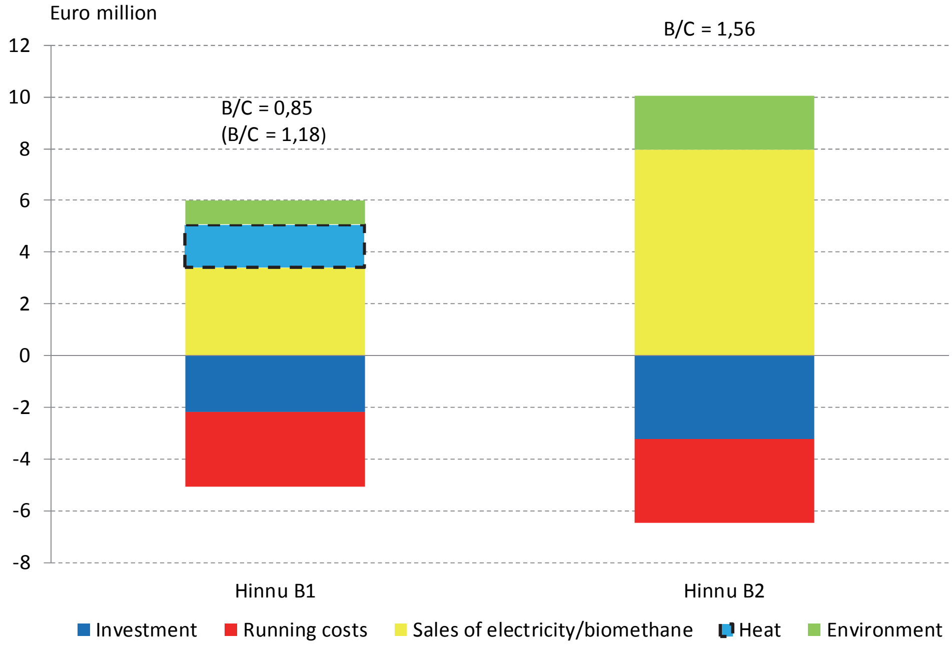

Figure 17. Social costs and benefits of biogas production at Hinnu pilot plant, present value (MEUR), Option B_1 and Option B_2 (compared to Base Case)

The results show that it is socially beneficial to produce electricity and heat from biogas at Hinnu Farm only if heat can be utilized, whereas producing vehicle fuel is socially more beneficial.

4. Lääne-Viru County: project results and scenarios

4.1. Biowaste, sludge and agricultural biomass: history and trends

Biowaste

Biowaste production levels in Lääne-Viru are presented in **Table 36**. The largest biowaste producers in Lääne-Viru are a meat processing company and a spirit distillery.

Table 36. Biowaste in Lääne-Viru County 2006-2008, tonnes

Type of waste	2006	2007	2008	
			Total	…of which households
Biowaste from food processing industries	75 483	60 994	6 334	-
Animal-tissue waste from preparation and processing of food of animal origin	6 385	29	6 334	-
Materials unsuitable for consumption from preparation and processing of food of animal origin	2	…	…	-
Materials unsuitable for consumption from preparation and processing of dairy products	16	15	…	-
Waste from spirit distillation	69 080	60 950	…	-
Municipal biowaste (household waste and similar commercial, industrial and institutional waste) including separately collected fractions	7 409	7 533	5 099	2 827
Biodegradable kitchen and canteen waste	…	2	4	…
Edible oil and fat	11	76	110	…
Biodegradable waste from gardens and parks	122	1 467	305	65
Biowaste in mixed municipal waste	7 276	5 988	4 680	2 762
TOTAL	82 892	68 527	11 433	2 827

Source: EEIC

As the table shows, biowaste yields can fluctuate considerably from year to year. For example:

1. The animal-tissue waste yield from the meat processing company was around 6,000 t in 2006 and 2008, but only 29 t in 2007 as large amounts of waste were recovered in that year.
2. Waste from the spirit distilling industry dropped from 60,950 t in 2007 to 0 t in 2008 due to bankruptcy of the distillery, whose annual biowaste was approx. 60,000 t in 2006 and 2007. The company re-started operations in 2010.
3. Biodegradable waste from parks and gardens was 1,467 t in 2007, but less than 400 t in 2006 and 2008. In 2007 the amount of waste was high because one company (Estonian Cells) reported 1,267 t of waste (due to a change of technology).

The main organizations involved in waste treatment in Lääne-Viru County are: the Uikala landfill, and waste management companies such as AS Ragn-Sells, AS Veolia Environment, and the NGO Lääne-Viru Waste Management Centre.

Uikala landfill, although situated in a neighbouring county (Ida-Viru County), is the main landfill site for Lääne-Viru County. Waste producers in Lääne-Viru County have been sending their waste to Uikala since the closure of their local landfill (Ussimäe prügila) in 2009. The Uikala landfill manages several waste centres, produces compost and collects biogas from the landfill (the company also plans to start producing electricity from biogas).

According to the Section 12 of the national Waste Act, municipalities are responsible for developing waste prevention and waste management. Municipalities organize the public procurement of waste services (transportation, treatment etc.) and oversee that the procurement conditions are followed. The municipalities are also responsible for preparing waste management plans which set the targets, measures and means for improving waste management and fostering waste prevention. Municipal waste plans must be in line with national waste plan.

Municipalities finance their waste prevention activities from revenues from environmental fees. In total, 75% of the environmental fees received from landfilling municipal waste go to the municipal budget and 25% to the state budget. According to the law, municipal money must be used for waste prevention and minimization and for improving waste management. In turn, the state's share of the environmental fees must be used for keeping environmental status, the reproduction of natural resources, compensation for environmental damages, and mitigating environmental impacts.

Sludge

Sludge production in Lääne-Viru County totalled 71,176 tonnes in 2007, 67,371 tonnes in 2008 and 61,659 tonnes in 2009 (average TS 14%). The biggest sludge producers in Lääne-Viru are the Rakvere Meat Processing Plant, Rakvere Wastewater Treatment Plant and Estonian Cell Ltd. In Lääne-Viru County, 72% of habitants are connected to the sewerage system (EEIC, 2010) (**Table 37**).

Table 37. Five largest sludge-producing companies in Lääne-Viru County, tonnes

Company	2007	2008	2009			
			treated sludge, tonnes	TS %	TS tonnes	Use of sludge
Estonian Cell AS (pulp and paper industry)	55 586	55 429	49 970	15	7 495	Energy production, agriculture
Rakvere Vesi AS	10 354	9 225	7891	15	1184	Drained sludge is passed to compost maker
Tapa Vesi AS	4 200	1 700	2200	5	110	Agriculture, soil for landscaping
OG Elektra Tootmine AS	430	420	230	5	12	Agriculture
Kadrina Soojus	280	220	463	2-15	40	Agriculture

Source: EEIC

Estonian Cell is an aspen pulp mill that started production in 2006 (www.estoniancell.ee). The mill produces products for the following applications: printing and writing papers, paper board and tissue. The company processes its wastewater mechanically and biologically. Sludge is composted and mixed with aspen bark.

Rakvere Vesi treats the wastewater from the town of Rakvere. The major source of industrial sludge is from the Rakvere Meat Processing Plant and the dairy products company Maag Piimatööstus AS. Sludge resulting from mechanical and biological treatment is delivered to Eesti Kompost OÜ for composting. The company plans to build a biogas plant, possibly in cooperation with the meat processing plant.

Companies producing wastewater sign an agreement with the wastewater treatment company. The wastewater treatment company sets the price for its wastewater management services depending on the amount of wastewater and the levels of hazardous substances it contains. The price groups for hazardous substances are set by the local municipalities. In Rakvere (the largest town in Lääne-Viru), the limit values for hazardous substances in wastewater are established by the local government council (15.09.2008). There are five pricing groups for wastewater management, ranging from 0.73 – 1.41 €/m^3 depending on the level of hazardous substances in the wastewater. If a client changes its price group (i.e. its wastewater quality), it must inform the wastewater treatment company 10 days prior to the change. The local municipalities are also responsible for preparing a sewerage development plan.

Manure

One of the most suitable raw materials for biogas production is manure from livestock farms. According to the EARIB register, there were 269 livestock farms in Lääne-Viru County in 2009; of these:

- 227 farms raised beef and dairy cattle, total: 39,000 animals,
- 19 farms raised pigs, total: 52,000 animals,
- 27 farms raised sheep, total: 5,000 animals,
- 13 farms raised goats, total: 99 animals,
- farms raised chickens, total: 46,450 animals.

The changes in animal numbers in recent years are shown in **Table 38**. According to the table, the largest sources of manure are pig and cattle farms. As the table shows, in Lääne-Viru County beef and dairy cattle numbers have recently been in decline, whereas pig numbers are on the increase.

Table 38. Number of livestock and calculated amount of solid manure (tonnes) in Lääne-Viru County, 2007-2009

Animal type	2007		2008		2009	
	animals	manure	animals	manure	animals	manure
Beef cattle under 12 months	8,497	16,994	8,344	16,688	7,615	15,230
Beef cattle over 12 months	20,919	144,341	20,451	141,112	19,957	137,703
Dairy cattle	12,528	150,336	12,021	144,252	11,544	138,528
Cattle total	41,944	311,671	40,816	302,052	39,116	291,461
Fattening pigs	21,202	14,841	23,834	16,684	24,460	17,122
Piglets	18,920	9,460	20,653	10,327	23,410	11,705
Gilts	30	15	857	429	438	219
Sows	3,913	15,652	3,279	13,116	3,567	14,268
Boars	109	436	84	336	14	56
Pigs total	44,174	40,404	48,707	40,891	51,889	43,370
Chickens	46,450	2,323	46,450	2,323	46,450	2,323
Sheep	3,604	5,406	3,499	5,249	5,003	7,505
Goats	99	149	99	149	99	149
Horses	200	1,800	300	2,700	200	1,800
Manure total	95,795	361,753	99,943	353,362	102,781	346,607

Notes: Manure amounts are calculated based on the data from the publication ''*Keskkonda säästev sõnniku hoidmine ja käitlemine*'', 2004, p 9.

In Lääne-Viru County, cattle farms are relatively small (70% of farms have up to 100 animals). In contrast, pig farms are relatively large (65% of farms have over 1000 animals), see **Figure 18** and **Figure 19**.

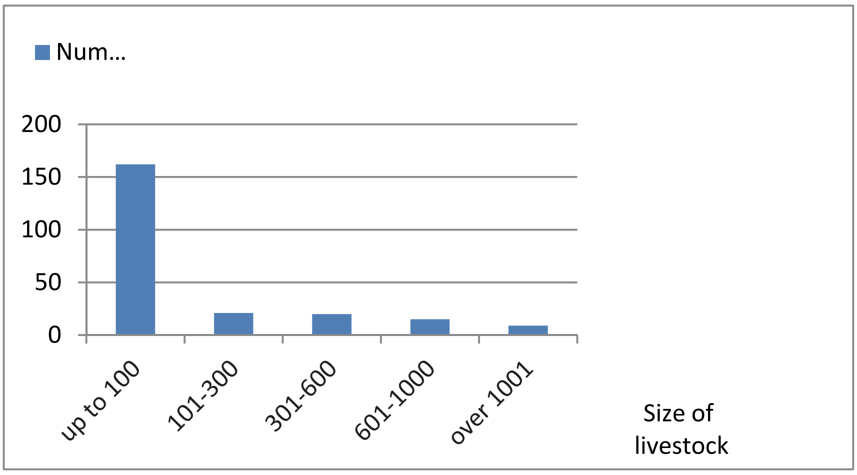

Figure 18. Lääne-Viru farms by livestock size: beef and dairy cattle, 2009

The largest cattle farms (with over 1000 animals) are Voore mõis OÜ, Laekvere PM OÜ, Karli Farm OÜ, Muuga PM OÜ, Herbaco AS, Kohala SF OÜ, Aaspere Agro OÜ, Müüriku Farm OÜ, and JK Otsa Talu OÜ.

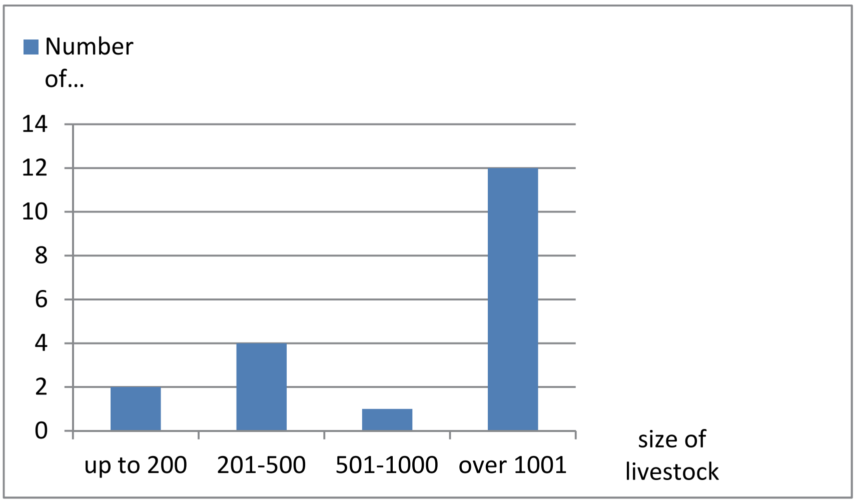

Figure 19. Lääne-Viru farms by livestock size: pigs, 2009

The largest pig farms (with over 1000 animals) are Tammis PM OÜ, Norkess OÜ, Viru Mölder OÜ, Voore Farm OÜ, Oru Talu, Oleg Grossi Talu OÜ, Ermo Sepa Talu, Kupna Mõis OÜ, Kõpsta Seafarm OÜ, Ruixi Mõis AS, Sf Pandivere OÜ, Markilo OÜ, and Vinimex OÜ. There are also two large chicken farms in Lääne-Viru: Oleg Grossi Talu OÜ (20,000 chickens, Rakvere vald) and Äntu Mõis (25,000 chickens, Väike-Maarja vald).

Cultivated and abandoned land

In Lääne-Viru, more than 600 farms grow crops. About 70% of these farms are relatively small – up to 100 ha of cultivated land (see
Figure 20), and only 40 farms have more than 500 ha of cultivated land.

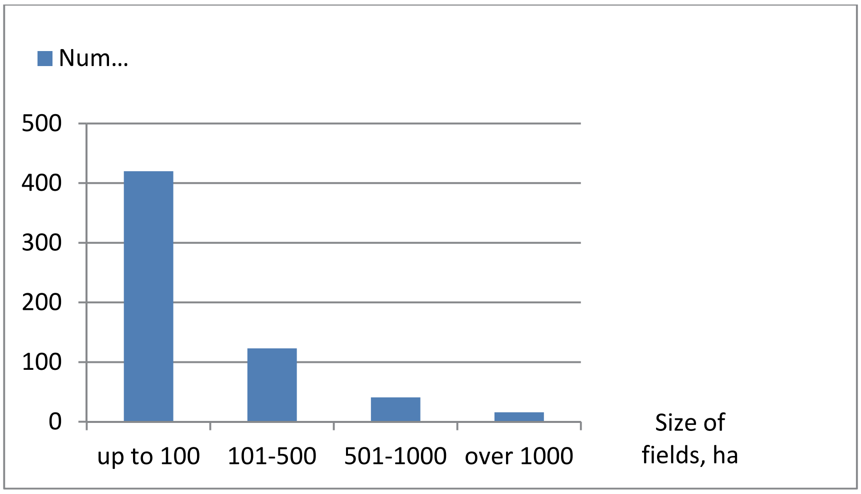

Figure 20. Lääne-Viru farms by size of cultivated land, 2009

The farms with largest cultivated land area (over 1000 ha) are Tammikus OÜ, Roela Suurtalu OÜ, Kuie Põllumajandusühistu, K & G Saarelt OÜ, Trovador OÜ, Kaarli Farm OÜ, Laekvere PM OÜ, Õitseng OÜ, Müüriku Farmer OÜ, Aaspere Agro OÜ, Karuvälja OÜ, Jk Otsa Talu OÜ, Muuga PM OÜ, Aru Põllumajanduse OÜ, Simuna Ivax OÜ, and Voore Farm OÜ.

Lääne-Viru farms had approximately 97,000 ha of cultivated land in 2009 (EARIB). The area of abandoned land was four times smaller – approximately 23,000 in 2009. Over the last few years the growth of cultivated land was 1-2%, whereas abandoned land grew 10-20% per year, probably due to the economic downturn during 2008-2009 (**Table 39**).

Table 39. Cultivated and abandoned land in Lääne-Viru County in 2007-2009

Land type	Area, ha		
	2007	2008	2009
Cultivated land	93,492	96,022	96,981
Abandoned land	16,913	19,005	23,299
Total	110,405	115,027	120,280

Source: *EARIB*

4.2. Biowaste and sludge prevention in 2020

4.2.1. Option A - continuing the present course of development

If the current development continues and no additional waste prevention measures are applied, the annual growth rates of biowaste and sludge are expected to be the following:

I Biowaste from food and beverage industries

Animal-tissue waste from preparation and processing of food of animal origin.

Annual growth 0.5–2%. A single large meet processing company accounts for the majority of this waste type in Lääne-Viru. As the consumption of meat in Estonia is relatively stable (70-73 kg/person), any increase in waste will be mainly due to increased exports (primarily to Russia and Ukraine), which are difficult to predict.

Materials unsuitable for consumption from preparation and processing of food of animal origin
Annual growth 0.5–2%. A single large meat processing company accounts for the majority of this waste type in Lääne-Viru. As the consumption of meat in Estonia is relatively stable (70-73 kg/person), any increase in waste will be mainly due to increased exports (primarily to Russia and Ukraine).

Waste from spirit distillation

30,000 t in 2011, annual growth 1–2%. The spirit distillery re-commenced operations in 2010 in Lääne-Viru. Waste yields may reach 30,000 t in 2011, although growth will be considerably less following re-commissioning of the distillery.

Interviews conducted with leading biowaste producers revealed that companies are minimizing their biowaste as much as possible to avoid paying rapidly growing environmental fees. Companies are choosing new technologies, products and markets to minimize their waste and to profit from waste minimization.

II Municipal biowaste (household waste and similar commercial, industrial and institutional waste) including separately collected fractions

Biodegradable kitchen and canteen waste

Annual growth 3%. Source-separation of biodegradable waste started in 2007. Collection is becoming increasingly regulated and more municipalities are forcing households and companies to use special containers for biodegradable waste.

Edible oil and fat

Annual growth 0.1%. The amounts of edible oil and fat will remain relatively stable, but may increase due to improved accuracy of data collection. Previously, edible fat was often documented under other types of biowaste (e.g. biodegradable canteen waste).

Biodegradable waste from gardens and parks

Annual growth 1%. Derives mainly from vegetable processing companies. Waste production may increase due to increasing demand for vegetables.

Biowaste in mixed municipal waste

The amount of biowaste in mixed municipal waste has been decreasing since the start of the economic recession in 2008. New growth in this biowaste is likely to remain minimal.

Households: annual growth 0.5%

The amount of biowaste per household depends primarily on household income. Before the economic crisis, wages were increasing 10-20% per year in Estonia, and households' biowaste correspondingly grew more than 10% per year. Potential positive impacts on waste amounts may include public campaigns on the dietary importance of vegetables and fruit, and planned improvements in municipal waste collection. The amounts of municipal biowaste may decrease, as consumers increasingly wash biowaste from plastic packages into the sewer (source-separated plastic packages are to required be washed relatively clean by the user).

Non-households: annual growth 0.2%

Increase in this sector will be less than for households, as profit-oriented businesses strive to control rapidly growing waste handling costs.

III Sludge

Annual growth in 2008-2012 of 2-3%, followed by a more stable 1-2%. More households are planned to be connected to the centralized sewerage system. Sludge yields from companies are expected to remain relatively stable.

The table below (**Table 40**) shows the annual biowaste production levels in 2020 if biowaste levels follow the growth rates discussed above.

Table 40. Estimated biowaste collection in Lääne-Viru County in 2020, tonnes

	2008, tonnes	Estimate for 2020, tonnes	Growth rate 2008-2020
Biowaste from food processing industries	6 334	7 137	12.7%
Municipal biowaste	5 099	5 555	8.9%
- households	2 827	3 203	13.3%
- non-households	2 272	2 352	3.5%
Sludge	67 371	78 967	17.2%
Total	78 804	91 659	

The forecast estimates are based on an average annual growth rate of the Estonian economy of 3-6%. If the growth rate is significantly different, the estimates must be revised.

The production levels of many companies in the food and beverage industry depend on export opportunities to Russia, Ukraine and the EU. Changes in exports will impact waste levels, but these changes are difficult to predict.

Changes in production technology may also influence waste production levels. These changes are not taken into account in the forecast estimates.

4.2.2. Option B - biowaste and sludge prevention

If the preventive measures described in this report (Chapter 5) are applied, annual growth in biowaste and sludge will slow by 2020. The effect of prevention is difficult to predict, as it depends on which measures are selected for implementation and how successful their implementation is, and on the state of the economy. Therefore, several sub-scenarios (options) of prevention are proposed (below), the first of which (B1) is considered the most realistic, and the third (B3), the most optimistic (**Table 41**).

Biowaste

Scenario 1. Biowaste from the food and beverage industry remains stable, municipal biowaste decreases max. 0.3% per year,

Interviews conducted with companies in the food industry revealed that companies are already implementing efficient waste prevention measures in order to reduce landfill costs. It is therefore expected that additional preventive measures will have no significant impact on the food industry. Biowaste from households, shops and services may, however, be affected by the measures. It is realistic to assume that during the first years of implementing preventive measures, waste levels will remain relatively stable. During that period, consumer behaviour will change gradually, leading to decreasing of biowaste levels at rates of, e.g., around 0.1% and 0.2% per year.

Scenario 2. Industrial and municipal biowaste decreases 15% compared to 2008.

The biowaste from households, commerce and industry will decrease 15% in 2020. Due to economic recession, the amounts of biowaste will remain stable or slightly decrease during 2008-2012. After that the preventive measures must decrease biowaste amounts at least 1.5% per year to reach 15% decline by 2020.

Scenario 3. Industrial and municipal biowaste will decrease 30% compared to 2008 2020.

Biowaste from households, commerce and industry decrease 30% by 2020. Due to the economic recession, the biowaste levels remain stable or decrease moderately during 2008-2012. After that, preventive measures must decrease biowaste levels by at least 3.5% per year to reach a 15% reduction by 2020.

Table 41. Comparison of biowaste prevention scenarios for 2020.

	OPTION B1	OPTION B2	OPTION B3
Decrease in biowaste from 2008 to 2020	up to 2%	15%	30%
Biowaste production in 2008, t	11 433	11 433	11 433
Production in 2020, t	11 354	9 718	8 003

Sludge

Sewage sludge levels may increase in the coming years if more households connect to the public sewerage system. Other potential factors increasing sludge levels include the installation of biowaste grinding mechanisms in kitchen sinks (placing an additional burden on the sewerage system), as well as moves towards centralized wastewater management (replicating the German and Swedish models). The Estonian sewerage system is not ready for increased levels of solid matter in wastewater.

Scenario A *– sludge prevention measures are not applied*

Scenario B – *sludge prevention measures are applied*

Given the legal tendencies outlined above, improvement of wastewater treatment technologies (need for phosphorus removal, integrated use of biofilm and activated sludge etc.) and our economic opportunities, the experts provide (A. Kuusik et al, Tallinn University of Technology Institute of Environmental Engineering) the following scenarios for sludge levels in 2020:

B1 *– sludge levels remain relatively stable compared to 2008;*

B2 *– sludge levels decrease 10% compared to 2008;*

B3 *– sludge levels increase 20% compared to 2008.*

The results of these forecast estimates for 2020 are given in following table:

Table 42. Sludge prevention scenarios for 2020

	Scenario B1	Scenario B2	Scenario B3
Sludge level decrease from 2008 to 2020	0%	10%	20%
Sludge production in 2008, t	67 371	67 371	67 371
Sludge production in 2020, t	67 371	60 634	53 897

The development of mote accurate scenarios needs a serious in-depth analysis of many aspects, many of which are not observed here.

4.3. Biogas potential and possible biogas plants in 2020

The following chapters provide descriptions of the future biogas options in 2020. Option A represents business as usual (BAU) and includes currently planned developments as well as the current use of biomass and biowaste. Option B represents the W-fuel case study and assumes that the biogas produced in the Rakvere pilot biogas plant is upgraded to biomethane quality for use as vehicle fuel. A summary of the options is provided in **Table 48**.

4.3.1. Option A - continuing the present course of development

Although by the end of 2011 there was no biogas plant in Lääne-Viru County, it is likely that a biogas plant will be built by 2020. A project to establish a biogas plant in the Vinni municipality has been in the planning stage since 2008; the plant will treat slurry from pig and cattle farms. The main parameters of the Vinni biogas plant are (OÜ 4E Biofond, 2008):

1 Expected volume of sludge and solid manure from pig and cattle farms – 88,000 t/y (approx. 20% of manure produced in Lääne-Viru County),

2 Biogas production: 300-350 m^3/h, approx. 2.98 million m^3/y,

3 Biogas is used to produce heat (for Vinni district heating network) and electricity (to public grid via AS Eesti Energia),

4 CHP heat capacity is 1175 kW,

5 Heat energy produced approx. 10.3 million kWh/y,

6 CHP electrical capacity 787 kW,

7 Electrical energy produced – approx. 6.9 million kWh/y,

8 Digestate from biogas production will be used in agriculture (spread on fields).

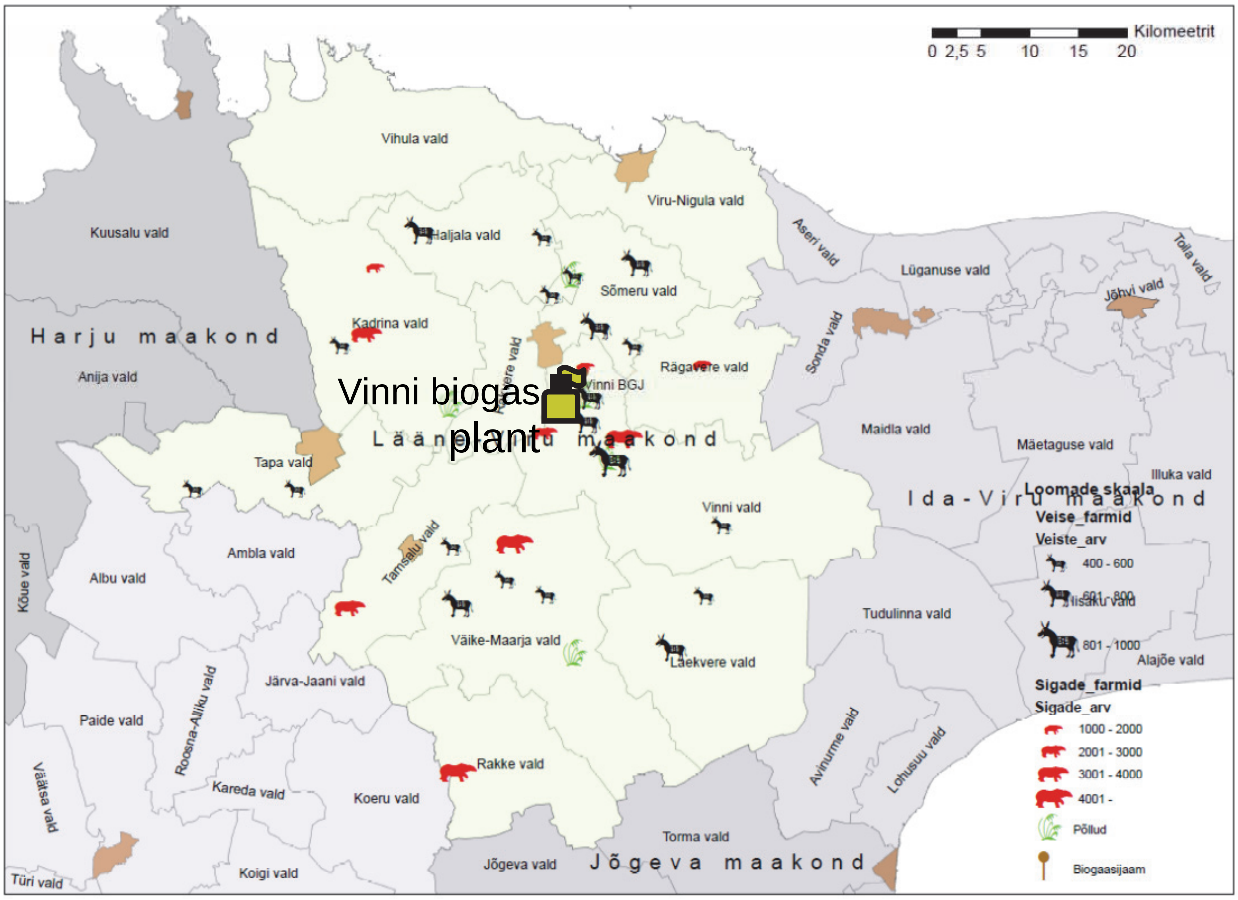

Figure 21. Biogas plant planned in Vinni municipality, and nearby cattle (*est veiste*) and pig (*est sigade*) farms
Note: *Põllud (est)*–fields

4.3.2. Option B – using biomass for biogas production

4.3.2.1. Biomass availability for biogas production

This chapter provides an estimation of how much biogas could be produced from different biomass types in Lääne-Viru County by 2020. The main resources for biogas production are biowaste, sludge, manure and energy crops. To calculate the biogas potential, first the amounts of resources are estimated, then the realistic availability of these resources for biogas production is evaluated and, finally, the feasible methane production is calculated (see **Table 44**).

The forecast estimates are based on expert opinion and recommendations of the project lead partner – the Agricultural Research Centre of Finland (MTT Agrifood Research Finland). Other organizations involved in the forecasting included the Ministry of the Environment of Estonia, the Department of Environmental Engineering at Tallinn University of Technology and the Ministry of Agriculture of Estonia. The assumptions and estimations for biowaste, sludge and manure are similar to the assumptions made for Harju County described in Section 3.3.2.1.The production estimation of energy crops for biogas production by 2020 is presented below.

Energy crops for biogas production. At present, energy crops are not used for biogas production in Lääne-Viru County. The Estonian Biogas Association estimates, however, that approximately 5% of cultivated land and 20% of abandoned can be used for growing crops for biogas, such as clover and reed canary grass.

In 2009, there were approximately 97,000 ha of cultivated land and 23,000 ha of abandoned land in Lääne-Viru. Both land types are expected to increase by 2020. According to expert opinion and recent trends, cultivated land is expected to increase by approximately 0.5% per year (reaching 102,450 ha in 2020) and abandoned land by approximately 2% per year (reaching 28,970 ha in 2020).

Abandoned land has been audited since the establishment of the agricultural land register in 2004. A proportion of the land abandoned in the early 2000s will be naturally forested by 2020 and therefore unusable for growing energy crops. To exclude such land areas, only land abandoned in 2009-2020 is taken into account in this report (see **Table 43**).

Table 43. Estimated harvest of energy crops in 2020 in Lääne-Viru County

Land type	2009	2020	Land for energy crops		Clover in 2020			Reed canary grass in 2020		
	ha	ha	%	ha	%	ha	VS tonnes/ year	%	ha	VS tonnes/ year
Cultivated	96 981	102 450	5	5 124	50	2 562	20 750	50	2 562	20 750
Abandoned	23 299	28 970 Accumulated during 2009-2020: 5 671	20	1 134	50	561	4 544	50	561	4 544

Notes: VS – volatile solids or organic matter

In this report, two types of energy crop are recommended for biogas production: reed canary grass (päideroog, *Phalaris arundinacea*) and clover (ristikhein, *Trifolium pratense*). The average annual yield of both crops is approximately 9 tonnes of dry matter per hectare (2 harvests per year) (Rohtsete.., 2007).

Table 44 shows approximate figures for the amount of biomethane that can be produced in Lääne-Viru County from different substrates in 2020. The total biomethane production potential is estimated to be about 24.4 million m^3/year. The largest methane potential comes from energy crops (about 66% of the total potential), industrial biowaste (approx. 13%), sludge (11.5%), agricultural slurry (approx. 9%) and municipal biowaste (0.6%).

Table 44. Biomass production and biogas yield in Lääne-Viru: W-Fuel scenario for 2020

Type of biomass resource	Production in 2008	W-Fuel scenario 2020	Can be practically used for biogas production in 2020		CH4 yield	Methane production
	tonnes	tonnes	%	tonnes	m^3/t FM	m^3/y
I Biowaste from food processing industries	6 334	36 334	-	-	-	Up to 3 151 200
incl. animal tissue waste	6 334	6 334	90%	5 700	216	1 231 200
waste from spirits distillation[5]	0	30 000	up to 100%	up to 30 000	64	up to 1 920 000
II Municipal biowaste	5 099	5 022	-	-	-	158 119
incl. biodegradable kitchen and canteen waste	4	4	33%	1.32	97	128
edible oil and fat	110	110	33%	36.3	288	10 454
biodegradable waste from gardens and parks	305	300	0%	-	-	-
biowaste fraction in mixed municipal waste	4 680	4 608	33%	1 521	97	147 537
III Sludge	67 371	67 371	100%	67 371	42	2 829 582
IV Manure[6]	345 266	583 504	-	-	-	2 174 900
incl. beef and dairy cattle slurry	494 354	501 770	31%[7]	155 549	10	1 555 490
pig slurry	78 626	79 412	78%[8]	61 941	10	619 410
solid chicken manure	2 323	2 323	0%	-	-	-
V Energy crops for biogas production	0	50 588 VS	-	-	-	16 061 690
incl. reed canary grass for biogas production	0	25 294 VS	100%	25 294 VS	300 m^3/t VS	7 588 200
clover for biogas production	0	25 294 VS	100%	25 294 VS	335 m^3/t VS	8 473 490
TOTAL						24 375 491

Notes: The method used to calculate crop, methane and manure yields is described in chapter 2.
FM – fresh matter (raw material)
VS – volatile solids (organic matter)

4.3.2.2. Proposed location of the biogas plant in Lääne-Viru County

Municipal sewage sludge and biowaste from the food industry are often considered the most suitable resources for biogas production. In Lääne-Viru, the biggest producers of these resources are the following three companies in Rakvere:

1 Rakvere Meat Processing Plant,

2 Estonian Spirit distillery, and

3 Rakvere Vesi wastewater treatment facility.

These companies are situated 1-2 km from each other (see **Figure 22**) and can ensure a stable flow of raw material for biogas production throughout the year. The biogas plant can be built near the wastewater treatment plant, enabling wastewater sludge to be pumped without requiring additional transportation.

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[5] In Estonia, this waste type is often sold to local farmers as animal feed. The availibility of such waste for biogas production therefore depends on the market price for this raw material.
[6] The base year for forecasting manure levels is 2009
[7] Manure from farms requiring a waste permit (over 300 milk cows, over 400 mature beef cattle, over 600 young beef cattle).
[8] Manure from farms requiring a waste permit (over 1000 pigs or over 300 sows).

Figure 22. Location of the largest biowaste and sludge producers: Rakvere Meat Processing Plant, Rakvere wastewater treatment plant, and spirit distillery Estonian Spirit Ltd.

In 2008, Rakvere Meat Processing Plant and Rakvere Vesi produced almost 20,000 tonnes of waste suitable for biogas production, spirit distillery was not operating. In 2020, it is expected that the amount of waste from Rakvere Meat Processing Plant and Rakvere Vesi will remain similar to 2008 (see **Table 45**) and the waste from spirit distillery will reach 30,000 tonnes (half of the amount in 2007).

Table 45. Methane potential of three largest biowaste and sludge producers in Lääne-Viru County. Forecast for 2020.

Company	Type of biogas raw material	2008	2020	CH_4	Can be practically used for biogas production in 2020		CH_4	TS	VS/TS	CH_4
		t	t	m^3/tVS	%	tonnes	m^3/t ww	%	%	m^3/year
Rakvere Vesi	Wastewater sludge	8 944	9 875	300	100%	9 875	28	12	77	273 732
Rakvere Lihakombinaat	Manure and urine, digestive tract content	700	711	400	100%	711	42	13	12	29 841
	Animal tissue waste, category III	6 371	6 467	580	100%	6 467	216	40	90	1 396 872
	Sludge	3 477	3 529	300	100%	3 529	25	9.4	88	87 580
	Animal fat	32	33	800	100%	33	288	40	90	9 361
Estonian Spirit Ltd	Waste from spirits distillation	0 (60 950 t in 2007)	30 000	336	33%	9 900	64	20	95	up to 632 016
Total		19 524	50 614	-	-	30 514	-	-	-	up to 2 429 401

The Rakvere suburbs are an ideal location for the county's first biogas plant due to the following reasons:

1) Rakvere accommodates the county's three largest producers of biowaste (named above).
2) If biogas is utilized in CHP, the heat energy can be directed to the Rakvere district heating system from September to May.
3) Biogas that is not used for CHP or as transport fuel can be injected into the natural gas pipeline situated in Rakvere.

4.3.2.3. Rakvere biogas plant technology and equipment

At present, the anaerobic fermentation technologies, equipment and associated control systems used in Estonia are imported. To increase equipment efficiency, the local climate and other specifications (e.g. raw material) need to be taken more specifically into account.

Grounds for selecting the biogas production technology

The choice of technology and equipment depends primarily on the substrates used. The amount of substrate determines the parameters for the technical equipment and the dimensions of the digester. The substrate quality (dry matter content, structure, origin) also determines the technology used. In addition, the substrate composition and dry matter content determine whether it is necessary to separate mechanical impurities or add liquid in order to be able to pump the substrate. Some substrates may also require pasteurizing in order to comply with hygiene requirements. The pre-treated substrate is directed to the fermentation tank, where it starts to ferment and release biogas. In the case of wet fermentation, single-stage technical solutions and the continuous method is mainly used. In the case of the two-stage method, a pre-fermentation tank is used. In the pre-fermentation tank, the substrate is prepared for the first two stages of the fermentation process (hydrolysis and acid formation). After that, the substrate moves to the fermentation tank where fermentation continues. Fermentation residue (digestate) is typically stored in a closed post-fermentation storage tank which allows gas collection, or it can be stored in an open-air tank from where it can be taken for use as agricultural fertilizer. The biogas from fermentation is stored and cleaned. Biogas can be used in internal combustion engines (e.g. in combined heat and power production units, CHP) or it can be upgraded for use as fuel for vehicles.

Figure 23 shows a schematic illustration of a single-stage agricultural biogas plant (including components) which is also used for other biodegradable waste which require pasteurization.

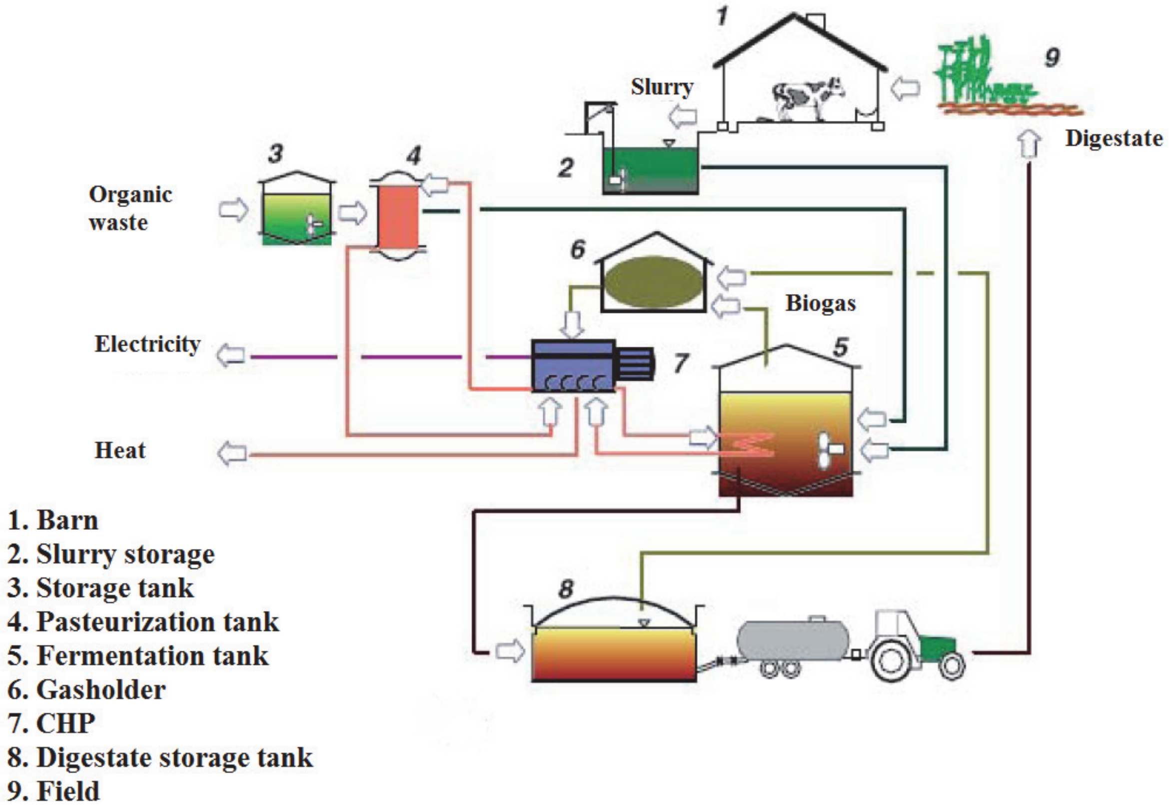

Figure 23. Simplified scheme of biogas production primarily from agricultural raw materials and use in a CHP plant.
Source: Handbook ..., 2009

Selection of biogas production technology

Considering the substrates available in Rakvere (sewage sludge, animal tissue residue, fats and alcohol industry residues), its natural surroundings, socio-economic conditions, and additionally available raw materials (liquid manure, biowaste), it is advisable that the proposed Rakvere biogas plant design be based on wet fermentation technology using a vertical fermentation tank (~3,000 m^3) and the complete mixing method. A pasteurization unit must also be added to the process as the substrates come from several sources and may be contaminated with pathogens. The digestate is not likely to be used as agricultural fertilizer, but rather in landscaping and as an additive to compost (20%).

Complete-mixing fermentation tanks are mainly used for biogas production from agricultural substrates. These are cylindrical and positioned vertically. This method is also used for other substrates if the dry matter content of the substrate is low. The fermentation tank has a concrete floor with steel or concrete walls. The container may be partially or completely dug into the ground, or erected on the ground. The container is covered with a gas-tight cover, which can be of varying design. Complete mixing is achieved by fitting a blender in the fermentation tank.

Biogas production process

Regardless of the technical equipment, agricultural biogas production can be divided into four distinct phases:

1. Pre-treatment: transport, storage, and feeding of the substrate;
2. Main process: biogas fermentation and separation;
3. Follow-up process: digestate storage and use;
4. Biogas storage, cleaning and use.

Transport. A proportion of the raw material for biogas production (sewage sludge) will be located near the planned biogas plant, while the remainder will be delivered from a distance of 2–4 km (from AS Rakvere Meat Processing Plant and Estonian Spirit LLC). If additional substrates are needed, liquid manure and slurry can be transported from the farms in the region. In this case, there will be a need to transport 55-60 tonnes of raw material to the biogas plant daily, requiring 3–4 trips a day depending on the volume of the transport vehicles.

If manure is to be used, it must be kept in mind that livestock farms are located outside the city and transportation of liquid manure to the city and digestate to the farms has several negative impacts (unpleasant odours and air pollution from transport).

Storage. Properly managed storage is important to avoid significant changes in the raw material during storage. Different substrates require different storage methods. The storage space required depends on the planned amounts of substrates and their speed of consumption. If the substrates are purchased, the use of delivery contracts specifying the time and quantity of delivery are important.

Due to malodorous emissions, substrates should be stored in a hall equipped with bio-filters or air-cleaners. This also protects plant equipment and enables operations in all weather conditions.

Sorting and mechanical removal of impurities

The level of sorting and mechanical removal of impurities used depends on the source of the substrate. Metal and stones, which are the most common impurity, usually sink to the bottom of the pre-fermentation tank and are removed periodically. Other impurities are removed manually either when the substrate is being received or during feeding of the substrate into the fermentation tank. Biowaste is the most problematic substrate with respect to process disruption. The Rakvere biogas plant will need to sort waste from the meat processing plant and biowaste separately, if it is used.

Substrate pasteurization. To meet the sanitary requirements of critical substrates (e.g. waste from the meat processing plant), preliminary thermal processing usually needs to be integrated into the production of biogas: the substrate must be heated to 70 °C for at least one hour.

Grinding, crushing. Grinding and crushing increases the surface area for biological fermentation and also increases the production of methane. If the substrate is crushed, the biological processes accelerates, however, it does not always increase the amount of biogas. The amount of methane depends on how long the substrate was in the digester. The most important factor is the right choice of equipment. The substrate can be crushed before directing it to the storage tank. Often, additional equipment is needed to sort and remove mechanical impurities. If the substrate is relatively hard/solid, grinding equipment is situated near to the pre-storage tank.

Premixing, homogenization. In the case of wet fermentation, the substrates are pre-mixed with water to obtain a mixture suitable for pumping into the fermentation tank. The water used in this process can be ordinary fresh water or used water from the fermentation process.

Addition of fermented water is advantageous, as it reduces clean water consumption and introduces fermentation bacteria into the fresh substrate.

Feeding substrate. There are two feeding methods: continuous and half-cycle. A continuous supply of substrate is desirable as this ensures a uniform, unbroken biological process. However, since this is difficult to achieve in practice, half-cycle feeding systems are nowadays most often used. The substrate is fed in small batches evenly over a twenty-four hour period. This means that the equipment needed to transfer the raw materials does not have to work constantly. It is essential to know the dry matter content of the substrate before designing the biogas plant and choosing the feeding technology.

Temperature has to be monitored when feeding the substrate into the fermentation tank. If the temperature difference between the added substrate and the substrate in the fermentation tank is big (e.g., after pasteurization, or in winter), immediate disruption of the fermentation process can occur, which can lead to a reduction in biogas production. To solve the problem, feed pipes can be insulated or heated.

The main fermentation process. The pre-treated substrate is directed to the fermentation tank, where it begins to digest and release biogas. The fermentation tank is the heart of the biogas plant. In the absence of oxygen, the biological process brings about the production of biogas from organic matter. If all four stages of fermentation (hydrolysis, acidogenesis, acetogenesis and methanogenesis) take place in one fermentation tank, it is called a single-stage production process. As the bacteria involved require a variety of conditions at different stages of their life cycle, a compromise with respect to creating optimal conditions for the different bacteria is needed. Because methane-producing bacteria are the most sensitive and multiply slowly, creating optimal conditions for these bacteria is usually the priority. To keep investment costs down, a single-stage fermentation tank has been chosen for the Rakvere biogas plant.

Follow-up process. The follow-up process consists of two parts: digestate storage and usage; and biogas storage, upgrading and usage.

Sometimes it makes sense economically and technologically to separate the solid and liquid fractions. The liquid fraction can be directed either back to the fermentation tank or to the field as nitrogen fertilizer. The solid fraction can be composted. To separate the solid and liquid fractions, the following equipment can be used: a press with sieve, centrifuges or screw separators.

If different substrates are fermented (industrial waste, sewage sludge, etc.), then the mixed substrates need to be pre-treated before fermentation or processed after fermentation in order to be able to use the digestate for composting. If pre-treatment is not carried out, the digestate can be used only for landscaping and earthfill. It is economically beneficial to use the fertilizing properties of the digestate as much as possible.

Digestate utilization. The digestate can be used as fertilizer or soil conditioner. The solid fraction can be composted to produce a more humus-rich end product.

Biogas upgrading. Biogas from anaerobic digestion of organic matter contains approximately 60-70% methane (CH_4), 30-40% carbon dioxide (CO_2), less than 1-2% hydrogen sulfide (H_2S) and small amounts of other substances and water vapour. Methane is the most important fraction, while the remaining ballast needs to be removed. If the biogas is to be upgraded for use as transport fuel, it must be purified free of sulfur compounds, water vapour and carbon dioxide. The most common methods for cleaning biogas are washing with water and pressure swing adsorption.

In Estonia, biogas is currently not upgraded to biomethane (i.e. at least 95% methane content), and there is limited practical knowledge regarding upgrading technologies as a result. The legal basis for feeding upgraded biogas or biomethane gas into the natural gas network is lacking, and the related quality standards are under still development.

Equipment

The main equipment of the biogas plant includes:

- tank for storing biomass,
- equipment for pre-treatment and feeding,
- fermentation tank,
- gasholder,
- digestate tank.

The main equipment of the biogas purification plant includes a double-coated low-pressure (up to 0.5 bar) membrane tank for balancing non-uniformities during production, purification and use of the gas; as well as purification equipment with compressors, high pressure tanks, and refuelling facilities.

As previously mentioned, there are many providers of various technologies and equipment. For this reason, it is important to evaluate all aspects of the technological solution, conditions of purchase, contracts, etc. A practical recommendation would be to ask for a supply contract for the project in the early stages of negotiations in order to avoid surprises later on.

Quotes for the purchase of biogas plant equipment can be sought from the following German, Austrian and Dutch companies: Zorg Biogas AG, Biogas and BAL Anlagenbau Langenau GmbH, Novatech GmbH, SchmackBiogasAG, BIOFermGmbH, Kompogas AG, COWATEC, and HaaseEnergietechnikAG and HoStB.V. Quotes for biogas purification equipment can be sought from CARBOTECH Schmack GmbH, Cirmac, Flotech, and MT Energie.

Use of the biogas produced in a CHP plant could produce more that 9 GWh of electricity and 9.8 GWh of heat. More than 50% of this energy would be derived from animal tissue waste from the Rakvere Meat Processing Plant and approximately 25% from waste from the spirit distillery Estonian Spirit Ltd (**Table 46**).

Table 46. Rakvere biogas plant: methane potential, electricity and heat capacity

Company	Type of biogas raw material	CH_4	Electricity	Electrical capacity	Heat	Heat capacity
		m^3/year	kWh_{el}	kW_{el}	kWh_{th}	kW_{th}
Rakvere Vesi	Wastewater sludge	273 732	1 039 525	130	1 103 852	138
Rakvere Lihakombinaat	Manure and urine, digestive tract content	29 841	113 324	14	120 337	15
	Animal tissue waste, III category	1 396 872	5 304 761	663	5 633 026	704
	Sludge	87 580	332 594	42	353 175	44
	Animal fat	9 361	35 548	4	37 748	5
Estonian Spirit Ltd	Waste from spirits distillation	632 016	2 400 144	300	2 548 668	319
Total:		2 429 402	9 225 896	1 153	9 796 805	1 225

The summarized technological specification data for the Rakvere biogas plant and CHP plant are presented in **Table 47.**

Table 47. Specification for the biogas plant and CHP plant in Rakvere

No	Parameter	Unit	Value
1	Amount of substrates	t/day	138
2	Biogas production*	m^3/day	11 090
3	Electricity production	GWh_{el}	9.2
4	Electric power	kW_{el}	1 153
5	Heat energy production	GWh_{th}	9.8
6	Thermal power	kW_{th}	1 225
7	Digesters	number	1
8	Volume of digester	m^3	3 000
9	Labour requirement	h/day	2
10	Area requirement	ha	0.4
11	Volume of digestate	t/year	25 300

* Assuming a biomethane (CH_4) content of 60%

Summary of future options

A summary of the two options elaborated is given in **Table 48** below. Option A represents biogas production according to current plans – it assumed that Vinni biogas plant will be erected as planned and produce approximately 3 million m^3 of biogas per year.

Table 48. Options A and B in 2020

Option	Input	Biogas production	Value added	Digestate output
A	Manure - 88,000 tonnes	Vinni biogas plant	Biogas – 2.98 million m^3/y, see chapter 1	44,000 tonnes
B	Biogas raw materials (sludge, animal tissue, fat, spirit distillation waste) – 50,614 tonnes	Rakvere biogas plant	See Table 45 and Tabel 46	25,300 tonnes

Option B represents the W-Fuel scenario according to which one more plant will be built. The plant will process waste from three companies. Option B implies a CHP plant that will provide about 9.2 GWh of electricity and about 9.8 GWh of heat per year.

4.4. Biomethane use as transport fuel in 2020

4.4.1. Location of the biogas upgrading plant

The main sources of substrates for biogas production (sewage sludge, animal tissue residue and alcohol industry residues) are situated in/near the town of Rakvere. To minimize transportation costs, the location of the biogas purification plant is recommended to be near to at least one of the biogas raw material sources. In addition, close proximity to the natural gas grid is preferred as this eliminates the need to build a container for surplus biogas, which can instead be injected into the natural gas grid.

Location A

An ideal location for the biogas upgrading plant would be near to the Rakvere wastewater plant (east or northeast side). This would enable wastewater sludge to be pumped to the upgrading plant, thus eliminating sludge transportation costs. The second primary source of biogas raw material – the Rakvere Meat Processing Plant – would be situated within a 2.5 km radius. If road transport is used (Arkna tee, Papiaru tn and Nortsu tee), the transport distance would be 3.8–4.4 km. The third key source of biogas raw material – Estonian Spirit – is situated on Kalda Street in Rakvere, at a distance of 2.1–2.7 km to the potential location of the biogas plant.

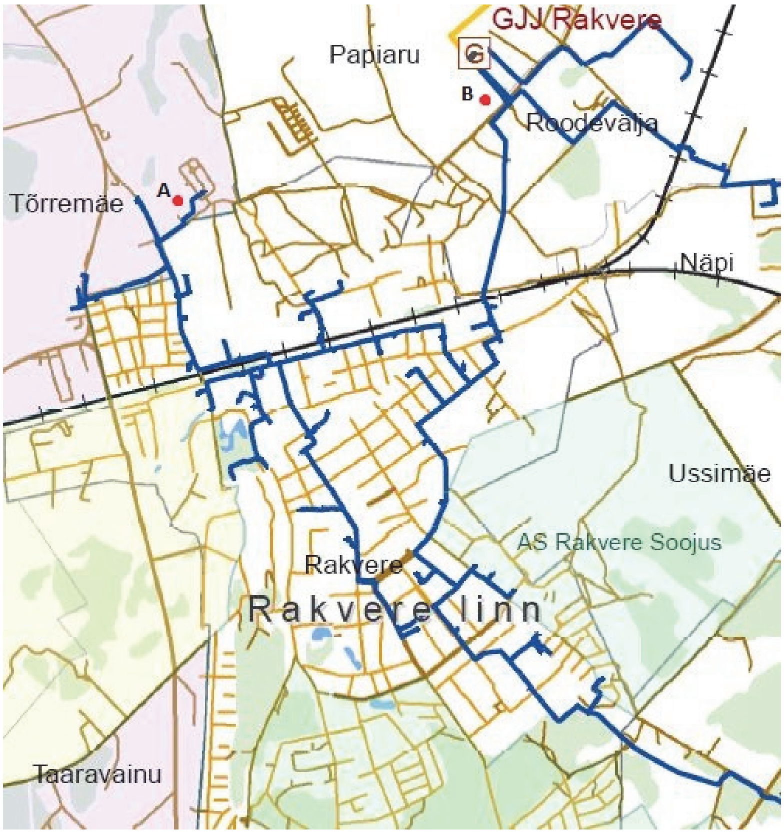

Figure 24. Biogas plant locations

Additional advantages of location A include the close vicinity of a shopping centre and the short distance to the Haljala main road, which has an average traffic volume of over 4,600 cars per day. As the main town bus routes end at the shopping centre, it would be convenient for them to fill up at this location. Furthermore, the gas surplus could be injected into the Rakvere gas grid, and if there is a gas shortage gas could be retrieved from the natural gas pipeline. The gas pipeline running from the biogas purification plant to the filling station near the shopping centre would be 500–700 m long.

Location B

Another suitable location for the biogas purification plant would be near to the Rakvere Meat Processing plant. A suitable location for the purification plant would be on the northeast side of the Rakvere Meat Processing Plant site, or across the road from the meat plant.

The Rakvere wastewater treatment plant would be within a 2.5 km radius. If road transport is used (Arkna tee, Papiaru tn and Nortsu tee), the distance to the wastewater treatment plant would be 3.8–4.4 km. The distance from Estonian Spirit to the potential biogas plant location would be 2.9–3.5 km.

The filling station would be situated near the Arkna tee road. The gas pipe from the plant to the filling station would be approximately 150m long. The advantage of this plant location is that the high pressure gas pipeline would be situated 350–450m from the plant, enabling gas to be injected into the main pipeline. AS Eesti Gaas is already planning biogas stations in the direction of Narva, it would be possible to sell biomethane to vehicles on the Narva highway (traffic volume over 5,000 vehicles per day). Otherwise, the location is not very suitable for local buses or local traffic. In addition, sludge from the wastewater processing plant would have to be pumped via a pipeline to the plant over a distance of 2–2.5 km. This option could prove unviable as the pipeline would cross several landowners' properties and the cost of the line would be high.

4.4.2. Transport of biogas raw materials

According to a recent Estonian study on biogas raw materials (Tartu linna ..., 2011), the cost of transport of animal waste is EUR 1.30 per truck kilometre based on a 5-tonne truck load. Although there are different types of waste from Rakvere Meat Processing Plant AS, the cost of all waste types averages at 1.3 euros per truck kilometre if a single truck load contains 5 tonnes of animal waste. As animal waste is problem waste for Rakvere Meat Processing Plant AS, the purchase price for the waste will be EUR 0.00 per tone (**Table 49**). In addition, the wastewater sludge would not be transported as the sludge source would be in the near vicinity of the biogas plant. Distillation waste from Estonian Spirit would be transported by 20-tonne trucks at a cost of EUR 1.30 per truck kilometre. A 25–30% increase in transport costs is estimated by 2020 (at annual inflation of ~2.5–3%).

Table 49. Transportation cost of biogas raw materials.

Company	Amount of biogas raw material		Cost of transport 2011	Truck capacity	Distance to transport	Cost of transportation	
	2008	2020				2011	2020
	t	t	EUR/km/truck	t	km	EUR	
Rakvere Vesi AS	9 225	9 875	0	-	-	0	0
Rakvere Meat Processing Plant AS	10 580	10 740	1.3	5	4.4	12 104	15 973
Estonian Spirit Ltd	0	9 900	1.3	20	2.7	0	2 259
Total	19 524	30 515			7.1	12 104	18 232

4.4.3. Biogas upgrading method

The upgrading method was decided based on an extensive study on upgrading technologies. It was noted that at higher biogas productivities (500-1000 m^3/h) there are no big differences between the costs or performance of water absorption, PSA, or chemical and physical absorption (see 3.4.3 Biogas upgrading method). Water absorption and PSA are the most proven and documented methods. On the other hand, the problem of methane losses during the upgrading phase is receiving increasing attention. Chemical absorption (with amines) seems to be the only technology available at the present capable of producing high quality biomethane with methane loses of < 0.1%. Amino wash was therefore selected in this study as the method of choice for biogas upgrading (**Figure 25**).

In the amino wash method, an aqueous amino acid salt solution is used to absorb CO_2 from the raw biogas. The only process stream required besides biogas is water, in which the amines are dissolved. H_2S has to be removed from the biogas before the treatment to prevent poisoning of the chemical. This can be achieved by biological aerobic oxidation by introducing a small amount of air or oxygen to the digestion tank. The biogas flows through a column which is filled with the amine solution. The CO_2 is chemically absorbed by the amine solution and the biomethane leaves the column. The CO_2 can be removed from the amine solution in a regenerative phase and the amine solution used again. The amines need to be replaced a couple of times per year, after which they constitute a waste stream. The amines can be separated from the resulting wastewater with a membrane and the cleaned water directed to the sewer. The waste streams remaining after the amine wash are CO_2 and amines (de Hullu et al., 2008, Ryckebosch et al., 2011, Wellinger & Lindberg, 2005).

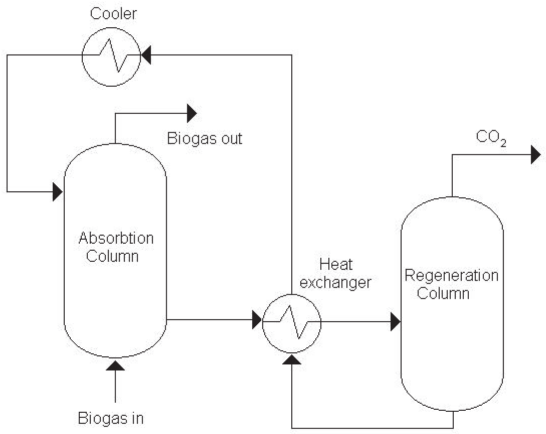

Figure 25. Amino wash (de Hullu et al., 2008).

The advantages of the amine wash method are its high efficiency (biomethane with >99% CH_4), cheap operation, the regenerative nature of the process, more dissolved CO_2 per unit volume compared to water, and very low CH_4 losses (<0.1%). Disadvantages include expensive investment, heat required for regeneration, corrosion, decomposition and poisoning of the amines by O_2 or other chemicals, precipitation of salts and possible foaming (Ryckebosch et al., 2011).

4.4.4. Potential users of biomethane

At present, the best technological solution for utilizing biomethane in transport is the use of compressed natural gas vehicles (CNG), as this technology works also with biomethane. There are currently no CNG stations in Lääne-Viru County and no CNG vehicles in the area. As the use of natural gas as a transport fuel is not common in Estonia, there are major restrictions on the users and the market for biomethane. One of the main potential users of biomethane in Lääne-Viru is the public transport sector. CNG buses are used in the city of Tartu and have proven to be cost-effective. Other transportation vehicles based in the vicinity of the biomethane station are also potential users. As the requirement to register motor vehicles according to their owner's address has become compulsorily only in the last few years, it is not possible to accurately determine the actual number of motor vehicles in any given region in Estonia.

Bus transportation

Most of the town and long-distance bus lines are serviced by diesel buses as this is the most cost-effective and best known option. Due to the lack of CNG stations in Estonia, it can be assumed that long-distance buses would not use biomethane as transport fuel. Buses with shorter, predetermined routes, on the other hand, can very successfully use biomethane as a fuel. As the location of the plant would be in/near the town of Rakvere, one of the most viable consumers of biomethane would be the local bus service.

The central lines are serviced by Go Bus, and consist of six local routes. Based on the average mileage from Tartu, the local buses clock a total distance of 80,000 km per year. With an average consumption of 45 litres of diesel per 100 km, the total adds up to 36,000 litres of diesel fuel per bus per year. The amount of biomethane needed to replace this conventional fuel would thus be 36,000 m^3 per year, as 1 m^3 is roughly equivalent to 1 litre of diesel or petrol.

Although the intercity bus lines are too long to be run on biomethane, the bus routes within Lääne-Viru County can be operated with a single filling of compressed biomethane. It is estimated, that a bus can drive 300 km on a full tank (100-150 kg) of pressurized biomethane. The majority of Lääne-Viru's regional lines (61 lines in total) are serviced by AS GoBus (39 lines). If CNG filling stations gain popularity, natural gas and biomethane could also be used for intercity bus transport.

Private transportation

The estimated average annual mileage of a private car in Estonia is 20,000 km, and the average fuel consumption is 7.5 litres per 100 km. The total annual fuel requirement of an average car can thus be met with 1500 m^3 of biomethane.

Table 50. Number of motor vehicles Lääne-Viru County, 2010

	Cars	Buses	Trucks	Motorbikes
Lääne-Viru County	29 959	228	4 689	1 058
…incl. Rakvere	7 433	31	1 164	242

Source: Statistics Estonia

Lääne-Viru County, including Rakvere, had 34,876 registered motor vehicles (excluding motorbikes and trailers) in 2010, about 75% of them in private use. By 2020, the car numbers are likely to increase by 3% reaching 35,922. Based on an optimistic scenario, 1.5% or 536 of those vehicles could be running on biomethane (e.g. 30 buses (5.6%), 20 trucks (3.7%), 20 waste collection vehicles (3.7%) and 466 cars (87%) in the pilot region). As with the corporate sector, raising awareness of biomethane among private car drivers takes time, and it also takes time for consumers to adapt to new technologies.

Most CNG-powered vehicles are trucks or buses. Car manufacturers currently offer a number of CNG vehicles, with CNG often marketed as an additional option for gas engine vehicles – so-called dual fuel cars. There are 28 different CNG-powered cars on the market, with all major car manufacturers represented – Audi, Chevrolet, Citroën, Fiat, Ford, Honda, Hyundai, Lincoln, Mercedes-Benz, Mitsubishi, Opel, Peugeot, Renault, Toyota, Skoda and Volkswagen.

Other possible users of biomethane

There are four major waste disposal companies operating in Lääne-Viru County. The companies each operate within a predetermined area, making them ideal candidates as biomethane users if the area they are covering is in the vicinity of a biomethane filling station. The average waste collection vehicle consumes 25 litres of fuel per 100 km and has an average mileage of 50,000 km/y. Thus, 12,500 m^3 of biomethane is needed to cover one waste collection vehicle's yearly fuel consumption.

There are four taxi companies operating in Rakvere. An average taxi consumes the same amount of fuel per 100 km as a personal vehicle, but has an average mileage of around 50,000 km per year. The amount of biomethane needed to cover the annual fuel consumption of one taxi is 3,750 m^3.

According to Statistics Estonia transport statistics, 65% of all bulk goods transportation takes place within a 50km radius. The main potential end consumers of biomethane include transportation companies of all types, logistics companies, street cleaning companies, postal services, the police, ambulances, etc. All transport vehicles that permanently operate in the vicinity of a biomethane filling station are suitable for using biomethane. The average fuel consumption of a transport truck is the same as a waste disposal vehicle, 25 litres per 100km, and the average mileage is 80,000 km/y.

Table 51. Potential number of vehicles fuelled by biomethane

Type of vehicle	Total biomethane production potential, m^3		Annual biomethane consumption per vehicle	Potential number of vehicles fuelled by biomethane	
	2008	2020	m^3	2008	2020
Cars			1 500	1 036	1 619
Taxis			3 750	414	647
Buses	1 554 422	2 429 402	36 000	43	67
Trucks			20 000	77	121
Waste collection vehicles			12 500	124	194

AS Eesti Gaas

As biomethane can be injected into the natural gas grid, one of the key potential consumers is AS Eesti Gaas. AS Eesti Gaas owns the gas transmission network in Estonia. Together with AS EG Ehitus and AS EG Võrguteenus, AS Eesti Gaas is a key concern in the field of buying, selling and distributing natural gas. In addition, Eesti Gaas provides services, installs new gas pipelines and develops the gas grid in Estonia. AS Eesti Gaas has 46,600 clients, including 45,100 private clients, 246 industrial clients, 53 district heating and heat providers, 6 CHP plants and 32 gas distribution companies.

AS Eesti Gaas has the infrastructure for receiving produced biomethane. The company has erected 2 CNG stations, one in Tallinn (Suur-Sõjamäe 56a) and one in Tartu (Tähe 135e). AS Eesti Gaas is planning to invest in similar stations near Narva and Pärnu in order to provide filling opportunities for city transport vehicles. In Tartu, this has had a positive effect and 5 city transport buses and some personal vehicles are now running on CNG. This has helped to raise awareness of compressed gas transport vehicles.

4.4.5. Biomethane filling station

The optimal location for a biomethane filling station is adjacent to the biogas plant, which would be situated on the east or northeast side of the Rakvere wastewater plant. In this case, the filling station would be situated close to the high-volume Haljala tee road (average traffic volume over 4,600 cars/day). Also located nearby is the local shopping centre where the town bus routes terminate, which offers a prime location for a filling station for buses.

Another suitable location for the filling station would be slightly to the south of the shopping centre. The distance from the biogas plant to the biomethane filling station would be 600–750 m. The cost of the gas pipeline varies depending on the pipe dimensions. An assumption is made that the used pipe will not be over DN 200. The cost of installing such a pipe would be approximately EUR 100/meter, i.e. EUR 60–75,000 for the entire biomethane pipeline.

Slow-fill and fast-fill are the two main types of filling station, the difference in investment cost between them being mainly due to the higher pressure demand in fast-fill stations. The electricity demand of fast-filling is also higher. Despite the higher cost, fast-fill is the preferred option. Other key factors affecting filling station price are size and additional equipment. As the filling station is connected to the natural gas pipeline via a connection at the biomethane plant, there is no need for storage at the filling station. **Table 52** presents example prices for filling station equipment. The cost of the biomethane pipeline from the biogas plant to the filling station is included in the total filling station price tag. The annual costs of the filling station are estimated at EUR 0.2 /Nm^3.

Table 52. Filling station and equipment costs

	Investment, fast-fill (EUR)	Investment, slow-fill (EUR)
Filling station equipment	335 000	210 000
Roads	30 000	12 000
Lighting	2 000	1 300
Connections to utilities	35 000	35 000
Civil engineering and permit	22 000	22 000
Visual identity	2 200	0
Property	35 000	35 000
Biomethane line	75 000	75 000
Investment, total	514 200	390 300

Source: Biogaasitankla…2010

The number of motor vehicles in Estonia rose steadily from the early 1990s to 2008 (Estonian Road Administration Statistics), although this growth is predicted to level off somewhat in the near future due to saturation of the market. By 2020, annual growth in vehicle numbers is expected to increase by 2-5%. As petrol and diesel prices rise, the numbers of alternative power source based vehicles, such as hybrids and electric vehicles, will increase. This creates a good opportunity for compressed gas vehicles and thus biomethane vehicles – Otto and diesel engines can be relatively easily converted to run on biomethane, and fuelling biomethane vehicles is similar to fuelling a petrol or diesel fuel car, thus offering a more convenient alternative to plug-in hybrids.

If the biogas plant discussed in this paper were not to go ahead, and if biomethane were not be used as transport fuel in Lääne-Virumaa, the transport sector as a whole will nevertheless undergo change, with electric alternatives entering the market. Overall fuel consumption will not rise in line with vehicle numbers as new technologies are resulting in increasingly fuel-efficient vehicles. Local fuels, such as biodiesel or oil shale petrol, are likely to be available. It is questionable whether biodiesel would be used pure or as an add-in to oil-based diesel oil. In either case, it is most probable that the biodiesel will not be sourced locally. Thus, there would be no locally sourced zero-emission fuel alternatives in the region.

If the proposed biogas plant is built, there would be more than one filling station. AS Eesti Gaas is currently considering building a CNG plant on the route to Narva. This could be built in Lääne-Viru County beside the Narva highway. A conservative estimate is that by 2020 30% (550 cars using biomethane or 22 buses) of the biomethane produced will be used for transport. This figure is highly likely, following the proven success of Tartu's CNG buses.

A moderate assumption of 60% usage of total biomethane would be possible if biomethane proves to be an attractive alternative to other transport fuels and if some transportation companies and local municipalities start using biomethane in their vehicles. This outcome could be possible if biomethane makes a positive public impression in Lääne-Viru.

Utilisation of all biomethane produced would require social and economic changes in the transport sector. Biomethane usage could be boosted by very high oil prices and if a very positive impression of biomethane as a transport fuel is achieved nationwide. This requires greater numbers of biogas plants and biomethane filling stations.

4.5. Impact assessment of the scenarios

4.5.1. Environmental and economic impacts of food waste prevention

Emission and cost savings from food waste prevention in Lääne-Viru County have been estimated by generalizing the initial data gathered and the results calculated for Finland in the W-Fuel project. The results presented here should therefore be considered as indicative only, and the factors presented in **Table 53** thus also represent areas requiring further research in Estonia.

Table 53. Environmental and economic impact assessment data for Finland (averages for all sectors and case areas).

Share of food waste among biowaste	Emission savings per prevented food waste volume, tCO_2-eq/ t	Cost savings per prevented food waste volume, €/ t
81%	4.6	5932

Each of the factors presented in **Table 53** is dependent on the national biowaste and food waste composition which, due to the lack of data on Estonian waste composition, is assumed here to be equal with Finland due to the lack of information related to Estonian waste composition. The emission savings per prevented food waste volume also depend on the national agriculture structure and imports, and include all life cycle emissions. Moreover, the cost savings per prevented food waste volume are mainly based on the national price level and are calculated from the waste generator's point of view. They include the purchase costs, usage cost (e.g. transporting, cooking and storing) and waste fees.

The environmental and economic impact analyses are conducted in three different waste prevention cases B1–B3, which are compared to a scenario in which no waste prevention has been implemented by 2020. The cases are introduced in **Table 54**.

Table 54. Compared cases.

Case	Description
Scenario A	No waste prevention measures implemented, biowaste amount increases business-as-usual
Option B1	Prevention target: Biowaste reduced by 2% compared to 2008 levels
Option B2	Prevention target: Biowaste reduced by 15% compared to 2008 levels
Option B3	Prevention target: Biowaste reduced by 30% compared to 2008 levels

In the environmental impact analysis the emission savings value presented in Table 53 has been directly applied. The economic impact analysis, however, takes into account the lower price level in Estonia. In this paper it has been assumed that the price level in Estonia will be approximately 75% compared to the price level in Finland in 2020 (Kiander 2012). The results are given in **Table 55**.

Table 55. Environmental and economic impacts on food waste prevention in Lääne-Viru County in 2020.

Lääne-Viru County	Prevented food waste volume compared to BAU in 2020, t	Emission savings in 2020, tCO_2-eq	Cost savings in 2020, M€ (in 2010 real terms)	Cost savings in 2020, €/capita* (in 2010 real terms)
Option B1	1338	4985	5	75
Option B2	2974	11081	11	167
Option B3	4689	17471	17	264

* Population forecast for Lääne-Viru County is 64,006 in 2020 (Statistics Estonia; Siseministeerium 2009).

Table 55 shows that achieving the food waste prevention target will save 5,000–17,000 tCO2-eq emissions and 5–17 MEUR in 2020 depending on the target level in Lääne-Viru County.

4.5.2. Environmental and economic impacts of biogas production and use as transport fuel

As regards the Hinnu pilot plant, careful control of the digestion process and environmentally sound management of digestate storage and application will minimize the climate impacts of biogas production. While the cultivation of energy crops and the use of digestate as a fertilizer affect nitrogen leakage at the Hinnu pilot plant, no such impacts are expected from the Rakvere pilot plant. Digestate is used for landscaping and will thereby replace the current use of sewage sludge and incineration of slaughter waste.

In Option B_1, the CHP plant supplies 9,134 MWh of electricity to the grid and provides 8,719 MWh to the district heating network of Rakvere town. The heat will replace natural gas which is currently used in the plants managed by Rakvere Soojus AS. In Option B_2, the assumption is that biomethane will be used as transport fuel. **Table 56** shows the saved emissions of the two options.

Table 56. Emissions savings Option B_1 and Option B_2 compared to BAU, Rakvere, 2020

		CO_2, tonnes	HC, tonnes	NOX, tonnes	PM, tonnes	SO_2, tonnes
B_1	CHP emissions savings in tonnes (BAU=average electricity)	8 568	0.37	9.0	3.7	57.5
B_1	CHP emissions savings in tonnes (BAU=natural gas)	3 827	0.37	5.6	0.0	0.0
B_2	Emissions savings passenger cars in tonnes	5 133	0.48	6.0	0.05	0.004

The environmental impact assessment is highly sensitive to the assumption of Base Case electricity generation. Replacement of one kWh of the Estonian electricity mix – which includes 87% oil shale electricity – with biogas achieves bigger emission savings than one kWh of biomethane used as transport fuel. However, if biogas replaces marginal electricity produced from natural gas, the result is the opposite.

Instead of expressing the environmental impact in tonnes, the emissions are weighted according to their damage costs. These damage costs correspond to the air emission values for Estonia presented in Section 2.4, see **Table 7**. Assuming the European Emission Trading System (EU-ETS) is not operational, suggests that replacing Estonian electricity mix with production of electricity and heat from biogas is better than producing transport fuel. When the EU-ETS is taken into account, the use of biomethane as transport fuel leads to a greater environmental improvement than electricity from biogas, irrespective of whether the replacement concerns average or marginal electricity. **Figure 26** shows the monetized value of the environmental impact of biogas use at the Rakvere pilot plant in 2020.

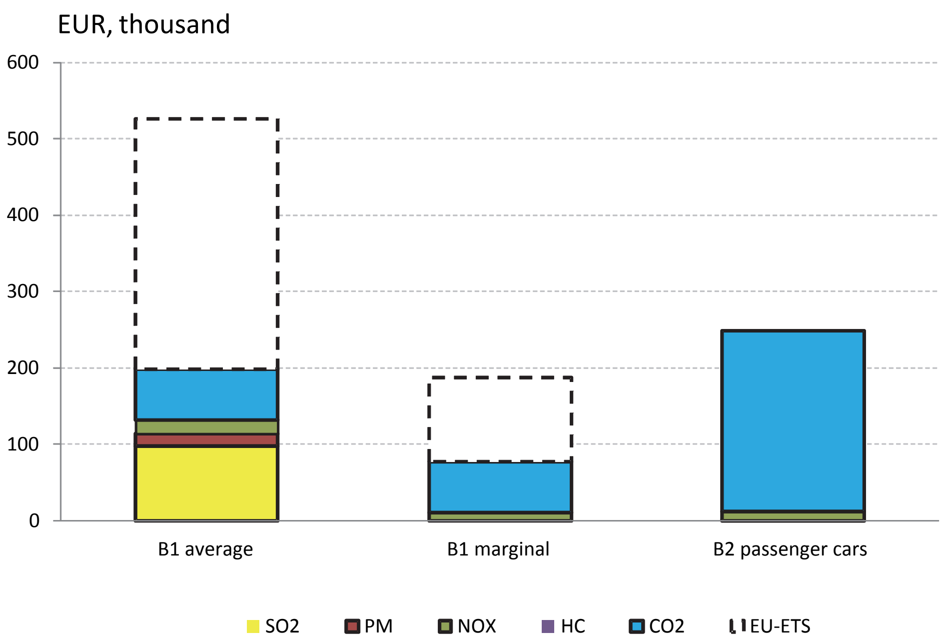

Figure 26. Savings in environmental damage costs, B_1 and B_2 (compared to Base Case), Rakvere pilot plant in 2020

Figure 27 shows the present value of the costs and revenues of biogas production at the Rakvere pilot plant during the assessment period.

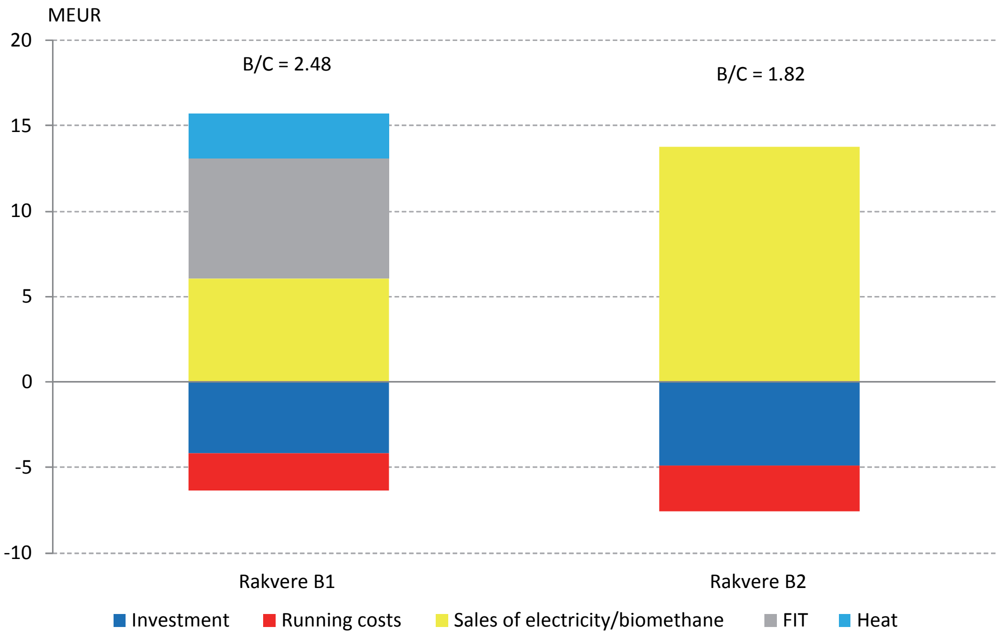

Figure 27. Costs and revenues of biogas production at the Rakvere pilot plant, present value (MEUR), Option B_1 and Option B_2 (compared to Base Case)

Figure 28 shows the benefit-cost ratio (B/C ratio). A value larger than one indicates that the option is profitable. Investment and running costs are lower if the Rakvere pilot plant chooses to produce electricity and heat. Since all raw materials are priced at zero, the running costs are much smaller in relation to investments than at the Hinnu pilot plant. The profitability is also higher. Assuming the current levels of support for renewable fuel based electricity generation, i.e. feed-in tariffs (FITs), remain in place, the expected B/C ratio for Option B_1 is greater than for Option B_2.

The above figure represents commercial profitability only. From the perspective of society as a whole, it is of interest to add the reduction in damage costs to the calculations. In order to present profitability from the social perspective, FITs are omitted from the resulting impact calculation. This is because the FITs cancel out, as the analysis now includes both those who pay FITs (a minus to electricity consumers) and those who receive FITs (i.e. an equally large plus to producers of renewable electricity). The figure below shows the social costs and benefits.

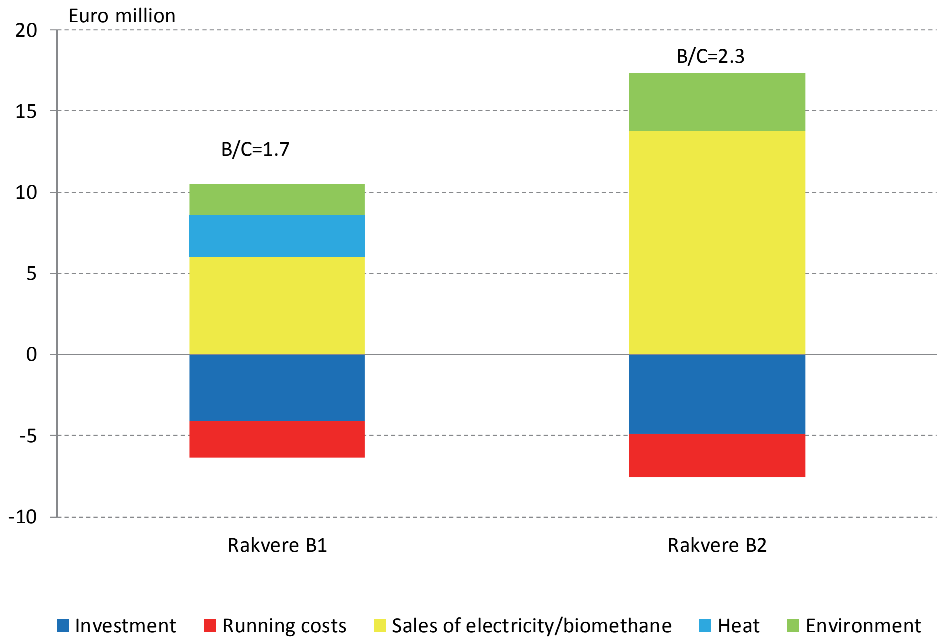

Figure 28. Social costs and benefits of biogas production at Rakvere pilot plant, present value (MEUR), Option B_1 and Option B_2 (compared to Base Case)

The results show that both options are socially beneficial whereas producing vehicle fuel is socially more beneficial.

5. Measures

5.1. Biowaste and sludge prevention

According to the EU Waste Directive, national waste prevention plans must include quantitative targets, prevention measures and indicators to help monitor and evaluate prevention progress. A review conducted in the present study of Estonian legal acts, regulations, and municipal and state-level waste plans showed that Estonian legislation does not provide biowaste prevention quantitative targets or indicators. To assist in formulating targets, indicators and choosing measures, the authors of the report recommend the following publications:

1. **Benchmark for Quantitative Waste Prevention, 2009.**
   Author: Association of Cities and Regions for Recycling and Sustainable Resource Management.
   Price: EU members - free, NGOs 30 EUR, other 60 EUR.
   Website: www.arcplus.org
2. **Waste Prevention. Overview of Indicators. 2009**
   Author: Bio Intelligent Service
   Price: Free
   Website: http://ec.europa.eu/environment/waste/prevention/pdf/WPG_indicators.pdf

5.1.1. Measures for biowaste prevention

Administrative measures to be implemented by the public sector

1. Informational and promotional measures

- Development of a Waste Prevention Benchmark: a system for data gathering and delivery (e.g. PETRA in Finland) and a directory of relevant resources and documents on waste prevention
- Promotion of material flow analyses and audits
- Development of waste assessment tools, as well as business case studies, fact sheets and waste prevention posters and pamphlets
- Preparation of guidelines on food and garden waste prevention; organising the provision of free advice and education for households, schools, offices etc.
- Awareness campaigns and information on waste prevention techniques (including TV programmes)
- Training programs for regional authorities
- Drawing public attention to companies performing well in the field of prevention
- Regular information and comparison of households' prevention results from different regions, competitions and awards
- Advice for companies producing sludge containing harmful substances

2. Monetary measures

- Provision of public funding for R&D in waste prevention (e.g. research into whey application and other material efficiency)
- Public funding of networks of prevention actors (prevention advisory and education services)
- Incentives for the biggest biowaste producers in the food and beverage industry to develop waste prevention measures

3. Legislative and other regulatory measures

- Integrating prevention targets and measures into waste and environmental legislation
- Integrating waste prevention into an environmental assessment process for large biowaste producers and waste treatment facilities
- Inclusion of waste and sludge prevention targets and material efficiency targets in environmental permits
- Making environmental accounting (annual data on waste amounts per production unit or per employee and the reasons for changes) compulsory for large waste producers.
- Taxes

- Standards for waste-preventive equipment
- Developing waste prevention/material efficiency auditing and services
- Enforcing waste prevention measures in publicly financed organizations
- Integration of waste prevention criteria in public procurement tenders or publicly financed institutions (schools etc.)

Prevention at source to be used by companies, public sector and households

1. Prevention in landscaping and gardening

Target group: Households, administrations (parks, cemeteries, etc.), schools and universities, hospitals and private business (golf courses, etc.)

Measures:

- use slow-growing grasses where possible;
- establish 'meadow areas' by allowing allotted grass-dominated green areas to grow wild;
- grass cycling – leaving grass clippings in-situ after cutting rather than bagging and collecting.

2. Prevention in catering, restaurants and food industry

Target group: Consumers (households, schools, administrations) and commercial establishments (bars, restaurants, school/university/hospitals canteens), food retailers.

Measures:

1) serve right-sized portions in restaurants;
2) charge a supplement when food is left on the plate;
3) prepare a guide to avoid food waste;
4) donate food – gather and deliver surplus food for human and animal use.
5) set prices for food according to the weight of the portion (where customers pay themselves) and have different size portions, priced accordingly;
6) avoid over-ordering by using accurate stock and ordering systems.

3. Prevention in retail

Target group: food retailers.

Measures:

- inform the public about targets and results on (bio)waste prevention in the retail chain;
- reduce prices for products near their best before or last selling date;
- avoid '2 for 1' prices;
- sell in loose weight to allow the customer to buy the desired amount:
- donate products nearing their best before or last selling date;
- decrease the range of easily perishable products.

5.1.2. Measures for sludge prevention

Target group: public sector and municipal and industrial wastewater treatment plants.

Measures:
- sludge prevention auditing as a precondition for contracts on industrial wastewater and sludge treatment;
- legislation and municipal orders to promote composting/urea separating toilets and (grey) wastewater treatment on site, with soil-treatment in sparsely populated areas;
- in the pulp and paper industry: adopt regular material flow auditing and the latest ultra-filtration systems to keep materials in the process and to avoid waste;
- reduce sludge in industry, households and the service sector.

 - use of environmental permits as a tool to reduce sludge from industry, services, and households (amount and hazardousness);
 - in sparsely populated areas sewage sludge can be reduced significantly by composting toilet waste.

5.2. Support scheme for biomethane

A challenge facing the deployment of biomethane is that the delivery, refuelling and consumption infrastructure of transport fuel is based on liquid fuels as the standard. All the technology is compatible with liquid fuels. This standard technology is not necessarily superior, and path-dependency hinders the introduction of alternatives. In order to introduce gaseous fuel into the market, clear incentives are required, both for consumption and production.

5.2.1. Governmental instruments

EU's directive (2003/30/EC) on the promotion of the use of biofuels for transport represents existing governmental guidance. It creates an operating environment where the markets begin to find the most economical option to fulfil their commitments. The directive is necessary for the deployment of biofuels, but benefits liquid biofuels that are compatible with standard technology, regardless of the advantages of other fuel options.

Public procurement is an effective way to promote the use of methane vehicles and biomethane. Municipalities can use environmental criteria when purchasing vehicles or transportation services. According to Finnish law (Laki 1509/2011), contracting authorities, contracting entities and certain operators must take into account energy consumption, carbon dioxide emissions, nitrogen oxide and hydrocarbon as well as particle emissions when purchasing road vehicles. More detailed information about ways to promote biofuels when managing vehicles and transport services in Finland can be found in Finnish (Lampinen, 2011).

Economic instruments

Several studies have found that biomethane is a superior alternative as a transport fuel in offering CO_2-eq. reductions and other environmental benefits (Persson et al. 2006). The fact that gaseous fuel technology is not the dominant standard makes access into the market difficult. However, the benefits of biomethane deployment are high, which means there are good reasons to introduce temporary economic incentives. Once the markets have developed, biomethane will be competitive with liquid fossil fuels.

A benchmark for the support level comes from the suggested feed-in tariff for biogas CHP in Finland. The draft law is under parliamentary review. The production of biomethane should be as profitable as CHP production, as otherwise the competition between different utilisation systems would be skewed. It is essential that the support level for biomethane is the same as for the biogas feed-in tariff from electricity production.

One challenge is that the production cost of biomethane is highly dependent on the raw material source used in the digestion process. Biowaste and sludge provide cheap energy outputs, but their amount is limited. Field biomasses, which have the largest potential, are on the contrary relatively much more expensive as sources of energy. The choice is between either introducing a simple scheme that is open to competitors to find the most profitable composition, which involves a high risk of overcompensation, or creating a more complicated scheme based on raw material sources. There are several options for organising an economic support scheme.

1. Investment aid

Investment aid is a one-time payment that makes it easy to forecast the necessary support amount. It reduces the risks of investment and provides safe surroundings for production, but does not encourage minimising the production costs. As an existing and rather axiomatic form of support, this type of aid has a tendency to raise the costs of investments. Overcompensation could be reduced by allocating investment aid according to the raw material used. Investment aid for digestion processes could amount to 0% for biowaste and sludge, 30% for manure, and 45% for field biomasses.

A problem is that the raw material composition may change during the lifespan of the plants according to the availability of raw materials and the competition situation. This problem can be reduced by defining limit values (e.g. +/-15%) within which the raw material composition should fit compared to the composition of the original raw material.

The problem with investment aid is that it does not allocate properly – the polluter does not end up paying. Also, a specific amount of annual investment aid can be granted. One of the good points of investment aid is that is does not transfer the costs to waste management and does not change the competitive position of waste management.

2. Agricultural support

Agricultural support for energy crops with crop rotation could be one option for support. A problem is that field crop production is already provided with support of around 550 €/ha, which means that the support level is 25 €/MWh converted from silage to biogas. This means that the existing support level is already relatively high.

Another challenge facing energy crop support is that the produced energy crops can be used only for energy production. This increases administration costs and prevents the trading of crops between biogas production and animal production. Active trade could reduce the production costs of silage by cutting the need for allocating fields for surplus production resulting from crop level changes from year to year.

3. Direct payments

The most effective support scheme is direct payments that are tied to the amount of biomethane consumed as transport fuel. Support could also be tied to the production amount, but if it is tied to the consumption amount, it provides a strong incentive for producers to enter the market. It also prevents biomethane dumping from plants whose profitability is based on incomes from waste treatments. Direct payments improve cost efficiency because they are allocated to biomethane production regardless of the type of raw material used. This makes biowaste really competitive, thereby decreasing incomes from waste treatment.

The goal is to promote foreseeable production and decrease the risks involved in investments and the evolution of technology. Direct payments can be arranged with tax payments or traffic fuel tariffs.

A system based on tax payments is similar to a feed-in tariff for electricity production from biogas. The advantage of tax payments is easy administration. The problems involved in this system are that the amount of support cannot exceed the budget and the annual budget makes the political process heavy, which decreases the forecast ability of biomethane production and increases the risk of investments. Also, sanctions arising from these payments are not allocated to the ones that are polluting.

The tariffs collected from the traffic fuel market are allocated to the ones that are polluting according to their fuel consumption. Tariffs can be collected directly from oil companies in the form of fuel taxes. The problem is acceptability, because such fuel taxes increases fuel prices, which are already high because of taxes.

As a compromise, direct payments could be arranged by means of tariffs paid from fuel tax. This is the most acceptable option and is allocated to the ones that are polluting. Recently, fuel taxation has been developed in accordance with environmental bases, but supporting biomethane with fuel taxes would introduce a supportive element that would spark interest in biomethane usage.

One option is to bind the tariff to other energy product’s prices, as done in Finland when peat price was bind to coal and/or natural gas price (Laki 322/2007). Biomethane price could be bind to oil price. This means that when oil price increases high enough, the support is not paid anymore. When oil price decreases, the amount of support increases so that the difference of these two products is the same.

5.2.2. Other instruments

When developing biomethane infrastructure, transport companies play an important role as potential users of the fuel since they have the much-needed volume of vehicles. Transport companies also often have fixed driving routes, which can be in a relatively small area. That is why for them it may not be essential to have a broad network of gas filling stations in order to use biomethane in their vehicles.

To ensure that production, distribution and consumption develop in tandem, regional cooperation between different sectors is needed. For example, some cities in Switzerland and Sweden have decided to run public transport on methane. This gives a more stable basis for biomethane producers as then they have one or few customers that use high amounts of fuel in a relatively small area, meaning that in the first phase relatively few refuelling stations are needed.

In other European countries several different measures are taken when biomethane is promoted for vehicle fuel. In Italy prerequisites for assistance have been that the gas grid is widespread and gas usage in the energy sector is intensive. Also, the domestic vehicle industry has made a concerted effort to develop and produce gas vehicles. Incentives have been created with tax allowances and support for eco-investments.

Sweden has promoted biofuels in traffic for several years and it is a leading country in the utilisation of biomethane as vehicle fuel. Sweden grants tax relief for biofuels and company vehicles. There is also demand for alternative fuel distribution, which means that refuelling stations have to have the option for biofuel refuelling. The Swedish government has also supported low-emission vehicles. In Stockholm, release can be granted from toll payments and there are also parking benefits for green vehicles.

6. Conclusions

According to Directive 2009/28/EC, Estonia must ensure that the share of energy from renewable sources amounts to 25% of its gross energy consumption and 10% of the energy consumption of its transport sector by 2020. The National Renewable Energy Action Plan for Estonia provides the framework for achieving these targets. While Estonia's current situation regarding the promotion of the use of energy from renewable sources is very good – according to the latest communication to Brussels a total of 24% or 770 ktoe (8.96 TWh) of gross final consumption has been achieved already in 2010 – in the transport sector the share remains negligible (8 ktoe, although even this is still produced unsustainably). Estonia's target is 90–100 ktoe. Biomass-based liquid and gaseous fuels are, however, under thorough development in Estonia. In addition, legislation and technical standards for these fuels are being prepared at the present time.

The main focus of the 'From Waste to Traffic Fuel' project was the production and upgrading of biogas to biomethane for use as transport fuel. The project's key criteria were that the biogas was to be produced and used sustainably using locally-sourced biodegradable waste materials from the food and beverage industry and the agricultural and municipal sectors. The ultimate aim of the project was to upgrade the biogas (produced based on anaerobic digestion of biodegradable waste, sludge, manure, slurry and energy crops) to biomethane with a methane content similar to natural gas, to be further used as transport fuel with the aim of reducing traffic-borne emissions, in particular CO_2. The project combined waste, energy and traffic solutions in order to decrease emissions, costs and raw material consumption.

The project aimed to promote waste and sludge prevention and to commence biogas production and its subsequent upgrading to biomethane for use as renewable fuel. The project promoted regional businesses and employment in waste treatment and 'green energy' production. The project focussed on two case counties in northern Estonia: Harju County – one of the biggest counties in Estonia – and Lääne-Virumaa County. A single pilot biogas plant was selected in each county as a case study: in Harju County, the pig manure-based Hinnu pilot biogas plant by pig farm, and in Lääne-Virumaa County, the Rakvere plant based on sewage sludge, animal tissue residue and alcohol industry residues from local companies.

On the basis of the gathered data, the biogas potentials and prerequisites of each county were analysed. Furthermore, the environmental, economic and other regional effects of the different options were compared. By developing research-based feasibility plans, the project partners provided solutions for public and private companies, local governments and research institutes. The project was implemented in close co-operation with municipal waste and sewage companies as well as stakeholders in industry and the agricultural and transport sectors. This report presents the project results for Estonia.

For the Harju County case study, the Hinnu pig farm, located 35 km east of Tallinn, was chosen to determine whether the biodegradable waste – slurry from the mid-size farm, sludge from the nearby Kuusalu settlement located next to a wastewater treatment plant, and harvested energy crops from surrounding abandoned and cultivated land – could serve as basic raw materials for cost-efficient biogas production. Hinnu farm has an average of 11,500 head of pigs. According to calculations, the planned pilot biogas plant, situated next to the farm, will be capable of producing 1.4 million nm^3 of raw biomethane annually. In addition, low-methane biogas could be used directly for co-generation of heat and power. This is presently the most widespread usage of biogas in Estonia. If the biogas were to be used by a CHP plant, the output potential would be approximately 5 GWh of electricity and 5.2 GWh of heat.

The alternative option proposed is to upgrade the biomethane for use as transport fuel, either via a local filling station for trucks and cars or fed into the natural gas grid via the main pipeline running along the Tallinn–Narva motorway. The resulting net energy output of approximately 12,000,000 kWh/year could fuel approximately 1,200 cars or 135 heavy vehicles (trucks) annually. Much higher overall value could be achieved by cleaning, upgrading the biogas to natural gas quality, i.e. biomethane. Biomethane is comparable to natural gas in properties, and the two fuels can be used in parallel, methane being the principal component in both. The key difference between biomethane and natural gas is that the former is produced using renewable energy sources, while natural gas is a fossil fuel.

In Lääne-Viru County, the Rakvere suburb was selected as an ideal location for a pilot biogas plant. Rakvere accommodates the county's two largest producers of biowaste, as well as a closely situated wastewater treatment plant. These local companies have an interest in biogas production and can ensure a stable flow of raw material throughout the year. The biogas plant can be built near the wastewater treatment plant, enabling wastewater sludge to be pumped directly without an additional transportation required. The design recommendation is to use wet fermentation technology with a vertical fermentation tank (~3,000 m^3) and using the complete mixing method. The addition of a pasteurization unit to the process is needed, as the substrates are derived from several sources and may be contaminated with pathogens. The digestate is not likely to be used as agricultural fertilizer, but rather in landscaping and as an additive in compost (20%). The proposed plant would have an annual capacity of more than 4 million Nm^3 of biogas (in average of 60% biomethane).

Biogas produced at the Rakvere plant could be upgraded for use as transport fuel. An ideal location for the biogas upgrading unit and filling station would be near to the biogas plant, which is also located close to the potential biomethane users – town buses and private cars stopping at a large shopping centre nearby, as well as vehicles from the nearby high-traffic Haljala road. Based on an optimistic scenario, biomethane from the proposed biogas plant could be used to fuel approximately 520 vehicles; for example, 30 buses, 20 trucks, 20 waste collection vehicles and 450 cars.

The gas surplus could be injected into the Rakvere gas grid, or utilized by a CHP plant for heat and electricity production. If all of the biogas were used in a CHP plant, it would produce approximately 9 GWh of electricity and 9.8 GWh of heat.

For both competing options, an assessment of the environmental and economic impacts of biogas production and its further use was carried out, and comparison of the options yielded surprising results.

According to the findings, the environmental assessment is highly sensitive to the assumption of electricity generation. Replacement of one kWh of the Estonian electricity mix – which includes on average 87% oil shale electricity – with biogas achieves bigger emission savings than one kWh of biomethane used as transport fuel. However, if biogas replaces marginal electricity produced e.g., from natural gas, the result is the opposite. The environmental impacts have been translated into monetary values based on national damage costs.

The results are further influenced by the EU Emission Trading Scheme (EU-ETS), which includes power generation from oil shale based power plants. If these power plants reduce their CO_2 emissions, they can sell their emission allowances to other participants of the EU-ETS, who can then increase their CO_2 emissions. This situation arises because there is a binding cap on CO_2 emissions within the EU-ETS. The implication is that as long as biogas electricity replaces electricity produced within the EU-ETS, the total level of emissions does not decrease, rather emissions are simply re-distributed to other sectors. When taking the EU-ETS into account, the use of biomethane as a transport fuel leads to a greater environmental improvement compared to electricity from biogas, irrespective of whether the replacement concerns average or marginal electricity.

According to the results of the economic impact analysis, it is socially profitable to produce biomethane. The results further indicate that, from the perspective of the society as a whole, it is more beneficial to produce transport fuel from biogas than to produce electricity and heat. In terms of commercial profitability, however, the result is the opposite. The investment costs are lower for a CHP plant than for an upgrading facility. However, the profitability of the plant is dependent on whether the heat from the CHP has a market, in particular, during the non-heating season. In addition, considering the current levels of support for renewable energy sources based electricity generation, i.e. feed-in tariffs, revenues are expected to be higher from sales of electricity and heat than from sales of biomethane as transport fuel. At the same time, the production of biomethane as transport fuel is an emerging concept in Estonia which needs, in addition to the development of technical standards, consideration of the use of financial support schemes in order to reduce current disincentives.

In case of both pilot studies it could be concluded that producing of biogas and upgrading it to the quality of transport fuel is more cost efficient from the point of view society as a whole offering more benefits compared to the cogeneration of heat and power.

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8. Appendices

Appendix 1: List of interviewed companies

Organization	Interview date	County
Eesti Gaas AS	28.06.2010	Harju
Eesti Munatooted AS	25.05.2010	Harju
EG Võrguteenus AS	21.06.2010	Harju
Estonian Cell AS	01.04.2010	Lääne-Viru
Ferda OÜ	6.05.2010	Lääne-Viru
Green Marine AS	01.07.2010	Harju
Hinnu Seafarm	26.05.2011	Harju
Horizon Tselluloosi Ja Paberi AS	26.05.2010	Harju
Jäätmekäitlejate Liit	02.02.2010	Harju
Keskkonnaministeeriumi jäätmeosakond	29.11.2010	Harju
Kopli Lasteaed	29.06.2010	Harju
Kungla Lasteaed	14.04.2010	Lääne-Viru
Lääne-Viru Jäätmekeskus MTÜ	1.04.2010	Lääne-Viru
Lääne-Viru Maavalitsus	23.03.2010	Lääne-Viru
Maag Piimatööstus AS	23.03.2010	Lääne-Viru
Markilo AS	13.05.2010	Lääne-Viru
OG Elektra Tootmine	15.04.2010	Lääne-Viru
Paldiski Biodiesel	10.06.2010	Harju
Paldiski Linnahoolduse OÜ	10.06.2010	Harju
Pansionaat Kuldne Sügis	14.04.2010	Lääne-Viru
Rakvere Haigla	02.06.2010	Lääne-Viru
Rakvere Linnavalitsus	14.04.2010	Lääne-Viru
Rakvere Lihakombinaat AS	15.04.2010	Lääne-Viru
Rakvere Reaalgümnaasium	14.04.2010	Lääne-Viru
Rakvere Vesi AS	23.03.2010	Lääne-Viru
Rigual AS	21.05.2010	Harju
Ruixi Mõis AS	6.05.2010	Lääne-Viru
S.K. Hooldekodu	14.04.2010	Lääne-Viru
Sagro AS	20.05.2010	Harju
Sisekaitseakadeemia Päästekolledzhi Päästekool	02.06.2010	Harju
Simuna Ivax OÜ	13.05.2010	Lääne-Viru
Spratfil AS	26.03.2010	Harju
Tallegg AS	25.05.2010	Harju
Tallinna Kunstigümnaasium	29.06.2010	Harju
Tallinna Vesi AS	19.03.2010	Harju
Viru Õlu AS	6.05.2010	Lääne-Viru
Voore Mõis AS	13.05.2010	Lääne-Viru
Õitseng OÜ	6.05.2010	Lääne-Viru

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